Understanding the Climate–Water–Energy–Food Nexus and the Transition Towards a Circular Economy: The Case of Morocco

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Abstract. The world is currently marked by increasing pressure on natural resources and a big demand for energy, water, and food. Energy, Water, and food are strongly interlinked, and the choices made in one area often have consequences on the others. These interconnections intensify and will be more complex as the demand for resources increases with climate change, population growth, changing consumption patterns, and a linear economy model of 'take-make-dispose'. however, a circular economy (CE) ensures that economic growth must not necessarily lead to more resource consumption. This paper aims to discuss the circular economy transition with a focus on understanding the interdependencies and complexities of system Climate-Water, Energy, and food security in Morocco. This work first outlines the problem of water resources management in Morocco and determined the areas of intersection between the food-energy-water sectors. It also attempts to explain why water circularity is part of the key factors to accelerate the transition from a linear economy to a circular economy to meet the Sustainable Development Goals, and how circularity can be implemented in the water sector. Finally, it studies two circular alternative solutions (water-saving - drip irrigation, and renewable energy) that Morocco uses to face climate change-induced water scarcity. ***Keywords***: Nexus climate-water-energy-food, circular economy, Sustainable Development, Morocco.

1 Introduction

By 2050, the global Earth population will reach 10 billion, leading to increased food, energy, and water needs and depletion of natural resources [1].

In many countries of the world, pollution and excessive water consumption put enormous pressure on water resource availability, food and energy security, environmental quality, and socio-economic development [2].

Water, food, and energy are strongly connected, and the choices made in one area often have consequences on others. This is referred to as the "water- Energy-Food" nexus.

This complex situation puts more pressure on scientists, and decision-makers to find alternatives and adaptation measures to tackle the current and future demands on natural resources and to reduce the impact of climate change, especially on water, food, and energy sectors.

The water- food- energy interconnections intensify as the demand for resources increases with population growth, climate change, and economic growth, and humanity continues using a linear economy model of 'take-make-dispose'.

However, a circular economy (CE) ensures that economic growth must not necessarily lead to more resource consumption.

This paper aims to discuss the CE approach with a focus on understanding the interdependencies and complexities of system Climate-Water, Energy, and food security in Morocco.

This work first outlines the problem of water resources management in Morocco and determined the areas of intersection between the food-energy-water sectors. It also reviews the latest publications about the water-energy-food nexus, attempting to explain why water circularity is part of the key factors of the transition from a linear economy to a circular economy and to meet the Sustainable Development Goals, and how circularity can be implemented in the water energy food nexus. Finally, it studies two circular alternative solutions (seawater desalination and renewable energy) that Morocco uses to face climate change-induced water scarcity.

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2 Understanding a complex nexus Water Energy Food

Historically, water management, agriculture, and energy policies have been made in isolation.
However, these systems are all interconnected. This interplay is called the food-energy-water nexus and this sector must be included as part of a holistic model.
In Davos Klosters 2011, the Nexus concept was first defined by The World Economic Forum during its Annual Meeting, where business leaders set out a call to action on the water, as a link between environmental concerns and economic growth [2].
All nexus conceptions share general perceptions of the present and future crises and offer solutions for more efficient resource management within a green economy, thereby specifically calling for integrated solutions concerning water, energy, and food. The principal objective of the water–energy–food nexus is about understanding and managing with action these often-competing interests while also ensuring the integrity of ecosystems [3].

2.1 Water-food, security

Currently, agriculture is responsible for a significant 70% of global freshwater withdrawals [4].
Agricultural water makes to produce fruits and vegetables and raise livestock, which is the main part of our diet. Agricultural water is used for irrigation, pesticide External and fertilizer applications External, crop cooling (for example, light irrigation), and frost control.
By 2050, the global population is expected to increase from 7.8 billion to 10 billion people [1,4].
To feed this population, food production must increase by 60-70% [3], which will put more pressure on agricultural water demand.
The growing global demand for food will further exacerbate existing vulnerabilities in water supply and food systems, and regress SDG 2 (zero hunger) and SDG 6 (achieve access to water and sanitation for all) if they are not properly considered in practice [4].

2.2 Water and energy

In general, there is a tight interconnection between energy production and the use of water resources, whether it is the use of cooling water for nuclear power or the production of oil from tar sands, coal liquefaction or gasification, or the recovery of natural gas from coal beds or the Water requirements for crops Biofuels.
The requirement of water in energy generation has been assessed in literature in terms of both withdrawal and consumption of water. However, In the wake of the implied impacts of the energy emissions on water, the association of the energy–water link with carbon emissions has assumed added importance in the scientific literature on this nexus. Harnessing of technologies to reduce carbon emission further exacerbates the demand for water resulting in additional fuel use to compensate for the demands of the carbon capture system and energy penalties [5].
Energy sector uses considerable quantities of water and degrades the quality of return water. the Choices we make in developing energy supplies can provide a severe strain on water quality and quantity.

2.3 Food and energy

Food security relates to the supply of food through production, processing distribution, and exchange. An efficient food production system requires a strong agricultural system and strong economic growth. But robust agriculture requires energy and industry. Energy is required for the entire food system including food production, harvesting, transport, processing, packaging, and marketing.
This has received limited attention in the water-energy-food nexus discourse so far but is an important factor that needs to be considered [1], and it's also important to mention that when there is an increase in agricultural productivity, the agricultural sector is supposed to become a more significant energy consumer. Going forward in this process, energy will be a fundamental input to ensure universal food security [6].
Food production further affects the water and energy sectors through the degradation of land, changes in overflow, disturbance of groundwater release, water quality, and accessibility of water and land for different purposes [7]. In this way, an important pillar of food security is perturbed which is the food production ecosystem.
Several initiatives and policies were implemented in different part of the continent and worldwide which are environmentally friendly but there is still a need for more ones and more coordinated and impactful ones.
In 2022, 45 percent of US corn was converted into ethanol [26]. Using corn to power our cars and machine can strain our food supplies. In addition, the industrial production of corn has led to algae blooms in waterways, harming water quality and aquatic life. Advanced biofuels like algae have the potential to produce fuel without threatening food supplies and with less demand for water and energy [8].
The diagram in figure 1 shows the interdependencies of three securities for welfare named nexus.

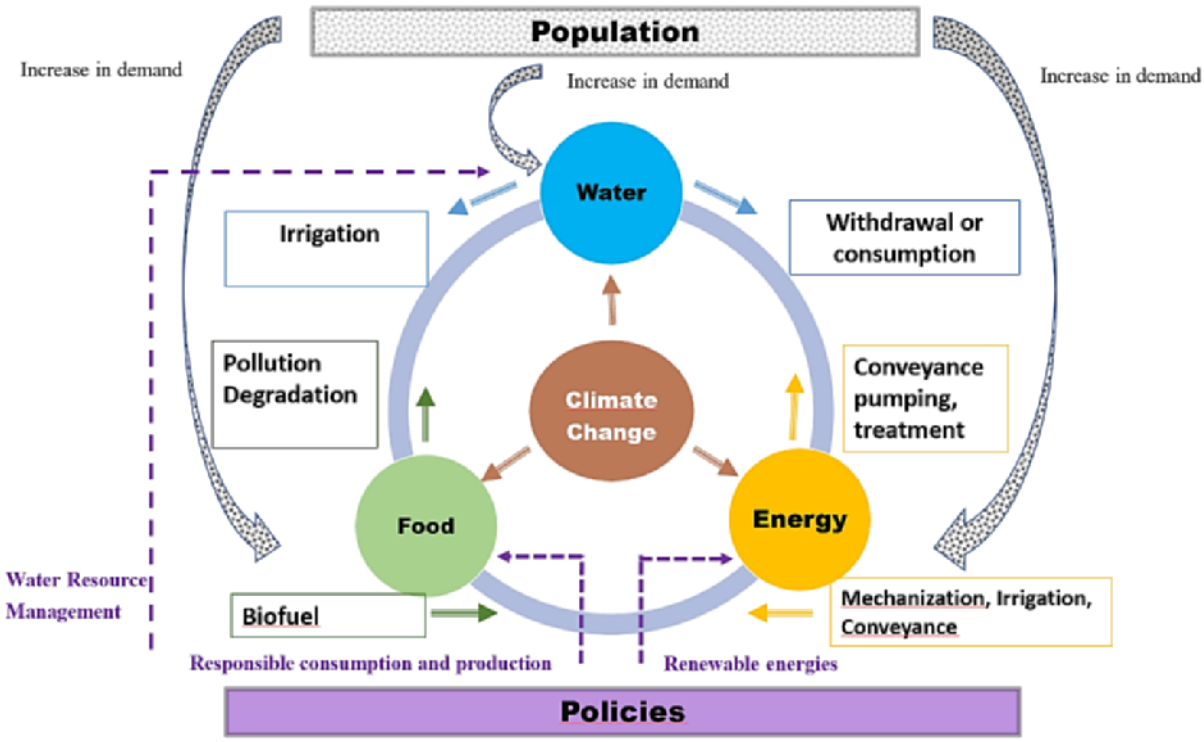

Fig.1. Circular economy for Climate water food energy

3 Nexus and transition to Circular Economy

Around the world, as demands on each component of the nexus' Water-Energy- Nexus' continue to accentuate, the siloed approach to policies involving limited natural resources impedes a sustainable future. Successful policy in all sectors needs to consider the links, synergies, and conflicts between them through a new economic model. The use of a CE approach can accelerate the adoption and the success of nexus thinking, recommending a system-integrated perspective through the analysis of the full lifetime of products [9].

The circular economy is about sustainably producing goods and services by limiting consumption, waste of resources, and uncontrolled waste generation. It is a model of production and consumption, which involves producing, consumption and recycling. In addition to saving significant production costs, the CE approach ensures sustainable development, as the life cycle of products is without environmental impact and much longer.

However, identifying which CE strategy incorporated in the development of products or services or in policy instruments is the most beneficial for the environment is not straightforward. For example, In the sector of energy systems, Algunaibet and Guillen-Gosalbez [10] show how policies focused solely on mitigating greenhouse gas emissions could potentially resolve the climate change problem by creating another, thereby leading to burden-shifting. On the other hand. The Choices we make in developing energy supplies can provide a severe strain on water quality and quantity.

Likewise, if we want to develop new water resources, for example, by reverse osmosis of saline groundwater, water reuse, or desalination, it is going to require considerable energy resources. Also, the choice to produce biofuels and the use of corn as a feedstock to make bioethanol have large implications for water [27].

Corn as a feedstock for biofuels requires considerable water to grow the crop. In addition, bioethanol requires significant quantities of water for the fermentation process to produce the fuel.

In this phase of uncertainty about how to choose the best strategy among recycling, reuse, and other CE options, life cycle assessment (LCA) and the Environmental Assessment are the key tools to perform an environmental sustainability analysis of products and technologies [9], providing a systematic path to measure the enhancements in resource productivity as means for promoting cleaner production [11].

For the food sector, the WEF impact management requires targeted action geared to two separate, yet interconnected points [9]:

- Reduced proportion of produced food that is wasted;
- Calculated management of unpreventable food loss and waste.

Breakthroughs in food processing have focused on water reuse by treatment and decreasing waste to minimize water use, whereas solutions for farm waste recovery can be used by feeding animals, composting, and by substituting food wastes for traditional anaerobic digestion feedstock [9].
For the Water and energy sectors, the transition to the circular economy can be summarised as water treatment, renewable energy, or biodegradable raw materials and goods, where eco-innovation (processes) and eco-conception (design) form the basis of this transition.

4 Nexus - Morocco case study

4.1 Water stress and climate change in Morocco

Morocco is situated in a transition zone between the temperate and rainy climate of central Europe and the arid climate of North Africa [28].
In Morocco, the Climate projections show gradually increasing aridity because of higher temperatures and reduced rainfall. Morocco shows not solely a decrease in mean precipitation but also a change in the precipitation distribution in extreme events [12,13].
Currently, the potential of water resources in Morocco is estimated at 22 Gm^3/year, or about 700 m^3/hab. compared to 2500 m^3/hab. in 1960. This share is expected to be below 500 m3/in by 2030. The surface water is estimated at 18 Gm3/year and groundwater at 4.2 Gm^3/year [18].
More than half of these resources are concentrated in the northern and central Atlantic watersheds with an average annual intake of the order of 11.3 Gm^3/year [12,13].

4.2 Energy in Morocco

Morocco's energy sector depends primarily on oil and coal imports that have heavy environmental and financial costs.
The production of oil and coal is not present in the country and a small amount of gas is produced and it's oriented to limited industrial use. Most of the energy needs of the country is coming from oil and coal. Electricity is also imported with an increasing cadence during the last decade to satisfy the demand in peak periods [6].

Table 1. Energy capacity by energy source [14,15]

Energy source	Production	Percentage
Fossil fuel	49.46 bn kWh	68,00%
Nuclear power	0.00 kWh	0
water power	11.64 bn kWh	16,00%
renewable energy	10.91 bn kWh	15,00%
other energy sources	727.34 m kWh	1,00%
Total production capacity	72.73 bn kWh	100,00%

The consumption of energy in Morocco increased during the recent years following population rise, urbanization expansion, and the economic growth (average annual growth of 4 %) [6].
Transport is the most consuming sector of energy in Morocco (35.9%) followed by the residential sector (24.9%), industry sector (23.6%), commercial and public services 8.0% and agriculture and forestry activities (7.6%). Consumption in the transport and agriculture sectors increased significantly during the last few years while the consumption in residential and industrial sectors decreased. However, it remained stable for commercial and public services [14,15].
Agriculture production activities rely on non-renewable sources of energy (diesel and gas) the main source of energy and electricity as the second source of energy [14,15].
According to the World Bank, CO2 emissions reached a value of 1.8 million tons per capita which comes mainly from the consumption of energy, electricity production, and industry [14,15].

4.3 Agriculture and food security in Morocco

Agriculture is a strategic sector, economically and socially. It plays major roles in terms of food security and nutrition, supply for agro-industry, employment, integration into the international markets, stabilization of populations in rural areas, and sustainable development. Agricultural sector remains the most important sector of macro-economy. The correlation between Gross Domestic Product (GDP) and agricultural GDP(AGDP) is very high. AGDP contributed to 12,65 percent of the GDP in 2022 and employs 39 % of the Moroccan population [6,15]

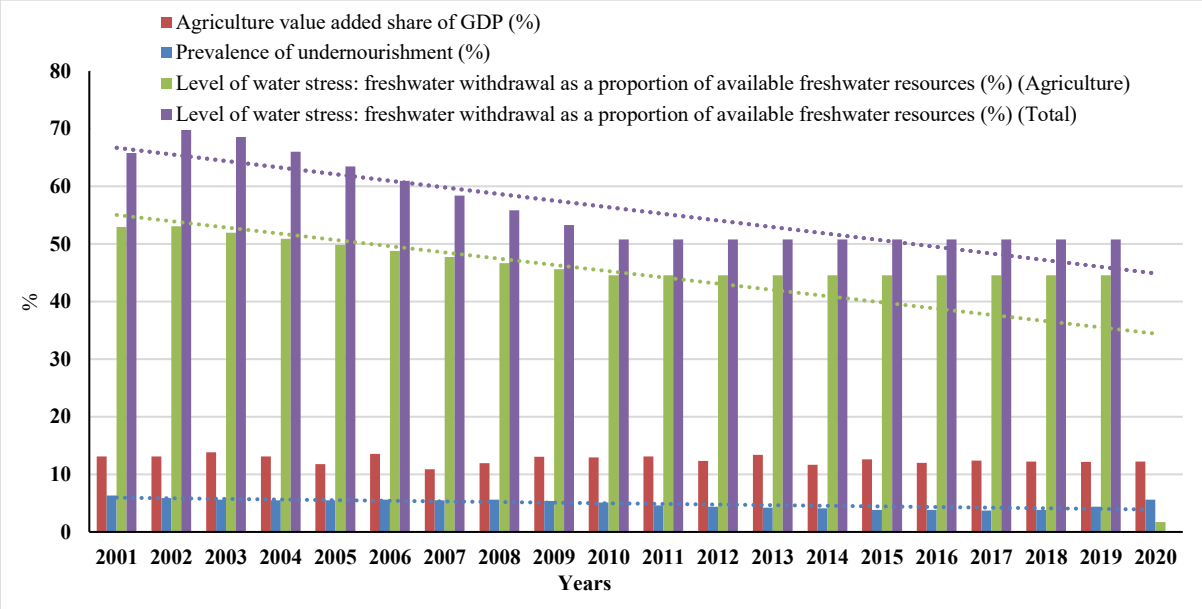

Figure 2. Water stress, undernourishment, and agriculture value in Morocco [16]

However, the consumed volume of the mobilized water resources is 85% and it leads to a negative impact on the quality of water resources through the leaching of nitrates and pesticides into groundwater [6]. Climate change is exacerbating the challenges faced by the agriculture sector. Agricultural sector consumes a significant share of national energy, mainly in irrigation systems (pumping, water distribution), tractors and engines, dryers, and livestock buildings (bovine milking blocks, air conditioning, and heating systems) in poultry farming, and feeding equipment). Those activities rely mainly on the use of diesel (46 %) and liquid gas (46%) in addition to a small percentage of electrical energy (8%) [15].

On the other hand, there is indirect energy consumption resulting from the use of inputs (fertilizers, livestock feeds) and the energy impact of investments in buildings and equipment. Morocco, home to cereal, olive, and livestock cultivation, these areas have rapidly decreased in size due to desertification and climate change. In addition, with the increase in population, the value of total arable land per person (hectares per person) in Morocco stood at 342 in 1993. Twenty years later, in 2013, the same value dropped to 240 (figures 4 and 5).

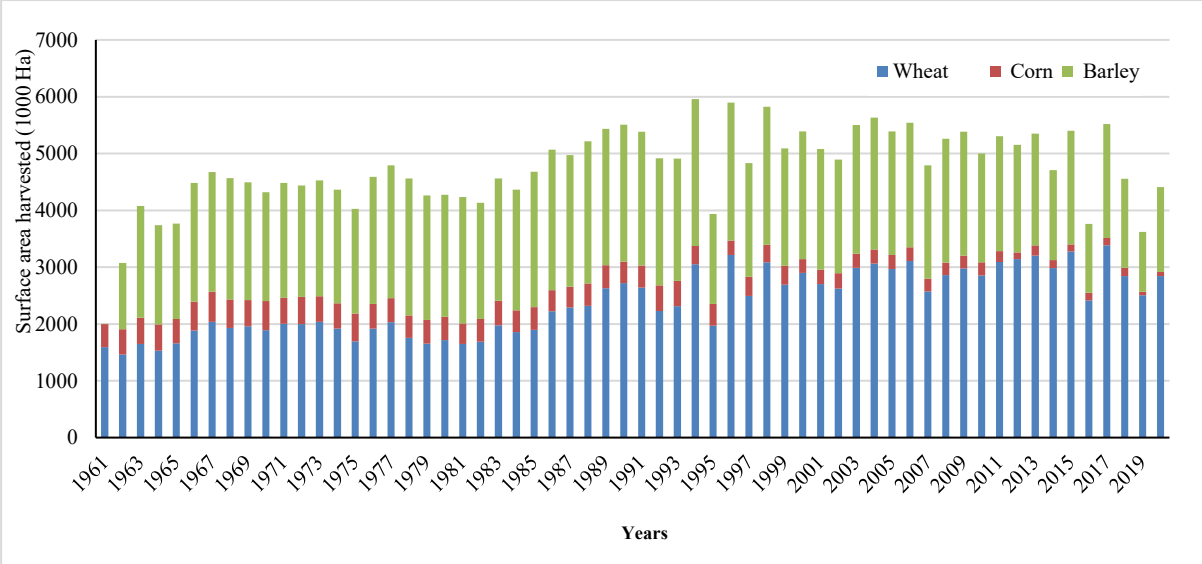

Fig. 3. Cereal Area harvested per crop (1000 ha) [16]

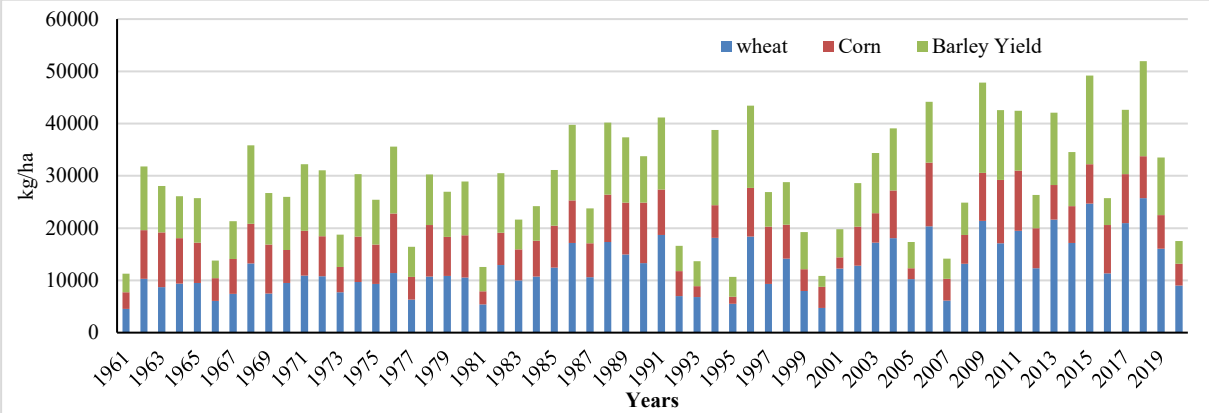

Fig. 4. Cereal Yield per crop (kg/ha) [16]

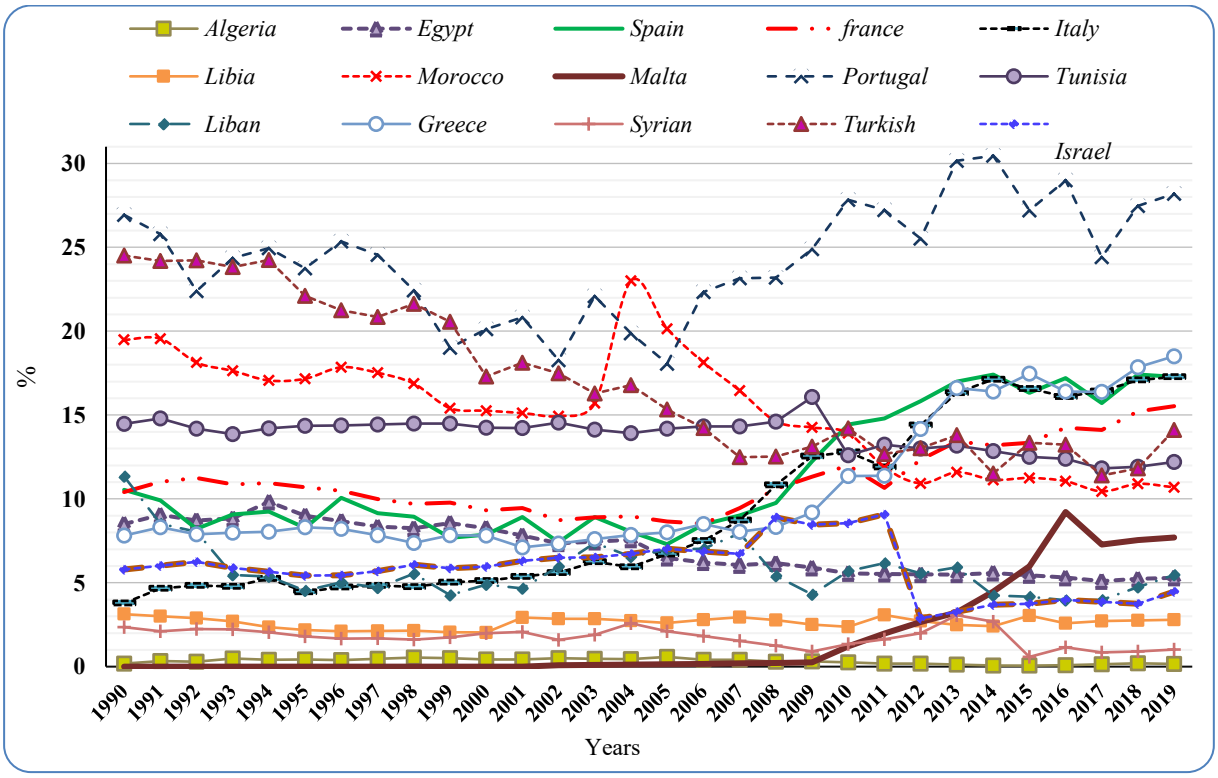

Fig. 5. Renewable energy consumption (% of total energy consumption) for Mediterranean countries [16].

Interactions between climate change, water, and agriculture are numerous, and complex and the search for a balance between food security, and sustainable and resilient agricultural production in a situation of changing climate is a challenge of unprecedented complexity for rural territories.

4.4 Morocco and transition towards a circular economy

Today, Morocco is in the process of transitioning towards a circular economy with an emphasis principally on renewable energies, water treatment, and saving water to adapt to climate change, reduce its impact and create new opportunities. this article focuses on renewable energies and water conservation policies

4.4.1 Renewable energies:

Not many countries in the world are leading the change in the circular economy model. EU countries lead the ranking based on the 2015 action plan, renewed in 2020 and valid until 2050, which is one of the main instruments of the Green Deal for Europe. Among the countries that stand out the most in circular production are the Netherlands, Finland, Germany, Belgium, France, Spain, and Portugal (figure 6) [16, 29].

For Mediterranean countries, Morocco is leading this transition with several green projects in the field of eco-innovation, the efficient use of natural resources, and renewable energies, in which it stands out as a world leader. It hopes to reach 52% by 2030. The goal is set for 2050, where all the energy consumed in Morocco will be 100% green [15].
Initiatives in the agriculture sector for reducing its energy consumption bill and its carbon footprint are conducted by the Ministry of Agriculture, forestry and rural development and the Moroccan Agency for energy efficiency (AMEE).
10 pilot farms were identified for testing the control and reduction of energy consumption and the results were promising. On the other hand, subsidies for solar pumping equipment are scheduled by the Ministry of agriculture in the short term for the replacement of diesel and liquid gas for water pumping [6].

4.4.2 Water policies in Morocco

Water policies in Morocco pursue the objective of increasing water supply through two levers of action: on the one hand by the mobilization of more water, historically by the construction of dams and more recently by desalination and reuse of treated wastewater, and on the other hand by saving water with the introduction of drip irrigation. The issue of water efficiency constitutes one of the main concerns of water for irrigation policies on the international and national levels.
Since its independence, Morocco prioritized the expansion of irrigated areas, which relied on a dams' policy that started officially in 1967. Forty years later, the country counts 149 large-scale dams with a capacity exceeding 19 billion m3 and 255 hill dams [17], between 1,500,000 and 1,700,000 hectares [18,21] of irrigated perimeters, and yet it still suffers from water scarcity.

Morocco already has the largest solar plants in the world, Nour I, and II, in Ouarzazate. It also has traditional hydroelectric power plants and a dozen wind power plants located in, Midelt, Tarfaya, Essaouira, Tangier, Boujdour, and Dakhla, among others [15].

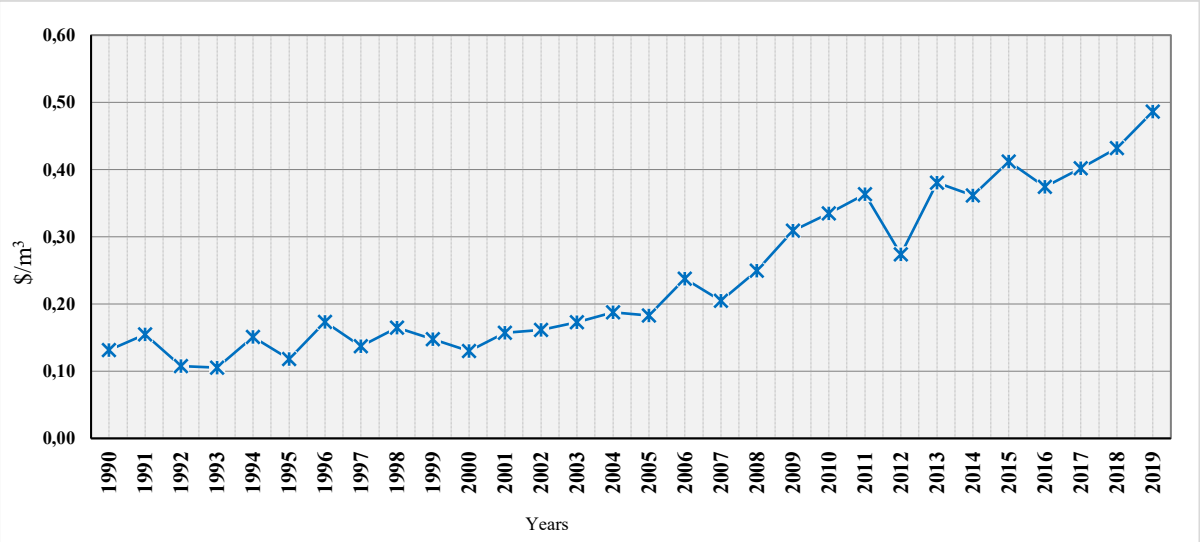

Figure 6. Irrigated agriculture water use efficiency (Morocco) ($/m^3) [16]

By 2019, 585 000 hectares were equipped with drip irrigation technology [19].
However, drip irrigation was the occasion for farmers to convert their plots into higher valued plants such as onions or potatoes which demand more water, or over-irrigation to achieve optimal yield was also often observed, putting more pressure on water demands.
On the other hand, a large part of the production coming from such perimeters is dedicated to exportation and not to the national market. 80% of the usable water resources (surface water and aquifers) are used to irrigate 15% of Morocco's "utilized agricultural land" which contributes up to 75% of the country's agricultural exports [20,21]. In reality, Morocco still relies on rainfall for its food security.
Reports show that the cereal sector which Moroccans depend on for food security remains unstable and highly dependent on rainfall [23, 24] and continue to record an increase in cereal imports (figure 8).
Meanwhile, the average annual growth rate of olive tree production is 7.4%, vegetables 1.2%, and citruses 6.3% [22]. In terms of exports, the average annual growth rate registered for fruits is 13.5%, vegetables is 8.5%, and fresh tomatoes is 5.6%.

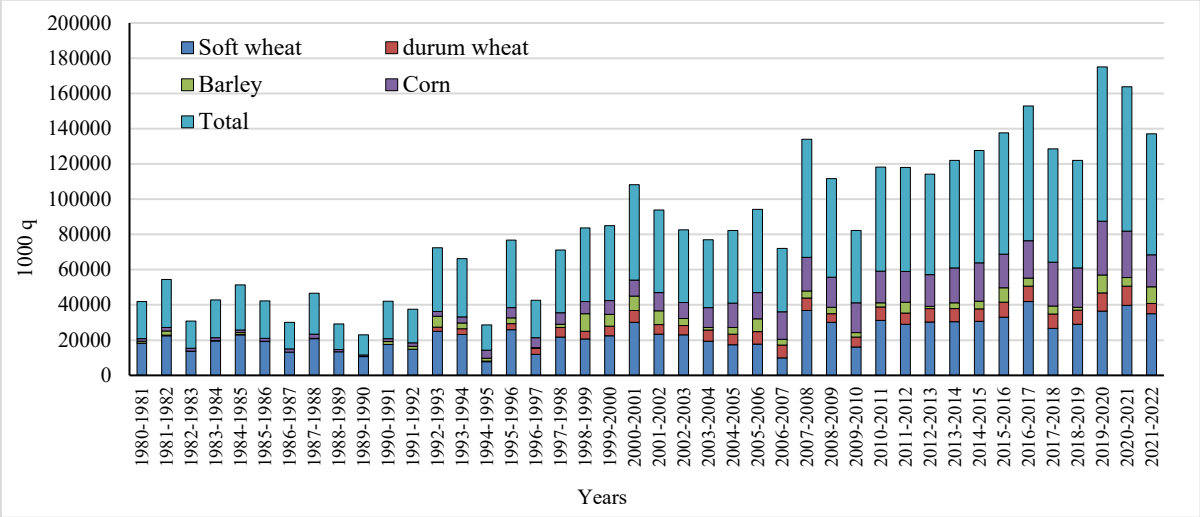

Figure 7. Cereal import in Morocco (1000 q) [25]

This rationale of "store and save" water however show its limits and the drip irrigation technique constitutes a paradoxically unequal agricultural water model. The increasing use of technology may have some benefits, but crucial issues persist. the water stored through multiple and expensive hydraulic systems is mostly exported in the form of citruses, other fruits, and vegetables which implies the export of a part of the much-needed water while small farmers have to deal with the consequences of lack of rainfall and depleted aquifers. One of the main conclusions of this article is that water policies, especially drip irrigation techniques, are largely formed in "isolation" from food security, and there is a lack of consideration of interdependencies - WEF Nexus.

5 Conclusion

Water is necessary vital for agriculture and to produce, transport, and use all forms of energy. Energy is required for the extraction, treatment, and distribution of water, as well as its collection and treatment after use. That implies that the choices made in one domain have direct and indirect consequences on the others. These interdependencies lie at the heart of what has become known as the "water-food-energy" nexus and intensify with climate change population growth, economic growth, and changing consumption patterns.

This work first explores the Climate Energy-Water-Food nexus in Morocco and how to leverage it to transition the country towards a CE and sustainable development and studies second two circular alternatives solutions (water saving - drip irrigation, and renewable energy) that Morocco uses to face climate change-induced water scarcity.

Today, Morocco is in the process of transitioning towards a circular economy with an emphasis principally on renewable energies, water treatment, and saving water adapt to climate change, reduce its impact and create new opportunities. For Mediterranean countries, Morocco is leading this transition with several green projects in the field of eco-innovation, and the efficient use of renewable energies. It hopes to reach 52% by 2030. however, the strategy of "store and save" water show its limits and especially the drip irrigation technique that constitutes a paradoxically unequal agricultural water model. The increasing use of technology may have some benefits, but crucial issues persist. the water stored through multiple and expensive hydraulic systems is mostly exported in the form of citruses, other fruits, and vegetables for export. while small farmers must deal with the consequences of a lack of rainfall and depleted aquifers. Morocco is exporting much needed water by favouring export-oriented agricultural strategies instead of national food security. Finally, one of the main conclusions of this article is that water policies are largely formed in "isolation" from food security, and there is a lack of consideration of interdependencies - WEF Nexus.

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