RES4AFRICA FOUNDATION

# Agrivoltaics:

## Harvesting solar energy in the Mediterranean

Morocco Algeria Tunisia Egypt Jordan Lebanon

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## Harvesting solar energy in the Mediterranean

**Morocco Algeria Tunisia Egypt Jordan Lebanon**

RES AFRICA FOUNDATION

enel Foundation as knowledge partner

ENEA
Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

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## About RES4Africa and this report

Born in 2012, RES4Africa (Renewable Energy Solutions for Africa) is a Foundation that works in support of Africa's just energy transition in order to achieve SDG7, ensuring access to affordable, reliable, sustainable and modern energy for all. It functions as a bridge between Europe and Africa: gathering a network of members and high-level international partnerships from all over the clean energy sector from both continents.

RES4Africa views that co-location of solar photovoltaic and agriculture could address competing water, energy and food demands in the Mediterranean, reduce land-use competition and meet the renewable country-targets. Drawing on existing practices, this report looks at the policy and legal environment concerning the installation of photovoltaics on agricultural lands and highlights six actions to steer agrivoltaics deployment in Morocco, Algeria, Tunisia, Egypt, Jordan and Lebanon.

# Acknowledgements

RES4Africa extends a heartfelt thanks to Enel Foundation for their support and to all partners and experts who took the time to read and contribute to this report.

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# Acronyms

| | |
|---|---|
| ADEME | French Environment and Energy Management Agency |
| AfD | African Development Bank |
| ANME | Agence Nationale pour la Maîtrise de l'Énergie |
| ASTGU | Agricultural Solar Tariff Generation Unit |
| BOS | Balance of System |
| CSP | Concentrated Solar Power |
| EBRD | European Bank for Reconstruction and Development |
| EEG | German Renewable Energies Act |
| EETC | Egyptian Electricity Transmission Company |
| ESCO | Energy Service Company |
| FAO | Food and Agriculture Organization |
| FiT | Feed-in Tariff |
| GHG | Greenhouse Gases |
| GW | Gigawatt |
| Ha | Hectares |
| IFAD | International Fund for Agricultural Development |
| IPCC | Intergovernmental Panel on Climate Change |
| IPP | Independent Power Producer |
| IRENA | International Renewable Energy Agency |
| KWh | Kilowatt-hour |
| KWp | Kilowatt peak |
| LCOE | Levelized Cost of Electricity |
| MASDAR | Abu Dhabi Future Energy Company |
| MASEN | Moroccan Agency for Sustainable Energy |
| MENA | Middle East North Africa |
| MESIA | Middle East Solar Industry Association |
| MITE | Italian Ministry of the Ecological Transition |
| MorSEEF | Morocco Sustainable Energy Financing Facility |
| MW | Megawatt |
| MWh | Megawatt-hour |
| OECD | Organisation for Economic Co-operation and Development |
| PPA | Power Purchase Agreement |

| | |
|---|---|
| PV | Photovoltaic |
| PNRR | Italian National Recovery and Resilience Plan |
| RED II | Renewable Energy Directive II |
| RES | Renewable Energy Sources |
| SHAEMS | Algerian Renewable Energy Company |
| STEG | Tunisian Company of Electricity and Gas |
| SMART | Solar Massachusetts Renewable Target |

# Foreword from RES4Africa

In a region where water, energy and food security pose real challenges, but sunlight is not in short supply, agrivoltaics seems an obvious solution for many southern and eastern Mediterranean countries. Agrivoltaics is pretty simple: agriculture, solar installation, both are brought together in the same space. Of course, they must be made to accommodate one another.

We strongly believe that combining crops and solar panels on the same land will allow countries in the region to harvest the sun twice, ease water stress and land use competition while feeding the growing population.

RES4Africa's first report on agrivoltaics aims to provide comprehensive information about the system definition, design and experiences from around the world to further identify enabling factors for deploying agrivoltaics in Morocco, Algeria, Tunisia, Egypt, Jordan and Lebanon.

This report has been prepared with the support of ENEL Foundation and in close collaboration with ENEA, Simbiosi and IPVF.

With this, we hope to accelerate the development of the agrivoltaic sector in the southern and eastern Mediterranean as a promising solution to address the water, energy, food nexus and meet the renewable energy targets.

Roberto Vigotti, Secretary General RES4Africa Foundation

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# **Harvesting partnerships:** A message from our Partners

## Harvesting partnerships: A message from our Partners

Committed to promoting agrivoltaics in the Mediterranean, RES4Africa partnered with ENEA, Simbiosi and IPVF on this report.

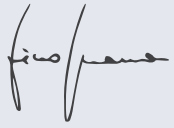
**ENEA** is the National Agency for New Technologies, Energy and Sustainable Economic Development, a public body aimed at research, technological innovation and the provision of advanced services to enterprises, public administration and citizens in the sectors of energy, environment and sustainable economic development. The agrivoltaics domain is of high interest for ENEA, which developed a vision for sustainable agrivoltaics that includes three disciplinary dimensions: landscape, energy, agriculture. With its interdisciplinary task force on Sustainable Agrivoltaics, ENEA ideated and supports the Italian Network for Sustainable Agrivoltaics, since November 2022 ENEA is the President of the Italian Association for Sustainable Agrivoltaics, and supported the Ministry for the Environment and Energy Safety in writing the Guidelines on agrivoltaic plants.

Ms Alessandra Scognamiglio

Senior researcher, licensed architect, PhD Architectural and Environmental Technologies at ENEA

**Simbiosi** is the parent company of some companies, originally attributable to Neoruralehub S.r.l. Simbiosi today is the first Nature Based Solutions Valley, which develops technologies, solutions and patents that can be used in many applications to save natural resources (air, water, materials and soil) and energy. Based on the concepts of the circular economy, "Nature-Based Solutions", and observing and studying the efficiency of natural ecosystems based on 25-year research projects, Simbiosi has developed the know-how, expertise and technologies to replicate the nature in optimizing the use of resources, aggregating innovation and proposing global solutions to use natural resources responsibly, reducing the amount of CO2 emitted, recovering resources from waste and producing energy from innovative renewable resources, thus providing resilience to the critical areas of the future. From the farm to the industry process, up to waste recovery, Simbiosi offers resource savings to combine economy and environment along the entire chain to connect clients with territories. In April 2022, TIP (Tamburi Investment Partners) signed an agreement to acquire a

minority share of Simbiosi to accelerate its development and support the Company's market growth in a strategic segment of the global economy.



Mr Piero Manzoni

Engineer, CEO & Founder of Simbiosi

IPVF strives to accelerate the transition to a low-carbon economy through world-class research, development, and training initiatives. We develop our activity with the same passion and integrity we use to operate our platform, craft our research programs and grow our teams. IPVF's research program embraces collaborative projects which are designed to enhance performances, reduce costs and improve photovoltaic module lifespan. The aim is, firstly, to improve currently-existing module production processes but also and, above all, to develop breakthrough technologies. IPVF is specialised in the development of cutting-edge photovoltaic technologies for a wide range of innovative applications, including AgriPV.

Mr Amaury Martin

Engineer specialist in novel photovoltaic technologies and applications at IPVF

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# Climate change in the Med:

## From a threat multiplier to an opportunity multiplier

# Climate change in the Med: From a threat multiplier to an opportunity multiplier

**The Mediterranean region is considered a hotspot of climate change**. The IPCC provides a scenario with an average temperature increase of around 2°C, an increase in sea level from 6 to 11 centimeters, a 5-10% reduction in precipitation, and an increase in the frequency of extreme events such as drought, heat waves and torrential rain by the end of the century. Although the whole region is highly exposed to the effects of climate change, some countries are more at risk than others. The impacts of global warming vary not only according to the exposure to climate risk, but also by the degree of vulnerability, or the geographical conditions and socioeconomic and institutional features of the affected areas. **Most of the southern and eastern Mediterranean countries have a higher level of vulnerability to climate change and a lower level of readiness to adopt and mitigate** as a large share of their economies depends on climate-sensitive sectors, such as agriculture. Also, over the years, short-sighted governance choices - focused on achieving economic efficiency objectives with less attention to risk mitigations and long-term planning - have weakened their resilience and readiness. Moreover, countries' adaptive capacity is limited due to financial constraints, as well as poor technological capability.

Global warming will exacerbate the phenomena of scarcity and qualitative degradation of natural resources in the region: a decrease in water supply by between 10 and 30%, while sea level rise will cause seawater intrusion into coastal aquifers, making water unusable for agricultural and drinking purposes. Water is not evenly distributed in spatial and resource terms across countries: in the southern Mediterranean, the share of renewable groundwater resources is 11%, while in the eastern Mediterranean countries it amounts to 20%. The great majority of groundwater resources (66%) are non-renewable.[1] Over the last 40 years, freshwater levels have decreased by two-thirds and are expected to fall a further 50% by 2050 with agriculture using approximately 85% of available resources.

FAO projects greater losses in the agriculture sector: a decrease in agricultural production of up to 50% if effective adaptation strategies are not adopted. Lower agricultural productivity will deteriorate the level of food self-sufficiency, increasing countries' dependence on agri-food imports and making them extremely vulnerable to fluctuations in international agricultural prices.[2] On this note, skyrocket food imports were witnessed during the COVID 19 pandemic in Egypt, Morocco, and Tunisia - countries with a growing population, an increasing water scarcity and arable land degradation. According to FAO, the phenomenon of soil degradation is essentially linked to demographic pressure, unsustainable agricultural practices, territorial fragmentations due to poor urban and mobility planning, extractive industries, and gradual marginalisation of nomadic practices.[3]

[1] MedECC, 2020, p.184.

[2] World Bank, 2021.

[3] From FAO Director Speech at Global Forum for Food and Agriculture in Berlin, 2022.

Sustained population growth rates coupled with scarce availability of fertile land and fresh-water resources represent a climate change "threat multiplier"[4] in the region: spill over and cascading effect on migration flows with social and political discontent. Such a domino effect reveals the urgency not only of undertaking a combined action of climate change mitigation and adaptation strategies but also of implementing measures able to decrease the level of vulnerability to environmental stress.

Recognizing the intertwined connection between climate adaptation and mitigation measures as a cross-cutting challenge that needs to be tackled in an integrated way in the region could reduce risks and ensure long term emissions target reduction. The urgency of addressing the challenges of climate change can accelerate the path towards a real green and inclusive transition by turning climate change from a "threat multiplier" into an "opportunity multiplier" through several technologies, among them agrivoltaics. Thanks to this system, crops are cultivated, water demand is reduced, solar resources are harvested. Morocco, Tunisia, Algeria, Egypt, Jordan, and Lebanon - endowed with huge solar potential - have installed large-scale photovoltaics (PV) to meet their decarbonisation targets. Yet, PV deployment happened on arid as well as arable land - putting further pressure on land availability for agricultural purposes. Agrivoltaics offer the dual use of land for energy and crop harvesting while minimising water use thanks to shading. To date, this system has been applied around the world - in many configurations, different sizes with variable crop production underneath or among the panels- but not yet in Morocco, Tunisia, Algeria, Egypt, Jordan, and Lebanon.

**This report aims to present agrivoltaics and contribute to its uptake in these countries by identifying the enabling factors to steer its deployment.**

The first chapter deep dives into the water-energy-food nexus in Morocco, Tunisia, Algeria, Egypt, Jordan and Lebanon and calls for an integrated approach to address these intertwined challenges.

The second chapter positions agrivoltaics as a promising experience for solar and agriculture harvesting with benefits on water usage. It expands on the definition, concept and system design of agrivoltaics with focus on open field application and crops-friendly cultivation.

The third chapter looks at the policy and legal framework concerning the installation of PV panels on agricultural land in Morocco, Tunisia, Algeria, Egypt, Jordan and Lebanon. It provides a thorough analysis of the latest strategies, laws, financing instruments, and targets governing solar development to identify the enabling factors for deploying agrivoltaics in these countries.

The report concludes with the fourth chapter gathering a list of best practices from France, Germany, Japan, Italy, the United States of America, Chile, Taiwan, and South Korea, going beyond the mere application of agrivoltaics, to spur its adoption on a political, strategic, regulatory and financial level.

[4] Mentioned in the European Commission and the High Representative of the Union for Foreign Affairs and Security Policy Joint Communication on the new, ambitious, and innovative New Agenda for the Mediterranean (February 2021).

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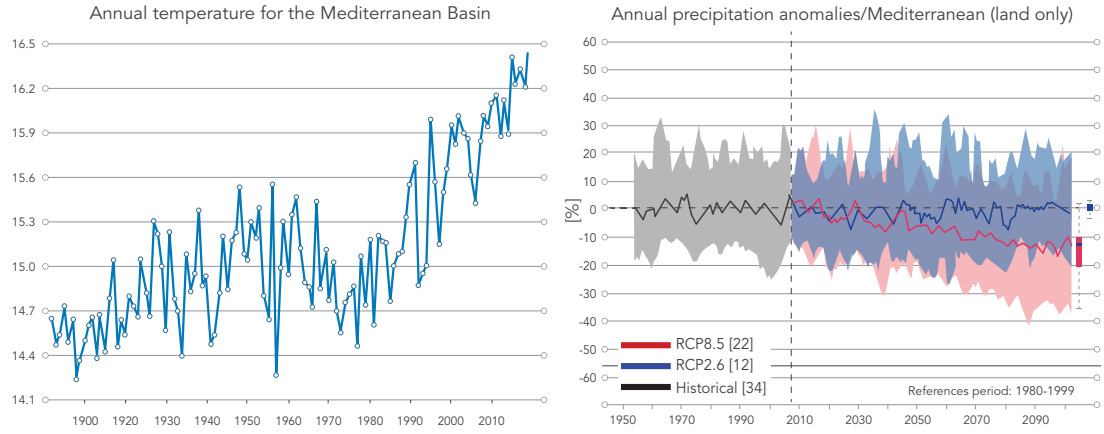
CHAPTER 1

# **Breaking the silos:** A systemic challenge calls for an integrated approach

# Breaking the silos:
## A systemic challenge calls for an integrated approach

During the second half of the 20th century and up to the present day, the Mediterranean Basin has been affected by accelerating climate and environmental change due to anthropogenic emissions of greenhouse gases and other human activities. There is robust evidence that annual mean temperatures have already risen 1.5°C above pre-industrial records - more than 20% higher than the global average change[5] - and they are projected to increase until 2100 in all the proposed scenarios. Heat waves will intensify in duration and peak temperatures and, despite the significant regional variation, summer rainfall is likely to be 10% to 30% lower in some areas (see figure 1).[6]

*Figure 1: Time-series of temperature over land for the Mediterranean based on the Climatic Research Unit (CRU) and simulated mean annual precipitation based on EURO-CORDEX 0.11° simulations 2020. Source: MedECC, 2020.*




**At the heart of this climate change equation, there are water, food and energy.** Their interconnectedness implies that if one element deteriorates, the consequences on the others are proportional or even more than proportional. Navigating these challenges in a context of rapid population growth, increasing energy and food demand calls to break the silo approach and adopt an integrated policy action to design solutions for water, energy and food insecurities. Considering the different contexts in the region and the importance of agri-food systems, it is therefore important to analyse the intertwined relations between water, food and energy in Morocco, Algeria, Tunisia, Egypt, Jordan and Lebanon before delving deeper into agrivoltaics - one of the most promising solutions to co-locate solar energy and agricultural land.

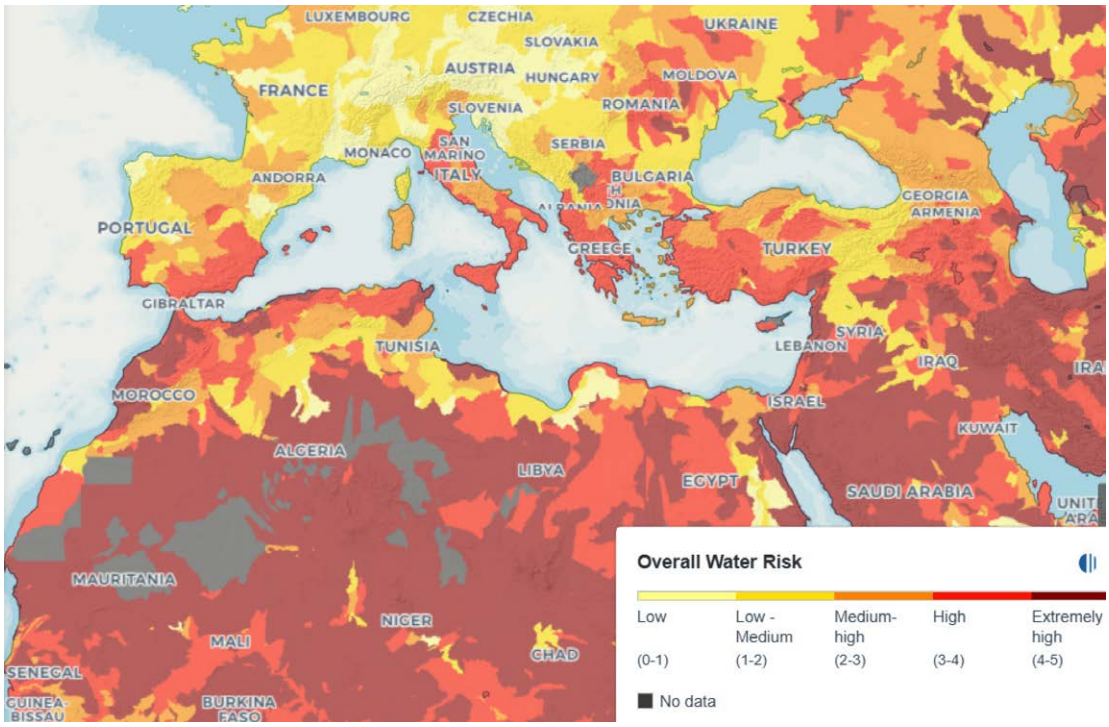
[5] IPCC, 2022.

[6] MedECC, 2020.

## 1.1 Water risks: Uneven distribution, scarcity and external pressure

**The region is one of the most water-scarce in the world and the severe impact of climate change exacerbated this situation**, causing a substantial reduction in annual rainfall, coupled with more frequent and intense heatwaves and droughts. According to the World Resources Institute,[7] water risk is extremely high in Jordan, Morocco, and Algeria, while it scores high in Lebanon, Egypt and Tunisia, and the situation is projected to worsen by 2050.

*Figure 2: Water risk map. Source: World resources institute, 2022.*




In **Jordan**, water scarcity is severely affected by the impacts of climate change, population growth (from less than 6 million people in 2006 to around 11 million today), the influx of refugees from different countries (1 million Syrians in the last decade, and the depletion of groundwater resources.

**Morocco** is experiencing a decline in its surface water: from an average of 22 billion cubic metres in 1978 to 15 billion cubic metres between 1979 and 2018. Water resources per person have decreased from 2,560 cubic metres per year in 1960 to 620 cubic metres per year in 2020, putting the country in a state of structural water stress (below 1,000 cubic metres) and approaching the absolute water scarcity threshold of 500 cubic metres per person per year.[8] The government announced the installation of several desalination plants to circumvent the successive dry winters that emptied the water reservoirs and jeopardised the high-value agricultural sector for the Moroccan economy.

[7] World Resources Institute, 2019.

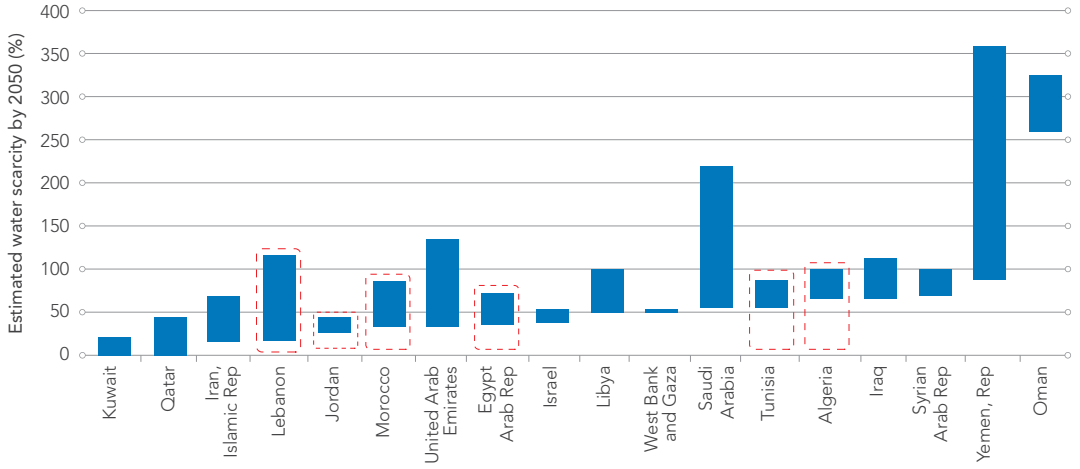
[8] World Bank, 2022.

In **Tunisia**, the availability of water per person per year has been below the absolute water scarcity threshold of 500 cubic metres for over 30 years now. In 2022, the country witnessed one of the driest years, making dams reach new water level lows. Nearing a water emergency, the government has prompted farmers to rationalise their water use for vegetable fields in an attempt to prioritise grains staples and export crops.[9]

Although **Egypt** is considered water-scarce, it has not yet reached the severe water scarcity level of 500 cubic metres per person per year. It is projected that it will reach the level of severe water scarcity by 2033 if water resources and water use remain unchanged, and the population continues to grow at its current rate. This could have severe consequences on the very critical agricultural sector.[10]

The heatwaves and droughts hitting **Lebanon** have led to the yearly available freshwater per person to drop from 1,400 cubic metres 30 years ago to 600 cubic metres today. In addition, the political and regulatory difficulties, experienced in the last five years, have prevented a proactive response to water challenges in the country - considered as a net food-importing country and greatly affected by the volatile food and energy prices.[11]

*Figure 3: Projected range of water scarcity in the MENA by 2050. Source: World Bank. 2018.*




Note: Figure estimates made using three Global Circulation Models (GCMs) and all the Shared Socioeconomic Pathways (SSPs) using emission scenario Representative Concentration Pathway (RCP) as reference. The lower bound on the range represents the best-projected outcome, and the upper bound represents the worst-projected

Looking at the future, water scarcity, along with highly variable and unpredictable rainfall events, poses a serious challenge for agricultural systems and more particularly for small-scale farmers who produce an important share of the food demand in the region. According to the World Bank, the projected water scarcity will range from the lowest value of 20% in Lebanon to the highest value of about 70% in Algeria in the best-projected outcome by 2050. In the worst-projected scenario, most countries will experience a water scarcity level nearing 100% (see figure 3). With this serious water shortage, food production in Morocco, Tunisia, Algeria, Egypt, Jordan and Lebanon will suffer greatly.

[9] Reuters, 2022.

[10] ibid.

[11] Middle East Institute, 2022.

## 1.2 Food insecurity: Worsening climate, increasing demand and supply shocks

According to the latest IPCC report, climate change is expected to result in a decline in crop yields in many southern and eastern Mediterranean countries, mainly due to the impacts of higher temperatures on the timing of crop growth and a reduction in the crop growing season. Rainfed and pastoral farming systems will suffer the most severe consequences, while irrigated lands will see a higher demand for irrigation and water transfer. At the same time, most crops will require additional irrigation, although in some cases the shortening of the growing season could lead to a decrease in irrigation needs. For instance, the typical crops that thrive in the Mediterranean climate could face some risks. Under a 2°C warming scenario, wheat yield in rainfed areas could decrease to 59%, and vegetables and fruits by up to 45% in some areas. The increase in temperature also has the potential to induce a higher evapotranspiration and render some crops non-viable.[12] **Building resilient agri-food systems - that can adapt to both demographic and environmental pressures and shocks - become an imperative**.

In **Morocco**, the most common crops are wheat (4 million tonnes in 2019), sugar beet, potatoes, olives, mandarins and lastly tomatoes. According to FAO, tomatoes have the highest rank per yield (around 906.456 hg/ha), requiring less arable land than all other crops for producing the same amount of food. Other important crops cultivated in Morocco are chillies, peppers, strawberries, cucumbers and sugar.

In **Tunisia**, the produced crop is also wheat with about 1.440.000 tonnes, followed by tomatoes, barley, olives, watermelons, chillies and peppers. When analysing crops by yield, the crops with the highest yield per hectare parameters do not correspond with those that are the most produced. The only crops that have large production volumes and excellent yields are tomatoes, which are always in second place.

In **Algeria**, potatoes are the most produced crop (around 5.020.249 tonnes, in 2019) but their yield (hg/ha) is the fifth highest among the crops produced. Another example could be related to tomatoes crops because they are the sixth crops for overall production (around 1.477878 tonnes) but the one with the highest yield (591.246 hg/ha).

**Egypt** produces about 30% of the agricultural and fish net value in the southern and eastern Mediterranean region. Indeed, the most produced crop is sugarcane with more than 16 million tonnes in 2019. It is followed by sugar beet, wheat, maize, tomatoes, and rice.

In **Jordan,** tomatoes are the most produced crop (with around 496.216 tonnes) followed by olives, potatoes, cucumber, gherkins, watermelons, chillies and peppers. On the other hand, looking at the rank per yield, the crops with the highest yield are cucumber and gherkin with 1.031.445 hg/ha. Also, we can find crops produced like lettuce, chicory, spinach, cauliflower and broccoli.

**Lebanon**'s most produced crop is potato with around 572.109 tonnes followed by apples and oranges. Tomatoes are the best crops with a yield of 464.521 hg/ha, followed by watermelons, bananas, onions, cucumber, gherkins, lemons and limes.

[12] IPCC, 2022.

*Table 1: Crops ranked per tonnes produced and per yield in Morocco, Tunisia, Algeria, Egypt, Jordan and Egypt. Source: Author's elaboration on FAO 2021 crops data.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Morocco | Rank per tonnes produced (2019) | Wheat | Sugar beet | Potatoes | Olives | Tangerine, mandarin, clementine | Tomatoes |
| | | [tonnes] | [tonnes] | [tonnes] | [tonnes] | [tonnes] | [tonnes] |
| | | 4.025.303 | 3.692.884 | 1.956.711 | 1.912.238 | 1.374.629 | 1.347.085 |
| | Rank per yield (2019) | Tomatoes | Sugar beet | Chillies and peppers | Strawberries | Cucumbers and gherkins | Sugar cane |
| | | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] |
| | | 906.456 | 645.937 | 487.036 | 485.751 | 484.793 | 459.009 |
| Tunisia | Rank per tonnes produced (2019) | Wheat | Tomatoes | Barley | Olives | Watermelons | Chillies and peppers |
| | | [tonnes] | [tonnes] | [tonnes] | [tonnes] | [tonnes] | [tonnes] |
| | | 1.440.000 | 1.300.000 | 940.000 | 876.877 | 450.000 | 443.632 |
| | Rank per yield (2019) | Water melons | Tomatoes | Sugar Beet | Onions | Pumpkins and squash | Straw berries |
| | | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] |
| | | 581.771 | 561.385 | 554.227 | 311.526 | 277.735 | 268.719 |
| Algeria | Rank per tonnes produced (2019) | Potatoes | Wheat | Water melons | Barley | Onions | Tomatoes |
| | | [tonnes] | [tonnes] | [tonnes] | [tonnes] | [tonnes] | [tonnes] |
| | | 5.020.249 | 3.876.876 | 2.206.866 | 1.647.746 | 1.613.729 | 1.477.878 |
| | Rank per yield (2019) | Tomatoes | Cucumber and gherkins | Water melons | Onions | Potatoes | Chillies and peppers |
| | | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] |
| | | 591.246 | 407.173 | 352.124 | 320.744 | 318.011 | 310.180 |
| Egypt | Rank per tonnes produced (2019) | Sugar cane | Sugar beet | Wheat | Maize | Tomatoes | Rice |
| | | [tonnes] | [tonnes] | [tonnes] | [tonnes] | [tonnes] | [tonnes] |
| | | 16.316.134 | 10.525.138 | 9.000.000 | 7.450.000 | 6.751.856 | 6.690.000 |
| | Rank per yield (2019) | Sugar cane | Sugar beet | Bananas | Strawberries | Tomatoes | Onions |
| | | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] |
| | | 1.157.427 | 507.170 | 447.299 | 390.966 | 389.659 | 350.326 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Jordan | Rank per tonnes produced (2019) | Tomatoes | Olives | Potatoes | Cucumber and gherkins | Watermelons | Chillies and peppers |
| | | [tonnes] | [tonnes] | [tonnes] | [tonnes] | [tonnes] | [tonnes] |
| | | 496.216 | 214.994 | 173.653 | 163.484 | 93.800 | 88.819 |
| | Rank per yield (2019) | Cucumber and gherkins | Tomatoes | Water melons | Spinach | Lettuce and chicory | Cauliflowers and broccoli |
| | | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] |
| | | 1.031.445 | 596.987 | 539.390 | 538.980 | 538.610 | 519.989 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Lebanon | Rank per tonnes produced (2019) | Potatoes | Tomatoes | Apples | Oranges | Olives | Wheat |
| | | [tonnes] | [tonnes] | [tonnes] | [tonnes] | [tonnes] | [tonnes] |
| | | 572.109 | 272.488 | 216.861 | 166.454 | 134.500 | 130.000 |
| | Rank per yield (2019) | Tomatoes | Water melons | Bananas | Onions | Cucumber and gherkins | Lemons and limes |
| | | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] | [hg/ha] |
| | | 464.521 | 460.153 | 382.468 | 369.478 | 364.316 | 288.742 |

Besides water scarcity, food sufficiency is hampered by the growing population. In the last ten years, food demand has grown at an average rate of 2% for various foods such as cereals, meat, dairy products, root vegetables and tubers, while local production has decreased and is expected to drop by 2030[13] due to climate aridity and desertification, leading countries to increasing food imports. According to OECD-FAO report, the value of net imports per capita has been on an upward trend since 2009 and is expected to be even higher in 2030.

With the outbreak of the COVID 19 pandemic, the countries experienced further stress on food import and stock strategies. Trade-related uncertainties and bottlenecks caused disruptions in trade and local supply chains, leading to food shortages, price increases, and decreased access to food for vulnerable populations. In 2020, Egypt imported 13.5 million tons of wheat, 500,000 tons more than in 2019 and about 10% above the average of the last five years.[14] The Ukraine war has also negatively impacted the global food and energy systems at large, but especially for countries that heavily rely on wheat and sunflower oil imports from Ukraine and Russia, such as Egypt, Algeria, Lebanon and Tunisia. On the other hand, EBRD estimates that 45% of agricultural land will be exposed to degradation: salinity, depletion of soil nutrients, or wind and water erosion. In an already arable-land scarce region, where arable land's share of total land ranges from 0.25% to 25%, land degradation poses an additional threat for crop production and agricultural output.

[13] OECD-FAO, 2013.

[14] FAO, 2021, crops data.

## 1.3 Energy: Transition on the background, security the (re)new(ed) concern

Among the analysed countries, only a few are hydrocarbon exporters but most of them are energy-dependent. With the exception of Algeria and Egypt, the other countries heavily depend on hydrocarbons imports to meet their energy needs. Being at the mercy of the international market, the high volatility of energy prices caused by the Ukraine war has penalised net energy importing countries like Morocco, Tunisia, Lebanon and Jordan, while energy exporters such as Algeria and Egypt were able to seal new energy deals with European countries. In terms of electricity production, oil and gas still hold the largest share in the electricity mix, while hydropower and other renewable energy sources are gaining prominence.

The heavy reliance on imports prompted the government of **Morocco** to take action by promoting investments in renewable energy sources and implementing energy efficiency measures to meet an increasing energy demand. In 2019, the government declared to achieve 52% of installed electricity generation capacity from renewables mainly from solar, wind and hydropower by 2030. The country is endowed with abundant solar resources, especially in the south, where irradiation levels reach higher values.[15] There is therefore a high technical and economical potential for technologies such as concentrated solar power (CSP) and solar PV to produce affordable electricity, but the latter is still not intensively deployed in Morocco. However, the government has expressed interest in encouraging the deployment of PV systems to allow grid connection of smaller-scale generation systems.[16]

In **Tunisia**, the electricity mix is characterised by 96,3% of natural gas and 3,7% of renewable sources (wind, solar and hydropower).[17] In the period 2010-2018, the natural gas production has decreased (-36%), posing a serious threat to the security of power generation. This also led to an increase in the electricity tariff impacting almost every consumer.[18] Currently the number of renewables operational plants in Tunisia is limited to some wind farms (245MW), many solar PV installations under the self-consumption scheme (95MW) and hydropower (66 MW). In order to foster their development and to reduce the hydro-carbon dependency, the government promoted the Tunisian Solar Plan (2016). This plan aims at developing an additional renewable energy installed capacity of 3.815 MW and therefore reach a target of 30% of energy generated by renewables and a 30% reduction of the primary energy consumption by 2030.[19] In June 2022, the government declared their ambition to reach 35% of renewable energy in the energy mix by 2035 and in January 2023 they launched tenders for 1 GW of solar.

[15] IEA 2016.

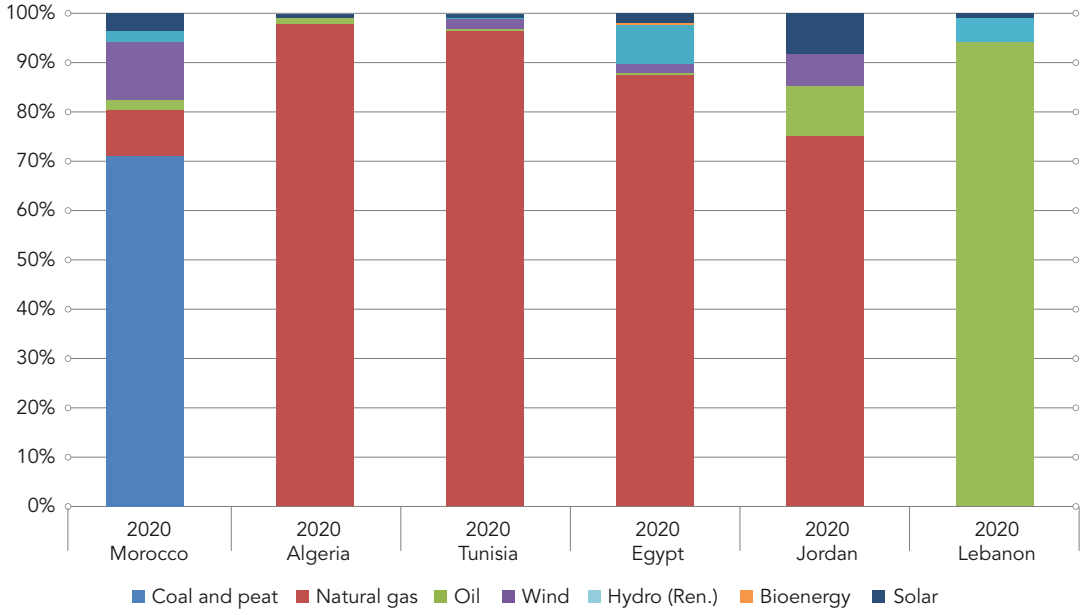
[16] ibid.

[17] H. Ritchie, 2020.

[18] Tractebel, 2019.

[19] ibid.

*Figure 4: Electricity production mix in the six countries. Source: Author's elaboration on IRENA 2022 data.*




**Algeria** is a large oil and gas producer and exporter, and they represent 94% of the country's exports. The government's dependence on crude oil for economic growth increases its vulnerability to crude oil price volatility. For this reason, since 2014, the transition of fossil fuels into cleaner forms of energy has become a priority for the Algerian government. In 2015, the country updated its Renewable Energy and Energy Efficiency Development Plan to 2030 putting greater greater focus on the deployment of large-scale renewables, including solar PV and onshore wind installations through various incentive measures. The renewables energy share will account for 27% by 2030, and its composition will be solar PV (13.575 MW), solar thermal (2.000 MW), biomass (1.000 MW), wind (5.010 MW), cogeneration (400 MW) and geothermal (200 MW).

*Figure 5: Total Renewable Capacity (MW) between 2012 and 2021. Source: IRENA 2022.*

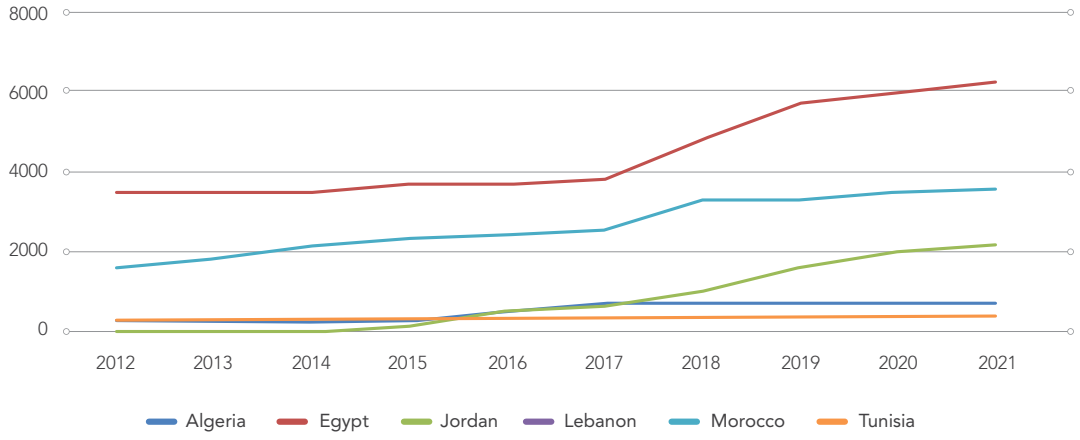
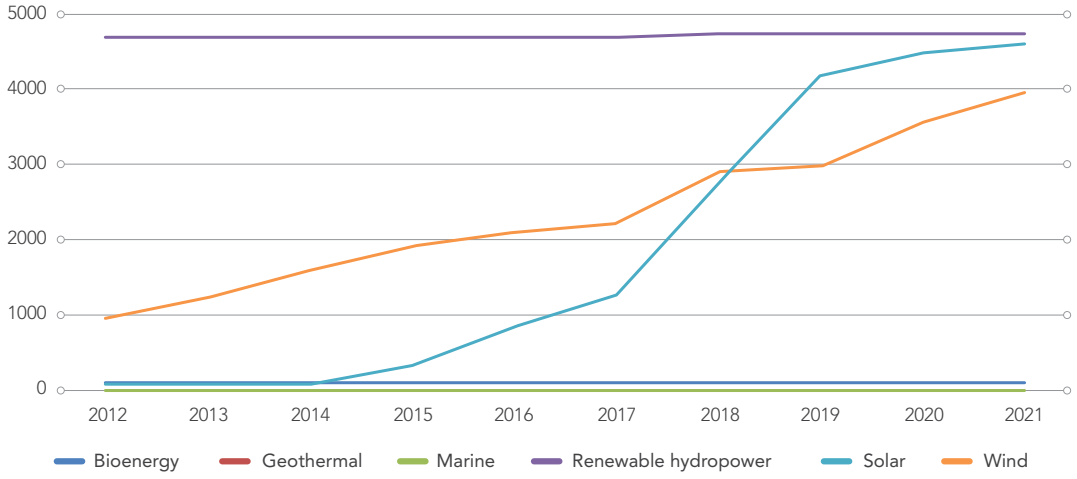


*Figure 6: Renewable energy growth between 2012 and 2021 in the six countries. Source: IRENA 2022.*




**Egypt** is the most populated country in the region, and it is facing a rising energy demand driven by rapid population growth and an expanding economy. This creates significant challenges to maintaining a steady and continuous supply of energy. In this context, the development of renewable energy in Egypt is pivotal to securing power production and tackling significant increases in carbon emissions. To meet these objectives, the government adopted in 2015 the Sustainable Development Strategy: Egypt Vision 2030 and the Integrated Sustainable Energy Strategy 2035. The latter increase the share of renewable energy to 42% of the electricity mix focused on wind and solar energy.[20] Today, the country's total installed capacity of renewables is set around 6226.5 MW, including 2832 MW of hydropower, 1675.5 MW of solar power, 1640 MW of wind power and 79 MW of bioenergy.

**Jordan** has great renewable energy potential with more than 300 sunny days per year and wind speed but suffers from a lack of primary energy reserves, resulting in a critical dependency on imports. This prompted the government to diversify the power generation mix and increase its energy security by developing renewable production capacity. The Ministry of Energy and Mineral resources expects that 30% of the power will be produced by renewables by 2030.

In **Lebanon**, challenges in the power sector and especially in power generation weight heavily on the Lebanese economy. The country relies on imports to satisfy its energy demand as the only sources of energy produced domestically come from solar water heaters, hydro power plants and a minor solar PV contribution.[21] In May 2023, after a six-year-long process, the Lebanese Energy Minister signed contracts with 11 consortia[22] that promise to generate a total of 165 MW of solar energy throughout the country. The Minister called the contracts a "historic moment" and a "major

[20] IRENA, 2018.

[21] IRENA, 2020a.

[22] Under the contracts, the companies are committed to build the power plants, operate them and sell the energy produced to Electricité du Liban (EDL) at prices that vary by region (footnote: Bekaa region power plants will charge 5.7 U.S. cents per kWh while power plants throughout the rest of the nation will charge 6.27 U.S. cents per kWh).

achievement" for the country "despite the special circumstances" that Lebanon has been going through since the crisis began in 2019. The companies will pay the construction costs and seek the necessary financing themselves - which must also cover the cost of the land, at the companies' expense. It is expected that once the production begins, the consortia will operate the photovoltaic farms for 25 years. After that, they will dismantle them as per the contract, in compliance with environmental standards.

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CHAPTER 2

# **Agrivoltaics:** A promising experience for solar and agriculture co-location

# Agrivoltaics:
## A promising experience for solar and agriculture co-location

As seen in the previous chapter, climate change is severely affecting the agriculture sector in Morocco, Tunisia, Algeria, Egypt, Jordan and Lebanon due to increasing global average temperatures, unpredictable precipitation, and more frequent extreme weather events such as droughts and hailstorms. Moreover, achieving decarbonisation goals to mitigate climate change and meet the increasing global energy needs will require significant continued investments in solar energy. IRENA[23] expects solar energy development to be the dominant renewable source of electricity by 2050. **The global cumulative installed capacity of solar PV is expected to rise** to 8519 GW by 2050 compared to 480 GW in 2018.

Sustained development of solar energy will depend on finding renewable energy solutions that synergise the co-benefits of energy production, ecosystem services, and other land uses. To address this growing issue, **greater emphasis needs to be placed on solar development, land sharing strategies that maximise the outputs of solar energy generation and multiple ecosystem services**. Agrivoltaics not only could mitigate climate change but also help agriculture adapt by providing protection and shade to crops and animals.

Agrivoltaics (also known as agro-photovoltaics, agriPV, agrisolar or dual-use solar) is considered one of the most promising agri-solar innovations for promoting the simultaneous use of areas of land for both the solar photovoltaic power generation and agriculture production. It consists in covering certain agricultural productions (vines, fruits, vegetables, orchards, herbs) or grassland for animal husbandry (including beekeeping)[24] or greenhouses[25] with a removable, adjustable, and dynamic roof made of photovoltaic panels. These panels are ground-mounted, sometimes lifted 2 to 4 metres off the ground, and further adapted to meet the requirements of sufficient space for animals or crop production underneath and/or in between the PV panels. These panels thus have a role in protecting against extreme weather and over-exposure to the sun. Whether different in heights and spacing, the arrays will inevitably cause changes in microclimatic conditions under the photovoltaic panels: a decrease in solar radiation and water consumption for crops, with an increased yield and water savings. This, coupled with higher electricity production, represents a win-win situation in the perspective of the water-energy-food nexus, with the immense advantage of no longer using hectares of arable land for energy purposes. Agrivoltaics could be a promising technical and economical practical solution for use of agricultural land, capable of overcoming the dominant separation of food and energy production and increasing land productivity by 35–73%.[26]

[23] IRENA, 2019.

[24] The establishment of solar-pollinator habitat could benefit biodiversity and restore ecosystem services such as crop pollination and pest control that may maintain or enhance production on nearby agricultural lands.

[25] Although some studies consider greenhouse and PV installation not agrivoltaics as they differ in structure and philosophy, particularly because of the controlled parameters in a greenhouse, this report introduces this system as a potential experience to harvest the sun and crops on the same land. Recent developments show the innovative use of PV in greenhouses.

[26] According to the research paper 'to mix or not to mix' presented at the Conference for Resilient food Systems for a changing world 2011.

The notion of agrivoltaics appeared in 1982 in Germany, when Adolf Goetzberger and Armin Zastrow wanted to maximise the utilisation of the land. The idea was to use arable land for both solar energy and plant cultivation to improve the overall production. But over the years, researchers learned that a high rate of photons could not increase photosynthesis. Knowing that, Akira Nagashima in Japan came up with the idea to combine PV systems and farming so that the excess light will not go to waste.

Thus, the prototype of agrivoltaics was developed in Japan in 2004. Since then, the technique was regarded as not completely mature, until 2011, when the results were first published and named agrivoltaics.

Across the globe, the method became popularly recognised under different names: for instance, it is referred to as agrisolar in SolarPower Europe report, solar sharing in Australia, Japan and South Korea, agrisolare in Italy, agro-photovoltaics in Germany, agrivoltaics in France, agriculture solar in the United States of America, solar parks in the United Kingdom. These various names do not differ in the application of the concept: co-locating PV panels on agricultural lands.

Agrivoltaics became well-practised following the reduction in costs of PV systems. In 2020 the average cost of PV modules per watt was around 0.17€/W compared to 4,35 €/W in 2000. The system has now spread to various countries around the world: China, India, Malaysia, Austria, France, Italy, Germany, Holland, the United States of America, Vietnam, India, Chile, etc. Japan launched the first agrivoltaic support programme in 2013 and a total of 1,300 small projects were approved from 2013 till 2018. China created in 2020 a 1 GW agrivoltaics complex in the eastern Yellow River basin.

In Italy, the installed system near the city of Mantova consists of 750 biaxial solar trackers mounted 5 metres height on a plot of 15 hectares. The system installed in Abruzzo uses 67 dual-axis solar trackers with various crops grown underneath such as tomatoes, watermelons and wheat, and generates a total output of 800 kWp.[27]

In Spain, agrivoltaics projects exist in several sites including Totana in Murcia, Las Corchas in Andalusia and Valdecaballeros and Augusto in Extremadura. At Totana, farmers cultivate aloe vera, pitaya (dragon fruit), caper, thyme, and pepper.[28]

In Greece, the Pezouliotika PV plant with a capacity of 3.5 MW is expected to host the cultivation of aromatic herbs, flowers, and mixes of plants capable of attracting pollinating species, and the installation of nests to improve the habitat of some bird species.[29]

In France, five solar projects that integrate beehives and flowering plants as a way of supporting biodiversity are proving that agrivoltaics is a win-win solution to address competing demands.

[27] Weselek et al., 2019.

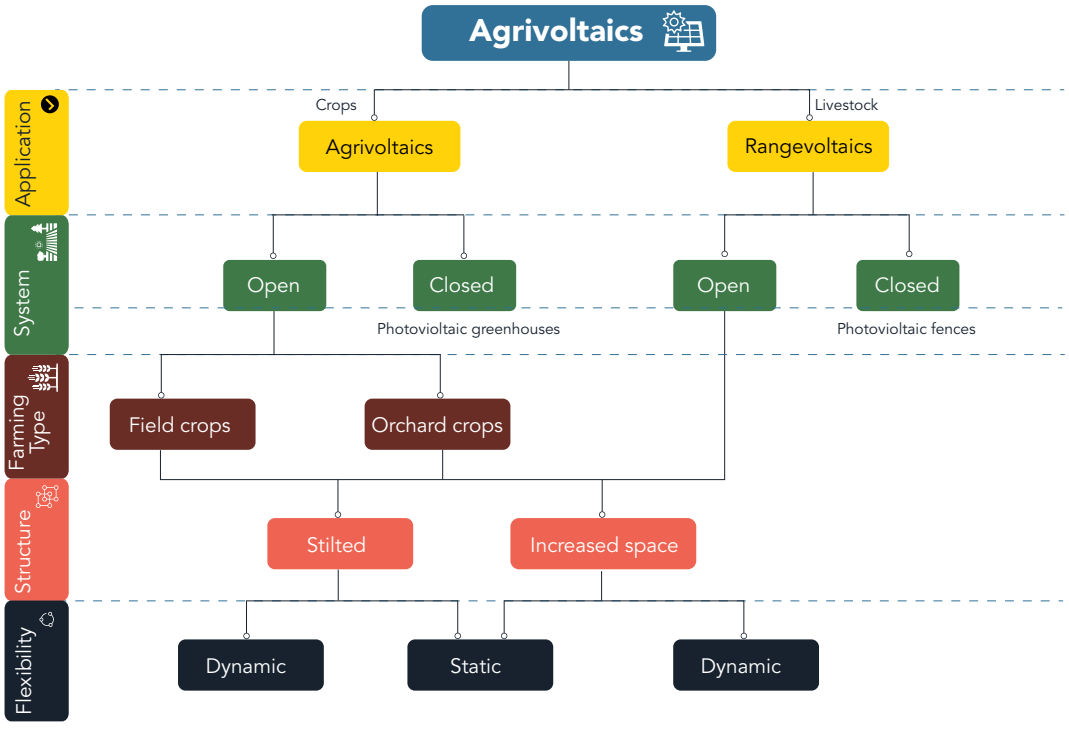
[28] https://www.enelgreenpower.com/media/news/2021/06/agrivoltaics-cohuna-plant.

[29] https://www.evwind.es/2021/02/13/agrivoltaics-new-sustainable-solutions-at-the-local-level/79334.

## 2.1 System design

Since its inception, agrivoltaics was adapted to be compatible with the different application, farming type, structure and flexibility, leading to the development of various system designs which can be classified through 5 levels of distinction as illustrated in figure 7.

*Figure 7: Five distinctions of agrivoltaics technologies. Source: compiled data from B. Willockx 2020.*




**1st distinction: type of application.** The system can be utilised in concomitance with crops (agrivoltaics), and/or with livestock (including beekeeping and rangevoltaics).

**2nd distinction: type of system.** Whether they are classified as agrivoltaics or rangevoltaics, the systems can always be open or closed. Under agrivoltaics, closed systems are called photovoltaic greenhouses PV and are placed on the roof of a transparent structure that allows the penetration of solar radiation to reach the crops. In some cases, the PVs are installed close to the greenhouses. This approach is particularly interesting as it allows continuous food production and electricity generation throughout the year as well as continuous control of $CO_2$ concentration, temperature and humidity.

On the contrary, in an open system it is hard to control meteorological conditions and therefore the volatility of performances remains high. Under a rangevoltaics application, closed agrivoltaics systems refer to enclosed areas in which animals

stay and, in this case, the solar panel replaces the agricultural fences. On the other hand, in the open case, panels are basically placed between or above the livestock.

- **3rd distinction: farming practices.** This distinction is only applied to agrivoltaics and can be divided into two groups: field crop farming and orchard farming. The first one relates to typical field crops wheat, potatoes and rice among others. These are cultivated annually as part of a crop rotation system and they typically have a low economic value with cultivation practices that are usually highly mechanised. The orchard farming refers to fruit or nut-producing trees. These crops are typically perennial, characterised by a higher economic value and require protection against extreme weather conditions.

- **4th distinction: structure**. There are two types of structures: horizontal (ground or stilt mounted, with or without trackers) or vertical.

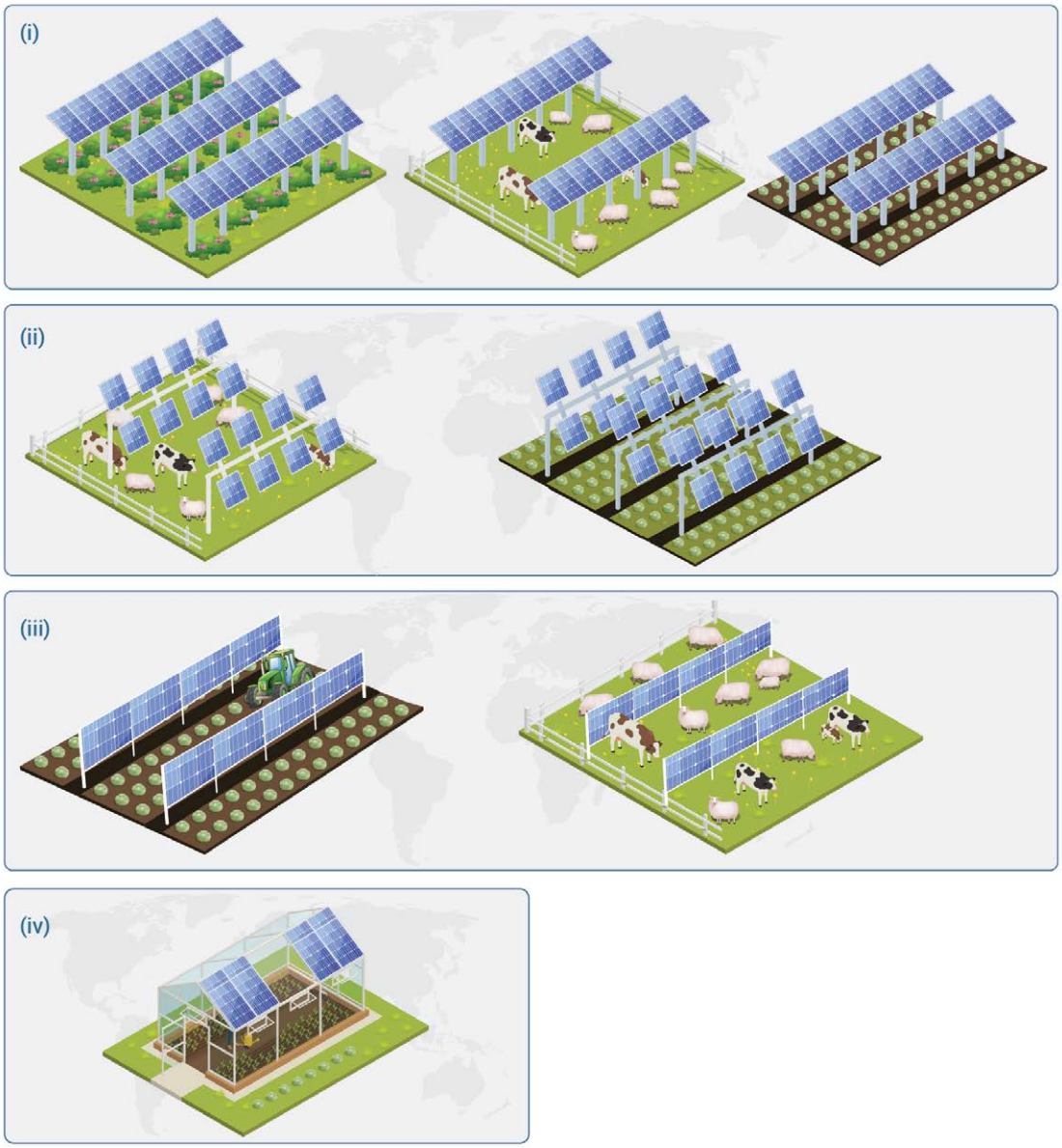
  In a ground mounted horizontal structure, the PV panels are close to the ground, with larger space between rows, as this space is used to grow crops or to let cattle walk freely. This structure results in lower PV array densities as the land underneath the modules cannot be utilised. On the other side, this application has some advantages, like the lower initial investment compared to the other configuration systems and the lower impact on the landscape.

  In a stilted structure, the PV panels are placed on stilts with height that varies from 2 to 5 metres from the ground. The height of the stilts ensures that enough sunlight reaches the crops to carry out photosynthesis processes or guarantee that livestock can roam underneath. Stilted structures are typically used in applications in which farming equipment is simpler, for example in orchard farming or cultivation with limited agricultural mechanisation. This structure increases the land use efficiency when compared to the ground mounted PV modules, providing the possibility of installing PV arrays with higher densities – until a certain value to ensure adequate crop yields – and therefore producing more electricity. Moreover, it ensures protection of crops and livestock against heat stress and other extreme weather conditions. The main drawbacks are the increased visual pollution due to the higher elevation of the PV modules and the higher investment costs due to the stilts, racks and additional structural equipment. The space between rows of the structure elements for both options must be in line with the dimensions of the available agricultural machinery, ensuring the feasibility of agricultural activities while maintaining a safe distance from the PV array. The increased space structure is similar to the photovoltaic greenhouse, where PV panels are placed directly on the transparent covering above the ground level. No stilts are needed in this case.

  In a vertical structure, crops are planted in between the PV rows, the small and bulky agriculture machinery could be used and animals could circulate in between the rows.

*Figure 8: The different structures of agrivoltaics, copyright RES4Africa.*

*(i) ground mounted horizontal structure with crops cultivation among and underneath the solar panels and cattle walking freely, (ii) stilted horizontal structure with trackers and axes for crops growth and cattle, (iii) vertical structure for crops growth and cattle, (iv) greenhouse with roof of transparent structure with semi-transparent or non-transparent modules*




**5th distinction: flexibility.** Whether ground or stilt mounted, the agrivoltaics can be static or dynamic. Static systems encompass fixed systems that are not movable from one field to another and are traditionally employed with large scale systems. Static systems require lower investment costs as well as lower operational expenditures. On the other hand, dynamic systems may be relocated from one area to another and temporarily used according to farming practices and needs.

## 2.2 Focusing on open systems: Design and economics

### The design

This report focuses on six designs for agrivoltaics in open systems. The first is a stilt mounted structure with fixed angle tilted PV modules. It is one of the earliest agrivoltaics designs installed in Europe with spaced rows of tilted PV modules at a fixed angle. This system is mainly used for crops which are grown on the full area of the field, such as wheat or corn. The height and PV row spacing are designed to let standard farming machinery to operate under the structure and give the proper amount of light to the crops. The PV rows spacing is a crucial parameter as it defines the ratio of illuminated/shadowed field area and must be adapted to the specific crop farmed on the field. This system has been widely experimented and studied, especially in Germany,[30] and is nowadays designed and installed by several companies in Europe.

*Figure 9: Stilt mounted PV modules on a rigid steel structure (left) and on a cable-based structure (right). Source: https://tse.energy/solutions-agrivoltaiques-et-agri-pv/*

The second is a stilt mounted structure with 1 axis tracking system. A variation of the previously described stilted mounted agrivoltaics system is the use of additional 1 axis trackers for each row of modules. This feature offers an additional flexibility in the management of the amount of light transmitted to the crops. Contrarily to the usual tracking behaviour which consists of following the sun path to produce more energy, the tracking algorithm in the systems is dynamic and reacts in real time to the weather conditions to optimise the amount of light transmitted and physically protect the crops in case of extreme climate events such as hail or unusually high temperatures.[31] This technology has been mainly developed and experimented on vineyards, especially in the south of France, but is now being tested on other types of field crops such as tomatoes, wheat, maize. The use of such a system implies a specific development of the tracking algorithm for each type of crops and geographical location of the field and a higher investment cost of the agrivoltaics installation.

[30] B. Willockx et al. 2022.

[31] F.J. Casares de la Torre et al., 2021.

*Figure 10: 1 axis tracked stilted mounted PV modules on a rigid steel structure.*
*Source: https://sunagri.fr/en/*

The third is stilt mounted structure with 2 axes tracking system: A stilt mounted structure with spaced PV modules 2 axis tracked has been developed and is being used mainly in Italy. It is used for field crops as the 2 agrivoltaics systems presented before. Although the tracking system ensures an optimal energy production of the PV modules thanks to the large distance between the rows of modules (8 to 12m). Its low Ground Coverage Ratio (GCR) cannot offer a consistent physical protection of the crops in case of extreme climate events. This system involves higher investment costs because of its structural Balance Of System (BOS).

*Figure 11: 2 axis tracked stilted mounted PV modules on a rigid steel structure.*
*Source: https://remtec.energy/en*

The fourth is ground mounted fixed tilted PV modules. This type of installation is also one of the earliest agrivoltaics system installed in Europe as it uses standard mounting structures similar to ground mounted PV plants. It differs from utility scale PV plants by increasing the space between each row of modules, allowing an open space for either farming of field crops or as a livestock pastureland. This type of installation limits the use of heavy agricultural machineries compared to stilt mounted structures. The interactions and potential benefits for the crops are limited but this design has been increasingly used for livestock as it can provide a temporary shelter to the animals in case of extreme climate events.

*Figure 12: Ground mounted fixed tilted PV modules. Source: https://www.akuoenergy.com/en/solar/agrivoltaics*

The fifth is stilt mounted semi-transparent PV modules. This design has been specifically developed and studied for orchards crops farming by research institutes[32] in collaboration with PV modules manufacturers. The use of semi-transparent modules directly placed above the trees involves a specific level of semi-transparency for each type of crop. Therefore, the level of transparency of the PV modules must match the quantity of light necessary for the crops to reach their optimal level of photosynthesis. This design is one of the latest developed in Europe and is still in a development and analysis phase, however it is a very promising design as it is the only one specifically designed for orchard crops.

*Figure 13: Stilt mounted semi-transparent PV modules. Source: https://www.baywa-re.de/en/solar/system-applications/agri-pv*

The sixth is the vertical walls with bifacial PV modules. The recent development of bifacial PV modules made this agrivoltaics system design possible. The modules are placed vertically like "walls'' with an optimal orientation East-West. Because of its very low ground coverage ratio this design is suitable for a variety of field crops, orchard crops and livestock farming. It has been especially experimented with potatoes and oats to find optimal spacing between the PV rows.[33] It must be noted that such a design offers an electricity production which is more constant along the day compared to traditional tilted modules, which can be an important argument from an economic point of view because of the lesser use of energy storage systems.

[32] B. Willockx et al. 2021.

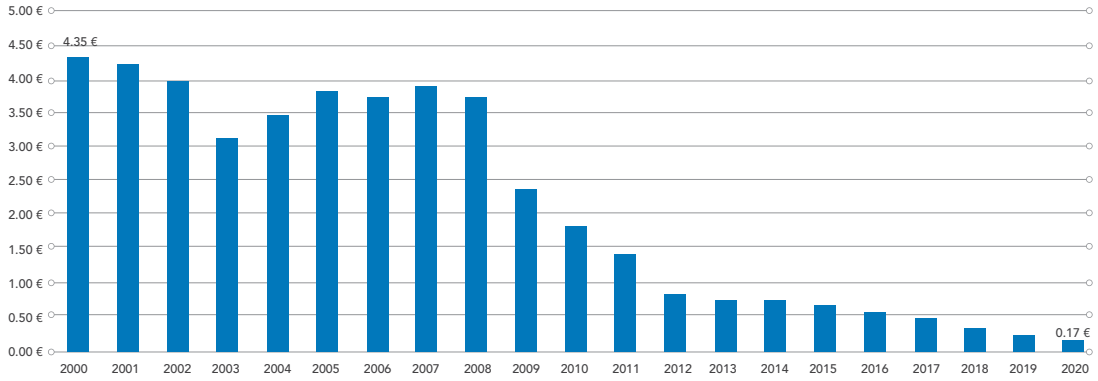
[33] P. Elia Campana et al. 2021.

*Figure 14: Vertical walls of bifacial PV modules. Source: https://next2sun.com/en/agripv/*

## Economic considerations

Over the past 20 years, the cost of PV panels decreased drastically as illustrated in figure 15. In 2000 the average cost of a PV module per watt was around 4,35 €/W, while in 2020 the cost dropped to around 0,17 €/W. This notable reduction made the agrivoltaics technology available and affordable to address persisting problems such as climate change, land conflict, food and water scarcity and fossil fuel exploitation. Yet, the price of agrivoltaics systems (considering the stilt mounted structure and the tracking system) compared to PV panels results higher. According to the study conducted in Germany on the economic viability and feasibility of the systems,[34] the Levelized Cost Of Energy (LCOE) of the agrivoltaics system was higher compared to the conventional ground mounted PV system but lower than a small-scale PV rooftop system. The LCOE for the use of traditional PV panels for electricity generation is around 0,033-0,043 €/kWh[35] whereas the LCOE of agrivoltaics is around 0,1-0,075 €/kWh.[36]

*Figure 15: Solar PV panel costs between 2000 and 2020. Source: IEA, 2021.*




The costs of agrivoltaic systems vary and depend, among other things, on the installed capacity and the agricultural management. Impacts on costs as well as

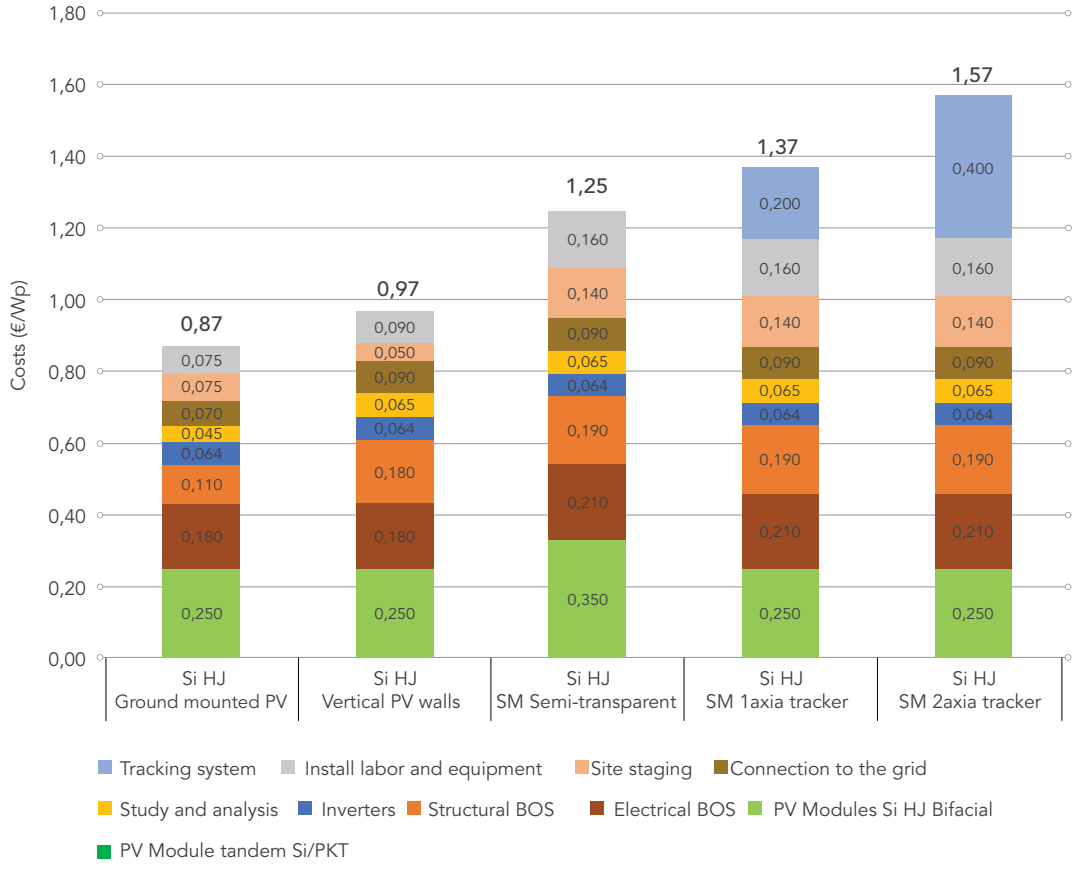
[34] S. Schindele et al., 2020.

[35] BNEF, 2020.

[36] S. Schindele et al. 2020.

revenues of agriculture are also highly dependent on location and system design. A general statement about the economic viability of agrivoltaics can hardly be made due to the diversity of its application. The investment costs of agrivoltaics systems tend to be higher than those of ground-mounted PV systems. This is mainly due to the more complex substructure, the use of special modules and the soil-conserving installation. Operating costs, on the other hand, can decrease because lease costs are shared and land maintenance is taken care of by the farmer. These different designs have different investment costs due to the additional materials used for the mounting structure, additional trackers or semi-transparent PV modules. As shown in figure 16, the ground mounted and the vertical PV walls are the most economical choice while costs for systems with 1 or 2 solar and controlled tracking[37] are higher.

*Figure 16: Agrivoltaics system costs compared across the six designs for a PV system with 100 kWp rated power (taxes, developer overhead and insurance not included). Source: A. Martin et al. 2022.*




Despite a large variation of investment costs of these agrivoltaics systems, the energy produced by the additional trackers, or the use of bifacial modules leads to a LCOE higher than utility scale PV plants and relatively constant for all systems. It ranges from 80 to 120 €/MWh (geographical location being the main influencing parameter).

[37] Weselek et al., 2019.

## 2.3 Cultivating crops under an open system

Agrivoltaics has a wide range of benefits for farmers, both immediate and long-term. Practices across the globe have highlighted protection against risks and climate disruptions, extreme temperatures frost or heatwave and hail protection. Other advantages include an increase in the overall yields' productivity[38] and land-use efficiency by 60%[39] and a reduction of water consumption by reducing plant evapotranspiration thanks to shading. Any sun received after the "point of light saturation" does not improve photosynthesis and plant growth.[40] Instead, it increases the plant's need for water. This, in turn, means they need to be irrigated more. But with agrivoltaics, the panels can be positioned to give the plants just the right amount of sunlight and shade required. Current studies[41] found that when irrigating every other day, the soil moisture stayed about 15% higher in the agrivoltaics system than in the conventional crop production plot. In addition, the shade provided cooler daytime temperatures and warmer night-time temperatures than in the conventional setting. Due to the reduced light under the PV arrays, evapotranspiration is diminished, determining a positive influence on soil moisture. The result is a significant increase in soil moisture, opening up to the possibility of reducing irrigation, with considerable water savings and improved management. Although shading has its benefits, it also has limitations. The selection of crops for an agrivoltaics system could include crops that are shade-friendly such as leaf vegetables, forage crops and herbaceous plants and berries.

When it comes to crop cultivation, not all crops can grow under agrivoltaics. The factor that primarily influences an agrivoltaics system's results is the type of crops. The selection of crops is a crucial aspect for the success of any agrivoltaics project in terms of both economic achievements and technical management of the system. The impact of the agrivoltaics on crop production is complex and multifaceted. It depends on the intensity of the solar radiation, the height of the PV system, water stress and irrigation levels, crops' rotation and shade tolerance. The height, relative position, inclination of PV panels and their density need to be adjusted according to the specific crop requirements in order to obtain both satisfactory energy and agricultural production. A viable option is the application of dynamic PV modules that allow automatic sun tracking to both meet crops' needs and manage daily and seasonal variation of light intensity.[42]

Practices around the world show that some crops thrive under the PV panels making farmland 70% more productive. Crops like lettuces, tomatoes, chard, kale, broccoli, spinach, peppers, carrots, brussels sprouts, and some herbs, as well as bedding plants, nursery crops, and short-statured fruit trees or shrubs, are crops that could benefit from being shaded. Comparative studies[43] show that tomato plants under agrivoltaics

[38] Dupraz et al., 2011.

[39] University of Hohenheim, 2017.

[40] Toledo & Scognamiglio, 2021.

[41] Al-agele et al., 2021.

[42] A. Weselek et al., 2019.

[43] University of Arizona, 2019.

plants produced double the amount of fruit as those without solar panels. Other crops, such as jalapenos, yielded the same amount of fruit and used substantially less water to do so. A study in Japan found that corn planted under PV panels outperformed traditionally grown corn by over 5%.[44] In this report, we focus on tomato, lettuce, pepper, cucumbers and strawberries as it is a common crop production in Lebanon, Jordan, Tunisia, Algeria, Morocco and Egypt.

## Tomato

Studies[45] conducted in south-eastern Spain suggest that increasing the PV shade at 50% results in a negative effect on the total tomato yield, which is reduced from a minimum of 10% (16,9 kg/m$^2$) up to around 40% (11,5 kg/m$^2$) with respect to unshaded field. Same evidence was found in another research: a 23% of PV shading in greenhouse systems had no negative effect on tomato crop yield. Their number and mass were higher respectively by 9.36 and 21% compared to tomato cultivation in an unshaded area. Other studies indicate that under moderate shading conditions – up to 50% reduction compared to full sunlight – an increase in the fruit yield is noticed together with an increased plant height and a decreased content of ascorbic acid, carotenoids and phenolics. It can be concluded that tomato crop production, growth and yield reductions occur when the PV shading ratio sets between 50 and 100%.

## Lettuce

Numerous studies and projects analysed the PV shading effect on lettuce growth and yield. Evidence shows that crop temperature, when cultivated under 25 and 50% PV shades and during different weather periods, is very close to the full-sun and the growth rate is only reduced at the beginning of the plant life cycle. Moreover, under the same PV cover ratio, lettuce yield factor is respectively 99 and 79% with respect to full-sun control yield indicating an almost linear correlation between the two factors. Studies[46] found that agrivoltaics systems do not have particular influence on lettuce's growth rate, but a decrease in water consumption due to a decrease of the evapotranspiration rate was noted. It has been found that by increasing PV modules' relative distance (up to 3,2 meters) there is an increase in the radiation up to 73% and in the yield between 81 and 99%. Other researches indicate that lettuce can grow inside PV greenhouses with 25 and 50% PV cover ratio. This allows to achieve an average yield of respectively 94 and 73%, with a reduction of only 5 to 6% compared to open agrivoltaics systems and respectively 6 to 27% compared full-sun controlled yield.

## Pepper

Studies indicate that under 22% of PV shade pepper plants show better yield and fruit mass compared to the base-case ones. An increase of 20,2% in the fruit weight and a 21,8% raise in the height were registered. In EGP cases, in Spain and Greece, the

[44] Sekiyama & Nagashima, 2021.

[45] S. Touil, 2021, A. Weselek et al., 2019.

[46] S. Touil 2021 and A. Weselek et al. 2019.

peppers (different species) showed an agricultural yield of more than 60%, respectively in standard on trackers agrivoltaics and fixed ones. In Italy, some sweet pepper species could be cultivated within PV greenhouses with a yield reduction below the 25% with a PV cover ratio of 25%. But with a 50% cover ratio, the uneven sunlight distribution can cause a significant drop in the crop yield, up to -31%. Worse figures can be seen for cover ratios of 60 and 100% which are clearly not compatible with the growth of sweet pepper species.

## Berries

Most of the research on the combination between berries – blackberries, raspberries and strawberries – and energy productions was carried out inside PV greenhouses with 32 and 100% PV cover ratio using respectively semi-transparent and non-transparent modules. In these cases, an increase of antioxidant activity in the crops was registered, together with higher anthocyanins, citric and fumaric acid. Shading was found to have a negative impact on the berries' sugar content. In 2020, opaque PV modules with a 25,9% cover ratio were used coupled with solar combined air source heat pump systems on a strawberry cultivation. This technology had a positive impact on the crop, making its chlorophyll content 1,3 times higher and the yield's value 1,2 times higher than the ones of unshaded crops. Therefore, strawberries can be cultivated under 25 and 50% shade with only a 25% loss in crop's yield, but cannot be grown with higher levels of PV cover ratio.

### Biodiversity-friendly agrivoltaics: the experience of Enel Green Power

**Between 2021 and 2022, Enel Green Power launched seven full-scale demonstration agrivoltaics projects in three different countries: Greece, Spain and Australia**, considering different climate conditions and standard (structure height 2,2-2,5m) PV plant layouts (fixed structure or on trackers, equipped with mono- or bifacial modules). The results of the projects will help define strategies to integrate agro-zootechnical activities within utility scale PV plants. The testing sites, each implemented on an area of 2-3 ha, will evaluate how various crops can be cultivated between and underneath the panels, according to the specific microclimates or shading.

The PV plants with specific cultivations are:

Greece:

- Pezouliotika PV plant, located in Thrace: cultivation of aromatic herbs, horticultural species, fruits (strawberry), flowers and mixes of plants capable of attracting pollinating species
- Kourtesi PV plant, located in Ilia region: cultivation of medicinal/aromatic herbs, cardoon and safflower

Spain

- Totana PV plant, located in Murcia region: horticultural species, pitaya (a tropical fruit rich in iron and vitamin E), medicinal and aromatic herbs, forage
- Valdecaballeros PV plant, located in Extremadura region: cultivation of medicinal and aromatic herbs
- Augusto PV plant, located in Extremadura region: cultivation horticultural species
- Las Corchas PV plant located in Andalusia: cultivation of lavender and flowers to attract pollinators, aromatic species

Australia

- Cohuna PV plant, grass cover for pasture and sheep integration

The species grown in the corridors between two modules' rows, compared with the ones in the control areas, free from modules, have an agricultural yield increase of: +40% for forage; +20% for thyme; +15% for oregano; +30% for eggplants; +30% for aloe; and +60% for peppers (different species). For strawberries an improvement of +18% in the yield production is recorded in the corridors; in addition, an increase of +14% is measured underneath the modules, reaching +36% using LED backlighting (full solar spectrum) only during the daylight hours.

EGP has adopted a holistic approach in the development of agrivoltaic demonstration tests, that is to foster a biodiversity-friendly agrozootechnical integration, preserving the local wild ecosystems, therefore only sustainable agricultural practices have also been implemented in the demo sites, using for example biodegradable mulching films of different colours. Moreover, a network of sensors measures agricultural parameters, to enable agriculture 4.0 and to reduce water (-15/-20%) and fertilisation consumption, improving the markets competitiveness of the agricultural partners, and energy production ones, to evaluate potential interaction with PV plants and daily O&M (operation and maintenance) activities.

Thanks to this holistic agrivoltaic, including the integration of domestic bees and promotion of "solar honey" production, several relevant results have also been obtained regarding the biodiversity and wild habitats: an increase of target species and the restoration of the ecological continuity with the surroundings.

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CHAPTER 3

# **Agrivoltaics in the MED:** Status and perspectives

# Agrivoltaics in the MED: Status and perspectives

In the Mediterranean region, several agrivoltaics and solar pump pilot programs, in partnership with European research centres and UN agencies, are underway in Algeria,[47] Morocco, Tunisia, Egypt and Jordan[48] to assess the compatibility, efficiency and profitability for energy and agriculture production. However, details on the system used, the crops cultivated and the performance, so far, are not available.

To check the potential of agrivoltaics, it is important to look at the policy and legal environment concerning the installation of PV panels over crop cultivation, in particular in terms of energy and land laws. In this chapter, the legislative framework governing the solar deployment in Morocco, Tunisia, Algeria, Egypt, Jordan and Lebanon is analysed to identify the enabling factors for the agrivoltaics deployment.

## 3.1 Morocco

Morocco used to be the largest energy importer in southern and eastern Mediterranean. Today, its challenge has shifted from becoming an independent energy producer to an exporter of renewable energy. In 2008 the government launched the National Renewable Energy and Energy Efficiency Plan to develop alternative energies to meet 15% of the country's domestic needs and increase the use of energy-saving systems. Since then, the government has set a more ambitious goal: to increase the share of renewable energy capacity to 52% of the total energy mix in 2030. As a result, significant major policies and incentives in the renewable energy market have been enacted to improve the legal and regulatory environment, in particular the Renewable Energy Developmental Law 13.09 (introduced in 2010 and updated in 2021 under Draft Law 40.19), Net Metering Legislation (Law 58-15), National Energy Strategy, Law of Self-Generation (Law 16.08), Green Bonds, Morocco Sustainable Energy Efficiency Financing Facility (MorSEEF), Tatwir Green Growth Program, Industrial Recovery Plan 2021-2023, Morocco Renewable Power Tenders (2010, solar auctions are led by MASEN).

*Table 2: Major policies and incentives for renewable deployment in Morocco, compiled from various sources.*

| | |
|---|---|
| Tatwir Green Growth<br>(2021) | • aims to foster the development of new green industry sectors and reduce industrial pollution by supporting micro, small and medium sised enterprise<br>• supports projects on energy transition projects centred around energy efficiency and renewable energy sources; start-up projects in the green industry sector; research and development of products with a negative carbon footprint; integration of clean technologies in manufacturing processes |

[47] There is a pilot agrivoltaics project in Algeria implemented by Fraunhofer's - the WATERMED 4.0 project funded by PRIMA Foundation. The solar panels are tilted at an angle of 15%, with a gutter installed in the central position to harvest rainwater. For further information .

[48] DW, 2022.

| | |
|---|---|
| Industrial Recovery Plan 2021-2023<br>(2020) | • aims to industry powered by the renewable resources; decreases the import dependencies; support market expansion through public demand and strengthens the Moroccan industrial sector on the international scene |
| Green Bonds<br>(2016) | • MASEN has issued Morocco's first green bond to finance the country's development of solar power<br>• the 1.15 billion dirham ($118 million) bond issue will help to fund three schemes that form part of the NOOR PV 1 solar power project. The schemes are to be developed in Laayoune, Boujdour and Ouarzazate with a total capacity of at least 170 MW |
| Morocco Sustainable Energy Efficiency Financing Facility<br>(2015) | • a credit line facility of up to €110 million developed by the EBRD, supported by the European Union (EU) and launched in 2015 in cooperation with the European Investment Bank (EIB), the Agence Française de Développement (AFD), and the Kreditanstalt für Wiederaufbau (KfW)<br>• since then, 257 sustainable energy projects in the private sector, small and medium sized businesses and corporates in Morocco.<br>• investments were used for stand-alone small scale renewable energy projects, commercial energy efficiency investments, building sector energy efficiency and/or renewable energy investments |
| Net Metering Law 58.15<br>(2015) | • amends Law 13.09 (2010) opening the renewable energy sources to the low voltage<br>• introduces the net-metering scheme for solar PV and onshore wind plants connected to high voltage<br>• allows private investors in renewable power to sell their surplus output to the grid, up to 20% of their annual production |
| Renewable Energy Law 13.09<br>(2010) | • promotes renewable energy development and provides a framework for developers and investors in clean energy projects. It does not put a limit on the installed capacity per project or per type of energy and provides a legal framework for energy export<br>• allows any individual to produce electricity from renewable resources. The electricity can either be used to meet the producer's power requirements (self-generation) or be fed into the medium- or high-voltage grid and sold to users. Under self-generation, any individual can reach the ceiling of 10 MW to 50 MW. A declaration is needed if capacity is between 20 kW and 2 MW and an authorization is required if generating capacity is equal to or higher than 2 MW |
| Self-Generation Law 16.08<br>(2008) | • amends Decree 1963 and raises the ceiling for self-generation by industrial sites from 10MW to 50MW<br>• conceived principally to support wind power, but applies equally to other renewable energy technologies including solar |

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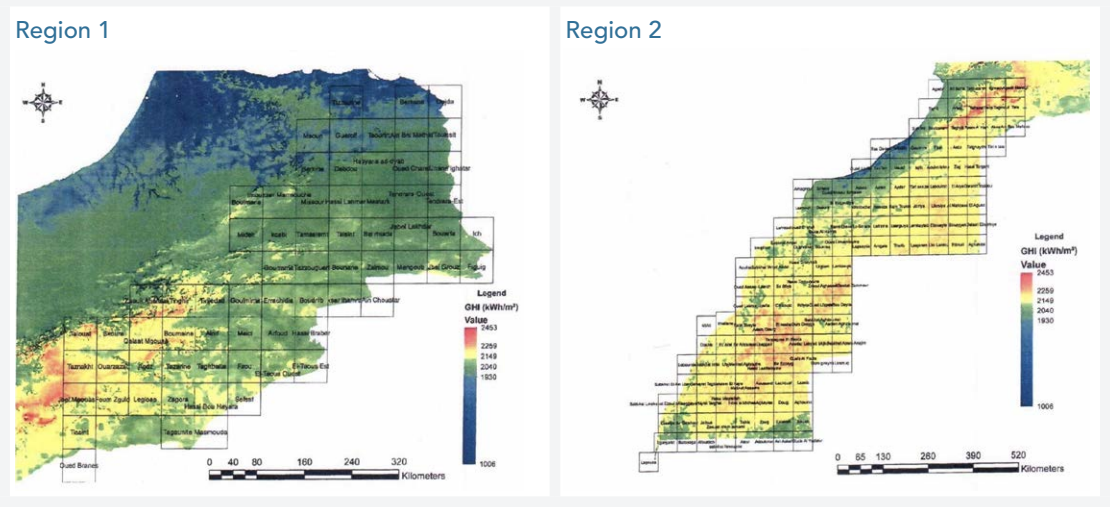
|---|---|
| Draft Law 40.19 for Renewable Energy<br>(2021) | • May 2022, the House of Representatives unanimously approved Draft Law 40.19. The Law amends Law 13.09 (2010) and Law 48.15 (2016)<br>• aims primarily to improve the business climate, enhance transparency and facilitates access to information related to investment opportunities<br>• simplifies licensing procedures, enhances the attractiveness of the renewable energies sector for national and international private investment, promotes industrial integration and contributes to the emergence of a national contracting and industrial fabric in the field of renewable energy technologies<br>• removes the zoning requirement for solar energy projects<br>• introduces carrying capacity (capacité d'accueil) defined as the maximum quantity of installed capacity from renewable energy sources that the national grid can accommodate without facing management constraints<br>• updates the self-consumption specifying that the self producer must be the owner of the self-generation installation<br>• opens, also, the possibility to entrust the construction and/or the operation and maintenance of the installation to a third party |

To date, Morocco has no feed-in-tariffs, but the government supports large-scale facilities on a project-to-project basis.

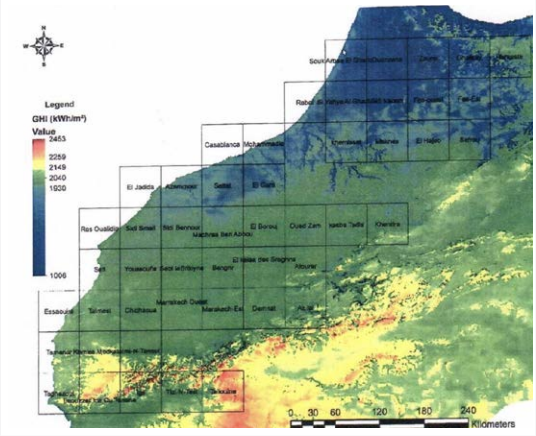
On July 2022, the Ministry of Energy Transition and Sustainable Development issued the Decree 2138.22,[49] updating the Decree 2.10.578 (2011) that identifies the regions and areas eligible for solar projects. The current Decree expands on the list covering all the country.

*Figure 17: Solar zoning map in Morocco. Source: Ministry of the Energy Transition and Sustainable Development, 2022.*




[49] https://www.mem.gov.ma/Lists/Lst_Textes_Reglementaires/Attachments/205/Arrêté%202138.22%20du%2029%20Dhu%20al-Hijjah%201443%20(29%20juillet%202022).pdf.

Region 3

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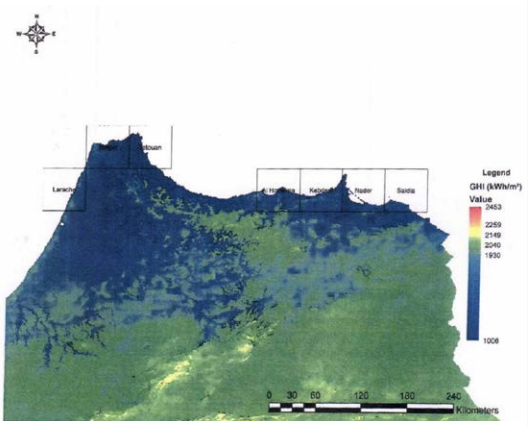



In April 2008 Morocco adopted the Green Morocco Plan whose land policy aimed to achieve private management of public lands (encouraging private investments) and establish conditions for promoting aggregation and public-private partnerships between different industrial areas. Moreover, it promoted growth of the sector without discrimination, addressing all types of agriculture, including modern agriculture (20% of cultivated area, highly productive) as well as traditional one (located at the unfavourable mountain areas and oases, occupying 80% of arable land.

In 2020 Morocco launched Green Generation 2020-2030 (building on the achievements accomplished by the Green Morocco Plan) which calls for the creation of jobs in rural areas and in agriculture.

As for dual-use of agricultural lands, the current legislation does not explicitly state whether the solar project and crop production can be co-located on the same land.

## 3.2 Tunisia

In December 2022, Tunisian Ministry for Energy, Mines, Renewable Energy launched two tenders to deploy 1.7 GW of solar capacity and 600 MW of wind power to be added to the grid. Projects will take place between 2023 and 2025. This is in line with the Tunisian Solar Plan in 2009 (updated in 2012) with a long-term objective to achieve 3.8 GW of renewable energy capacity by 2030. To achieve these objectives, the government has passed various laws and incentives to speed up renewable energy development including Law 12-2015 on electricity production from renewable energies, Tunisian Investment Fund, Energy Transition Fund Decree 983-2017 and fiscal support on renewable energy components.

*Table 3: Major policies and incentives for renewable deployment in Tunisia, compiled from various sources.*

| | |
|---|---|
| Decision supplementing Law 12.2015<br>(2017) | • establishes the specifications for connection to the grid<br>• defines the contract for self-consumption in low voltage (net metering), in medium and high voltage<br>• establishes the PPA contact for the authorisation scheme |
| Decree 983.2017 on Energy Transition Fund<br>(2017) | • funds amount to 100 million Tunisian dinar (Ministry of Finance 2018) through loans (to date not operational) subsidies (through ANME)<br>• primarily intended for commercial companies with the objective to reduce their energy bill<br>• non-profit projects for renewable generation of electricity under self-consumption can benefit from this fund |
| Law 71.2016 in Investment Fund<br>(2016) | Establishes the Tunisian Investment Fund<br>• the resources of the Fund consist of State resources, loans and grants from within and from abroad and all other resources<br>• the interventions consist in granting subsidies for the execution of direct investment operations in key sectors including RE and equity contributions<br>Establishes the facilities for projects of national interest (Decree 398-2017)<br>• a deduction of profits from the corporate tax base within the limit of ten years<br>• an investment premium in the limit of one third of the investment cost including the expenses of intramural infrastructure works with a cap of 30 million dinar<br>• state participation in the expenses for infrastructure works |
| Decree 1123.2016<br>(2016) | • sets the conditions and procedures for the production and sale of electricity through renewable energy sources |
| Law 12.2015<br>(2015) | Distinguishes three main support mechanisms for renewable energy projects:<br>• generation for export (currently not applicable)<br>• self consumption, sale and surplus<br>• generation to meet domestic needs under a PPA<br>• Tunisia's PPAs fall into two groups: a) the authorisation regime, covering projects below 10 MW for solar and 30 MW for wind, awarded through simple tenders; and b) the concession regime, covering projects over 10 MW for solar and over 30 MW for wind, awarded via competitive concessions<br>• the Law clearly states that foreigners are not allowed to buy or take advantage of agricultural land, unless leased |

| | |
|---|---|
| Renewable Energy Law on electricity production<br>Law 74.2013 (2015) | • encourages investment in renewable energy towards increasing the contribution of renewable energy electricity to 30% equivalent to 3.8 GW of total electricity production by 2030<br>• boosts investments in the electricity sector, creates 10 thousand jobs and reduces the debt of STEG |
| Tunisian Solar Plan<br>(published in 2009 - revised in 2012) | • national program aiming at reaching the renewable energy development strategy targets<br>• aims to achieve 3.8 GW of renewable energy capacity by 2030 |
| Law 7.2009 on Energy Efficiency and RE provisions<br>(2009) | • authorises energy companies producing electricity from co-generation to sell their production to the public utility STEG and transport it through the national grid<br>• allows any establishment, or group of establishments in the industry, agriculture and services, to produce electricity from energy saving, co-generation or renewable energy, and to sell it to STEG (limited to 30% of the energy produced) |

Renewable energy components benefit from a value added tax reduced to 6% (compared to a rate of 18%). Under the three schemes (self-consumption, authorisation regime and the concession regime), the land for PV construction is not specified whether it can be allocated for dual use (agriculture and energy). What is clear from the Law 12-2015 (2015) is that foreigners cannot buy and cannot take advantage of agricultural lands unless leased. Still, a blurred area remains on whether a Tunisian farmer can cooperate with a local or international energy producer to use the agricultural land for energy and crop farming combined. In the absence of clear criteria for the allocation of state land to private investors, the Ministry of Industry, Energy and Mines (MIEM) is considering an alternative Law that allows temporary occupation of state land by the private sector for a period not exceeding three years[50]. Where land use has been authorised, it is the Technical Commission for Renewable Energy that verifies the appropriateness of renewable energy projects located on state land.

## 3.3 Algeria

In recent years, Algeria has made tentative steps to exploit the country's abundant renewable energy potential. The government has built up and repeatedly reconfigured the state's institutional architecture around renewable energy, but has been slow to take more substantive action. In 2017 the government enlarged the Ministry of Environment to include a renewable energy portfolio, before spinning this off in 2020 as the new Ministry of Energy Transition and Renewable Energy. The same year, it established a dedicated renewable energy engineering college at the University of Batna to develop national expertise. In 2021, it created the National Renewable Energy Company (SHAEMS, meaning sun in Arabic) under Sonatrach and

[50] IRENA, 2021.

Sonelgas joint ownership to manage renewable energy procurement, particularly solar. In 2021, SHAEMS launched 1 GW solar tender (to be awarded under 25 years concession agreement as Algeria aims to reach 16 GW of renewable energy capacity by 2035.[51]

*Table 4: Major policies and incentives for renewable deployment in Algeria, compiled from various sources.*

| | |
|---|---|
| Law 99.09 on the Management of Energy<br>(1999) and National Programme for Renewable Energy Promotion | • defines the conditions, framework and application processes of Algeria national policy to manage energy<br>• establishes a general framework for the national use of energy, energy conservation and energy efficiency, the development of renewable energy and environmental protection through reducing GHG emissions and air pollution<br>• promotes of renewable energy as one of the pillars on the National Programme for the Management of Energy<br><br>Under this Law, the National Programme for Renewable Energy Promotion is created<br>• it is a five-year plan, incorporated into Algeria's 2020 Sustainable Development Strategy and is assessed yearly<br>• regulates the training activities, knowledge diffusion, research and development activities of the Algerian government, taking into account the economic, environmental and social costs of renewable energy |
| Law 22.18 on investments<br>(2022)<br><br>(replacing the 2016 Investment Law) | • removal of 49/51 rule for strategic sectors, which previously placed a 49% limit on foreign ownership of Algerian companies<br><br>Under this Law, investments are classified under three categories:<br>• Sector regime lists the strategic sectors including renewable energy for this reason recipients of specific incentives (Financial Law)<br>• Zone regime specifies the strategic areas and regions particularly those with natural resources<br>• Structuring investment regimes that have a high potential for creating wealth and jobs |
| Renewable Energy and Energy Efficiency Development Plan 2011-2030 /2015-2030<br>(launched in 2011, revised in 2015) | • solar energy (both solar PV and solar thermal) is recognized by the Algerian government as a primary renewable technology to be developed<br>• aims to install 22 GW of power generating capacity from renewable sources between 2011 and 2030<br>• the Plan forecasts that solar electricity production will increase up to 37% of total national electricity production by 2030 |

51 Blomberg NEF, ClimateScope, 2022.

| | |
|---|---|
| | Revision in 2015<br>• focuses on the large-scale solar PV installations and onshore wind due to the decrease costs of technology<br>• introduces biomass, cogeneration and geothermal technologies into the mix until 2020<br>• aimed to install 4.5 GW of new projects by 2020 and reach an overall of 22 GW by 2030 (out of which 13 575 MW of solar PV) |
| Decree 13.218 for Feed-in-Tariffs for solar PV installations<br>(2014) | • aims to support Algeria in achieving its renewable energy targets<br>• tariff is differentiated for the size of the plant and the payments are divided in two phases. The tariff level for Phase I is set flat. The payments in Phase II are determined by the number of equivalent hours of annual operation<br>• only plants with a capacity equivalent or larger than 1 MW can benefit from the FIT programme |
| Renewable Energy National Fund<br>(2009) | • provides financial support to actions undertaken within Renewable Energy and Energy Efficiency Development Plan 2011-2030 and other eligible renewable projects |
| Law 04.90 on Renewable energy promotion in the framework of sustainable development<br>(2004) | • aims to promote sustainable development in Algeria, protect the environment and contribute to the international effort to curb climate change impacts<br>• establishes a set of tools to promote the development and use of renewable energy: (i) a complete Certification of Origin system to attest to the renewable source (ii) a National Observatory for the Promotion of Renewable Energies to promote renewable energy at both national and international scale (iii) a financial incentive framework, determined every year in the national Finance Law, to benefit activities promoting research and development of renewable energy |
| Law 02.01<br>(2002) | • sets the basis for the liberalisation of the electricity sector and establishes an Energy Regulator (CREG)<br>• grants IPP the right to access the grid and sell power produced to large consumers<br>• to date no renewable energy project is implemented under this Law |

## 3.4 Egypt

During COP 27, Egypt launched the NEXUS Programme comprising 9 projects with a total cost of US$14.7 billion. It is a transformational strategy that moves from a narrow sectoral approach to a more focused and structured model of linkages between sectors. Three leading institutions will support Egypt: the African Development Bank for the Water pillar, IFAD for Food and Agriculture, and the European Bank for

Reconstruction and Development for Energy. In May 2022, Egypt launched its 2050 National Climate Change Strategy designed to consolidate all aspects of climate change in one document to be a basic reference that ensures the integration of climate change dimension into general planning of all sectors in the country. The strategy did not include an overall emissions reduction goal. But it indicated the planned investments of US$211bn for mitigation and US$112bn for adaptation. Among the most important mitigation measures, the country aims to increase the share of renewables in its power mix to 42% by 2035.

*Table 5: Major policies and incentives for renewable deployment in Egypt, compiled from various sources.*

| | |
|---|---|
| Decree 2.2020 on net metering (2020) | • replaces previous decrees announced by Egyptian Electric Utility & Consumer Protection Regulatory Agency (EgyptERA) in relation to net metering<br>• sets the rules that the solar plant must be installed within the boundaries of the customer's premises - either be installed on rooftops or to be ground-mounted only within the boundaries of the premises. Solar plant installed on adjacent land to the customer's premises cannot currently net meter<br>• sets a maximum aggregate capacity of installing solar plants across the country not exceeding 300 MW<br>• the maximum capacity for plants owned by one customer should not exceed 25 MW in aggregate or 20 MW per project<br>• allowed small-scale renewable energy projects in the residential, industrial and commercial sectors (with a maximum capacity of 20 MW) to feed electricity directly into the low-voltage grid.<br>• EgyptERA shall determine a balancing charge to be paid by the customer as a cost for combining renewable energy into the grid according to its voltage |
| Investment Law 72.2017 (2017)<br><br>Decree 2310 on Executive Regulations (2017) | • determines the electricity and energy sector covering the designing, construction, production, management, operation and maintenance of electricity and power plants whatever their sources, distributions and sales networks |
| Integrated Sustainable Energy Strategy to 2035 (ISES 2035) (2016) | • enhances energy security through diversification of supply sources, improves energy efficiency, advances corporate governance, and makes the energy market more competitive and sustainable. ISES aims to generate 20% of national electricity generation from renewable sources (including solar, wind, concentrated solar power (CSP), and hydro) by 2022 and 42% by 2035. In addition, coal has been phased out of the energy mix and replaced by renewables |

| | |
|---|---|
| Electricity Law 87.2015<br>(2015) | • regulates all electricity activities with the aim of replacing the current single buyer model and establishing a fully competitive electricity market where electricity generation, transmission and distribution activities are fully unbundled<br>• allows private sector participation in electricity generation and distribution<br>• sets out the framework for market liberalisation through de-monopolising generation and distribution activities<br>• restructures the roles of EgyptERA and the Egyptian Electricity Transmission Company (EETC), in particular in relation to ensuring freedom of competition in the power sector market<br>• codifies the fundamentals of permitting and licensing, including for renewable electricity production |
| Presidential Decree 17.2015 on renewable energy tax<br>(2015)<br><br>(amending the Investment Law 1997) | • incentives include trimming sales tax to 5% from as high as 10%, and setting customs duties on equipment used for production at 2%<br>• non-tax incentives offered to energy producers include funding the expenses paid to extend infrastructure facilities to the project's land. Such refund will be after the commencement of the project, subsidising the technical training programs of the employees as well as the social insurance subscriptions and allocating the land owned by the government free of charge or at discounted prices |
| Renewable Energy Law 203.2014<br>(2014) | • identifies four main mechanisms: state-owned projects with competitive bidding for engineering procurement and construction contracts, competitive bidding for build-own-operate contracts, feed-in-tariffs, and a merchant scheme and independent power production through third party access<br>• offers certain investment incentives and tax reductions to this sector<br>• land for renewable energy projects may be allocated free of charge if the project is deemed of strategic interest. Otherwise, 2% of the production is generally payable yearly for land lease |
| Egyptian Solar Plan<br>(2012) | • sets the targets to install around 3,500 MW of solar power plants (2,800 MW CSP + 700 MW PV) by 2027<br>• private investment share of these installations is estimated for 67% through competitive bidding, feed-in tariff and third party access schemes<br>• the incentives provided for wind energy projects will be applied for solar projects |

## 3.5 Jordan

In November 2022, Masdar the Abu Dhabi Future Energy Company, signed a Memorandum of Understanding with Jordan's Ministry of Energy and Mineral Resources to explore collaboration in renewable energy projects with a total capacity of up to 2 GW. In 2021, renewable energy accounted for 26% of Jordan's energy production, compared to 20% of Jordan's energy production in 2020.[52] This is in line with the government's efforts to reach the 2030 target of 3.22 GW of renewable energy sources capacity, equivalent to 31% of total installed capacity. According to MESIA 2023 report on Solar Oultook[53] Jordan has 1,498 MW of commercial PV projects under PPAs and 1,027 MW of small-scale installations under net metering and wheeling schemes, and is expected to introduce energy storage legislation in 2023.

*Table 6: Major policies and incentives for renewable deployment in Jordan, compiled from various sources.*

| | |
|---|---|
| Law 21 on Investment Environmental Law<br>(2022)<br><br>(replaced the Investment Law of 2014) | • defines the tasks and powers of the Ministry of Investment, establishes the Investment Council and the Incentives Committee, and regulate the establishment, supervision and management of development and free zones in Jordan, as well as develops and simplifies commercial and economic activity<br>• Art. 13.2 specifies that the Council of Ministers, upon recommendations, may subsidise energy and water costs and support renewable energy projects. Art 13.4 grants tax or custom exemptions or reduction in return for employing a minimum number of Jordanian labour force |
| 2020-2030 Energy Strategy<br>(2020) | • sets a 2030 target of 3.22 GW of RES capacity, equivalent to 31% of total installed capacity<br>• aims at diversifying energy forms, increasing the contribution of indigenous energy sources, improving energy efficiency in all sectors and reducing the impact of energy costs on the national economy, making Jordan a regional hub for all forms of energy exchange<br>• one of its objectives is to enhance the integration between the energy and water sector[54] |
| Jordan Green Growth National Action Plan 2021-25: Energy Sector<br>(2020) | The action plan identifies actions to meet five overall objectives:<br>• Enhance Natural Capital<br>• Sustainable Economic Growth<br>• Social Development and Poverty Reduction<br>• Resource Efficiency<br>• Climate Change Adaptation and Mitigation |

[52] https://petra.gov.jo/Include/InnerPage.jsp?ID=43933&lang=en&name=en_news.

[53] MEMR, 2020.

[54] MEMR, 2020.

| | |
|---|---|
| National Strategy for Agricultural Development (2016-2025)<br>(2016) | • seeks to improve resilience of farmers and agricultural areas in general.<br>• aims to maintain biodiversity, reduce desertification, spread drought-resistant plants, enhance forest protection measures and green belts, better manage water and soil, protect grassland and grazing |
| Law 13.2012 on IPP access<br>(2013) | The rules and conditions of IPP access to market are governed by Law 13.2012 on Renewable Energy and Energy Efficiency (REEL) and its subsequent amendments, which set up the following mechanism:<br>• Direct proposal submission (build-own-operate projects offered through competitive bidding)<br>• Self-consumption (wheeling and net metering)<br>Furthermore, when it comes to land use provisions, the Law (article 4)[55] foresees that the Ministry shall identify the "Land Use List" and land that appears in the approved Land Use List shall be allocated for renewable energy projects |
| Law 13.2010 on Renewable Energy & Energy Efficiency<br>(2012) | • provides the legislative framework to encourage exploitation of renewable energy sources, further supply-side energy efficiency and streamline private sector investment through incentives<br>• under the law, the Ministry of Energy and Mineral Resources is in charge of enacting the law, and a first order of business was the identification of geographic areas for renewable energy exploitation. These areas, coordinated with the Ministry's Energy Master Plan, will be prioritised for development in a Land Use List, approved by the Council of Ministers. Areas identified for exploitation that are 'treasury land' (owned by the state) shall be allocated to renewable energy projects. Lands owned by individuals shall be purchased based on existing legislative authority, if approved by the Council of Ministers<br>• specifies the purchasing arrangements of the electricity from bulk suppliers; much of this framework is pre-existing in the General Electricity Law<br>• individual homes may also produce their own renewable electricity, and sell any surplus energy back to the grid, with the price set by the purchase tariff specified in the Bulk Supply Licensees or the Retail Supply Licensees |
| Jordan Renewable Energy & Energy Efficiency Fund<br>(created in 2012 - operation between 2015-2019) | • created under the Law 13.2010 on Renewable Energy & Energy Efficiency<br>• provide necessary funding for Energy Efficiency and RE measures at the end-user's level<br>• eight key sectors were covered including agriculture: install PV solution for 70 small and medium farms<br>• last update on this fund dates 2020 |

[55] Law No. 13 Of 2012 concerning Renewable Energy and Energy Efficiency Law, ILO NATLEX database.

| | |
|---|---|
| General Electricity Law 64. 2003<br>(2003) | • is a general regulatory framework for the generation, distribution and sale of electricity in the Kingdom, and has been updated over the years<br>• states that energy efficiency shall be a national priority<br>• allowed private energy companies to access the electricity grids as well as set guidelines for renewable energy projects. Large-scale projects (above 5MW) would be contracted through competitive tendering (no longer necessary due to the provision in the renewable energy Law), small-scale (below 5 MW) through direct negotiations and very small scale (below 1 MW) for auto-generation and only to be bought during peak demand |

## 3.6 Lebanon

Lebanon is currently battling one of its worst economic crises in decades. The country defaulted on its national debt in 2020, and its currency has collapsed in value, and continues to devalue. This has made it difficult to stop subsidies on fuel imports in persisting power cuts in all regions. The country is currently suffering from a catastrophic electricity situation, with about 50% of the Lebanese people deprived of electricity, while the majority receive it insufficiently. Private generators provide a large part of the need at a high financial cost for the Lebanese. This has prompted Lebanese citizens to turn to solar energy. According to the Lebanese Center for Energy Conservation, estimates indicate that the solar production in 2022 was around 250 MW. Between 2010 and 2020, the number of projects operating on the solar energy system (upon the facilitation letter approved) reached 2,500. In 2022, the number rose to 25,000 projects; a tenfold increase from the previous figure.

*Table 7: Major policies and incentives for renewable deployment in Lebanon, compiled from various sources.*

| | |
|---|---|
| The Distributed Renewable Energy Draft Law<br>(2022) | • establishes an "intermediary" between the investor and the investment through the licences awarded for production<br>• stimulates the private sector to invest, depriving it of production, transportation and sale<br>The draft Law, in its current form, provides:<br>• generating 1.5 MW of RE without permission<br>• generating between 1.5 and 10 MW of RE based on permission given by the regulatory authority<br>• generating more than 10 MW of RE based on the licensing system and energy purchase contracts between the regulatory authority and the private sector<br>This applies to the production of distributed renewable energy, which benefits from the various arrangements of the net metering system. In light of the current situation, surplus production from renewable energy is wasted |

| | |
|---|---|
| The Energy Conservation Draft Law<br>(2022) | • Complementing the Distributed Renewable Energy Draft Law, as energy efficiency is a priority before production<br>• aims to enhance energy efficiency and fulfil international commitments in terms of reducing emissions and improving energy efficiency |
| Law 462.2002 regulating the electricity sector<br>(2002) | • it has not been implemented to this day<br>• political interventions have obstructed the appointment of the regulatory authority for the electricity sector, as stipulated in the Law, by amending article 7 and transferring powers to the Council of Ministers<br>• stipulates a partnership with the private sector in a regular and transparent manner to contribute to the production and distribution processes<br>• under this Law, Electricité Du Liban should be transformed into a public company, owning 51% of the shares, while the private sector owns the remaining 49% of the shares<br>• It gives the right to produce up to 1.5 MW of electricity for private use, without obtaining a permit or licence |

The primary source of legislation is the Lebanese Constitution of 1926 which, as amended, protects land rights. A few years later, the Land Property Code was issued to set the legal procedures for the purchase of real property. The Code regulates, among others, types of property and rights of property (such as right to ownership, right to dispose, right of surface, right of usufruct). Foreign ownership in Lebanon is governed by Legislative Decree 11614.1969 and its subsequent amendments, notably Law 296.2001. These rules provide that a foreign person/individual or Lebanese entity deemed as foreign can own up to 3,000 square meters of land without prior permit or authorisation. The acquisition of property above 3,000 square meters requires approval by the Council of Minister. However, going one step further, it has to be acknowledged that the lack of a land policy in Lebanon is affecting the relevance of some land-related legislation. This often results in overlapping rules and regulations and hampers good land governance[56]. Finally, when it comes to agrivoltaics, the current legislation does not explicitly state whether the solar project could be installed on fertile agricultural lands and whether the land can be jointly used for solar and crop farming.

Our analysis reveals that Morocco, Tunisia, Algeria, Egypt, Jordan and Lebanon have in place some enabling factors for agrivoltaics deployment with some degree of differences between the countries. All countries have shown political commitment to spur PV solar renewable energy: they enforced their commitment in their National Strategies - whether to reduce greenhouse gas emission or to transit to green and efficient energy sector - adopted and updated their energy Laws and have put in place financial incentives and instruments to deploy solar. After analysing the existing laws, **the table below summarises the enabling factors for developing agrivoltaics in the six countries.**

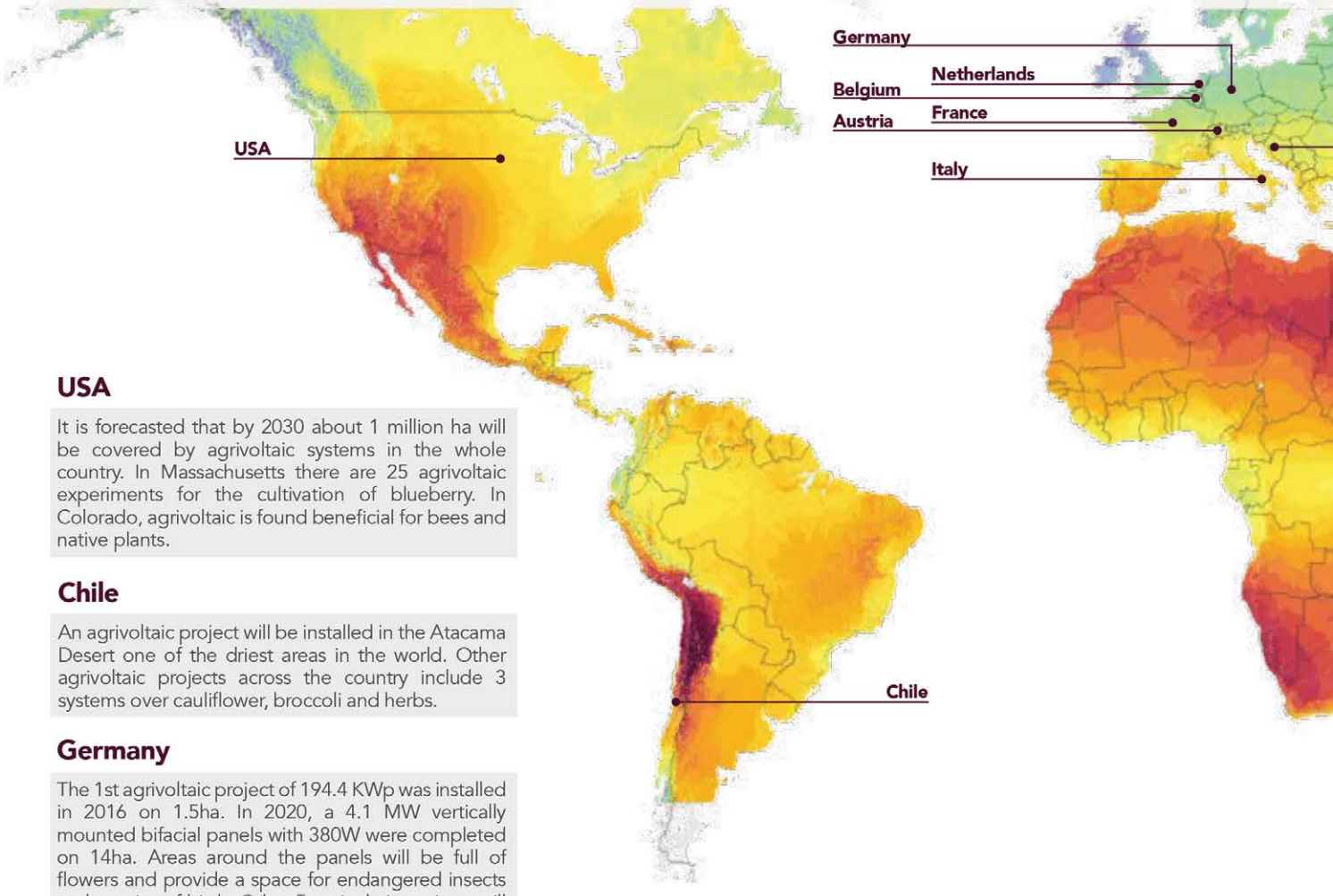
[56] United Nations Human Settlements Programme, 2022/

*Table 8: Enabling factors for agrivoltaics deployment in the six countries.*

| Country | Enabling factors for the agrivoltaics development |
|---|---|
| Morocco | • National Strategy recognised the role of solar and renewable energy in the energy mix with a 52% of renewable energy capacity of the total energy mix in 2030<br>• Legislations enabling the PV deployment and investments opportunities include the renewable energy Law, self-consumption, net metering giving access to low and medium voltage and allow energy production from solar energy for personal use or feed the grid<br>• Financial incentives and support schemes for private sector, micro, small and medium sized businesses and corporates in Morocco<br>• The list of regions and areas for solar projects was updated in 2022 covering all the country<br>• Green Generation 2020-2030 calls for a resilient and eco-efficient agriculture by enhancing water efficiency and soil conservation and supporting farmers in the transition towards renewable energy |
| Tunisia | • The National Solar Plan sets a long-term objective to achieve 3.8 GW of renewable energy capacity by 2030<br>• Laws and Decrees to promote solar development including net metering, self-consumption, PPA for solar projects below 10 MW under the authorisation regime and over 10 MW under the concession regime. Law 7.2009 allows any establishment, or group of establishments in the industry, agriculture and services, to produce electricity from energy saving co-generation or renewable energy, and to sell it to STEG (limited to 30% of the energy produced)<br>• Financial schemes through tenders and funds for RE project of national interest |
| Algeria | • Renewable Energy and Energy Efficiency Development Plan 2011-2030 aims to install 22 GW of power generating capacity from renewable sources by 2030 with focus on solar energy<br>• Legislations to deploy solar including feed-in-tariffs (for a capacity equivalent or larger than 1 MW) and tenders. Removal of 49.51 rule for strategic sectors including renewable energy<br>• Investments initiatives to support solar investments and job creation including the Renewable Energy National Fund<br>• Established the National Renewable Energy Company under Sonatrach (the national state-owned oil and gas company) and Sonelgas (the national TSO) joint ownership to manage renewable energy procurement, particularly solar |

| | |
|---|---|
| Egypt | • NEXUS Programme (WEF) supported by AfD, IFAD and EBRD was launched at COP27 and Egypt adopted the 2050 National Climate Change Strategy with the aim to increase the share of renewables in its power mix to 42% by 2035. Also, the Egyptian Solar Plan sets the targets to install around 3,500 MW of solar power plants (2,800 MW CSP + 700 MW PV) by 2027<br>• Legislations enabling the PV deployment including Electricity Law, Renewable Energy Law and net metering (the maximum capacity for plants owned by one customer should not exceed 25 MW in aggregate or 20 MW per project)<br>• Investments plans supporting businesses including non-tax incentives offered to energy producers, competitive bidding, feed-in tariff and third-party access scheme<br>• Based on the Energy Law, land for renewable energy projects may be allocated free of charge if the project is deemed of strategic interest. Foreigners could sign a joint agreement with a local for access/use of the land |
| Jordan | • Adopted between 2020 and 2021 several national strategies for deploying renewable energy in the energy and agriculture sector: 2020-2030 Energy Strategy sets a 2030 target of 3.22 GW of RES capacity, equivalent to 31% of total installed capacity, one of the objectives is to enhance the integration between the energy and water sector; Jordan Green Growth National Action Plan 2021-25: Energy Sector focuses on five key areas including Climate Change Adaptation and Mitigation (potential agrivoltaics stream); National Strategy for Agricultural Development 2016-2025 with focus to improve resilience of farmers and agricultural areas in general, in particular better manage water and soil<br>• Existing Law on IPP access to market (2013) and General Electricity Law (2003) establish three mechanisms: competitive bidding (BOO) and tenders (above 5 MW), direct negotiation (below 5 MW) and self-consumption (wheeling and net metering below 1 MW)<br>• Renewable energy in agriculture is promoted under the Renewable Energy & Energy Efficiency Law; farmers could benefit from this Law for deploying solar on their land |
| Lebanon | • Distributed Renewable Energy Draft Law (2022) enables generating 1.5 MW of RE without permission; generating between 1.5 and 10 MW of RE based on permission given by the regulatory authority; generating more than 10 MW of RE based on the licensing system and energy purchase contracts between the regulatory authority and the private sector<br>• Solar panel installation requires a submission of a facilitation letter to the Lebanese Center for Energy Conservation presented by individuals and private entities<br>• Energy Conservation Draft Law (2022) promotes energy efficiency in all sectors |

# SOME GLOBAL PRACTICES OF AGRIVOLTAICS




## USA

It is forecasted that by 2030 about 1 million ha will be covered by agrivoltaic systems in the whole country. In Massachusetts there are 25 agrivoltaic experiments for the cultivation of blueberry. In Colorado, agrivoltaic is found beneficial for bees and native plants.

## Chile

An agrivoltaic project will be installed in the Atacama Desert one of the driest areas in the world. Other agrivoltaic projects across the country include 3 systems over cauliflower, broccoli and herbs.

## Germany

The 1st agrivoltaic project of 194.4 KWp was installed in 2016 on 1.5ha. In 2020, a 4.1 MW vertically mounted bifacial panels with 380W were completed on 14ha. Areas around the panels will be full of flowers and provide a space for endangered insects and species of birds. Other 5 agrivoltaic projects will be tested on blueberry, red currant, strawberries and blackberries.

## Netherlands

In 2020, 5 agrivoltaic projects were installed. The largest one is in Zevenaar, with a capacity of 2.7 MWp covering an area of 3.2ha of different berry crops. By 2021, it is planned to install 45 MW agrivoltaic projects in the country.

## Belgium

The agrivoltaic project in Bierbeek Flanders is placed at 4.6m covering pear orchards. In 2021, the project will expand including bifacial solar tracking on a fixed stilled structure.

## France

Since 2000 France has greatly invested in agrivoltaic. In Piolenc, 280 PV panels at a 4m height cover vineyard. While in Mallmort 196 PV panels cover apple orchards at 5m height.
Since 2020, the French consortium for agrivoltaic has mobilised €1bln to deploy around 300 agrivoltaic projects in the country by 2030.

## Austria

The 1st agrivoltaic was built in 2007 on a 0.1ha area with PV panels placed at a height more than 5m. In 2020, a 11.5 MW agrivoltaic project including sheep farming and 25,780 PV panels over 12.5ha has been installed.

## Italy

Agrivoltaic projects are found in Mantova and Abruzzocovering 60+ ha of agricultural land of cereals, forage, tomatoes, and watermelons. In Mantova, PV panels are placed at height of 5m on a 15ha land. The Recovery Plan foresees €1,1bln investments to install 1 GW of agrivoltaic.

## Croatia

In 2017, a research project on agrivoltaic initiated. PV panels of 500 KWp will be installed over a variety of crops. The aim is to test shade effect. Part of the electricity produced will be used to irrigate and operate the agriculture machinery.

## India

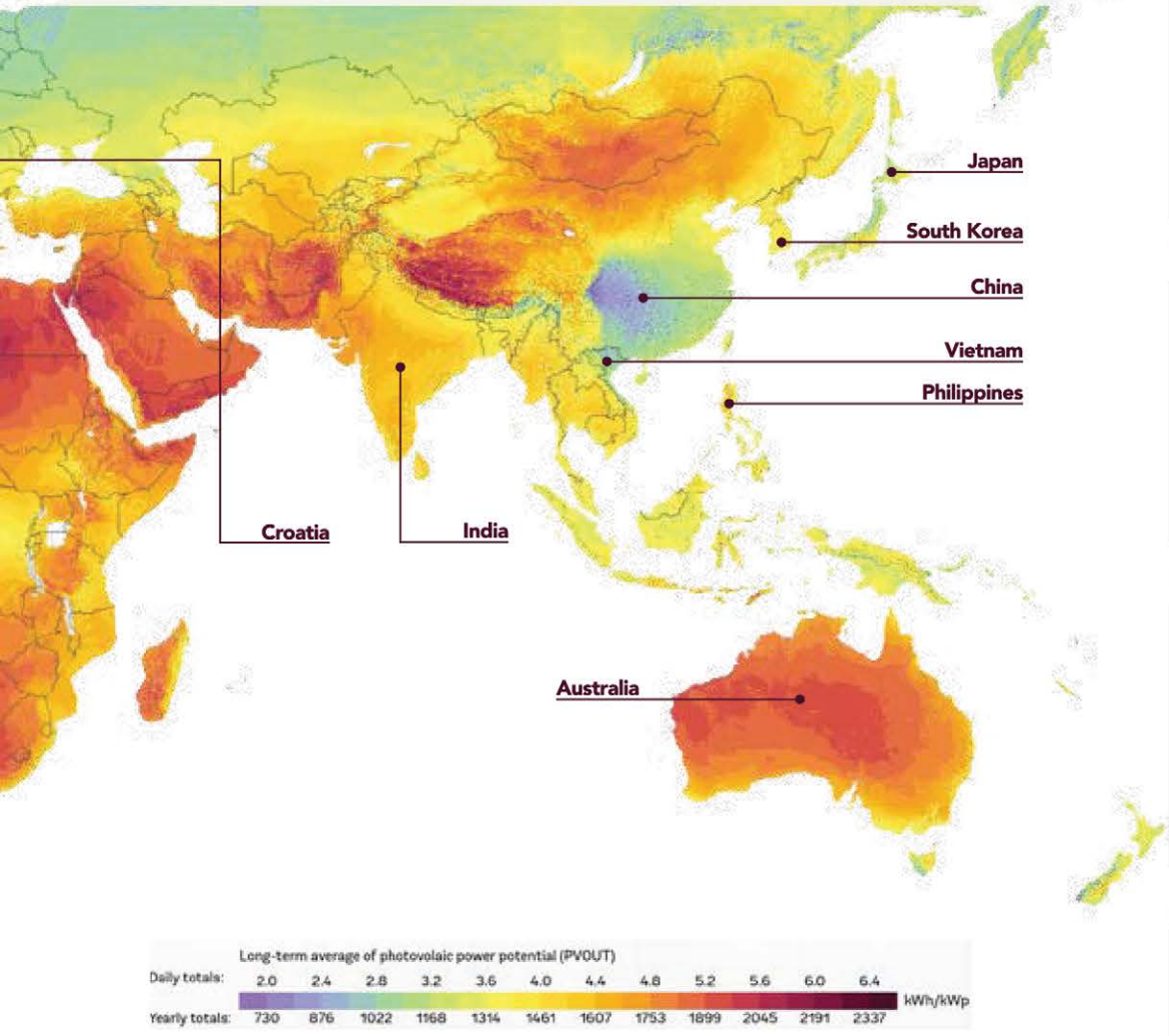
Agrivoltaic gained momentum in India as a result of land use conflict and high RE targets. To date, there is around 16 agrivoltaic projects covering over than 40 crops. As of 2019, India counted on 5 MW of installed agrivoltaic.

## Japan

The 1st agrivoltaic project was installed in 2003. In 2020, around 2000 agrivoltaic farms exist accounting for 0.08% of national solar generation. Over 120 variety of crops grew under the PV panels and some projects were secured under the Feed - in Tariff scheme. In 2020, changes to the FIT scheme added preferential treatment to agrivoltaic.

## South Korea

The 1st agrivoltaic project of 100 KWh was installed over rice, cabbage, ginseng, soybeans, garlic and other local vegetables. In 2019, the Korea Agrivoltaic Association was created as the government aims to install 100,000 agrivoltaic systems by 2030.




## China

In 2020, renewable energy from agrivoltaic accounted for 40 GW. Today, agrivoltaic projects are mainly found in Xinjiang, Gansu, Quinghai and cover forestry crops, vineyards, goji berry and watermelon.

## Vietnam

Recently, studies are conducted to install agrivoltaic over shrimp farms as the conflict between land use is increasing. The project is expected to reduce water use by 75% and increase land-use rate by 65%.

## Philippines

In Tarlac city, the agrivoltaic system, installed at 1m height, covers turmeric crop production and generates 71 MW of clean energy. In 2021, the government aims to install agrivoltaic in the agriculture and fishery sector.

## Australia

In 2021, an agrivoltaic project will be installed on a 163ha sheep farm in the New South Wales. It will include 260,936 PV panels at 460 Wp each and a battery storage system. PV panels will be positioned at 2.3m height and will have a single axis tracking system generating 260,000 MWh of solar energy annually.

*GLOBAL SOLAR ATLAS

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CHAPTER 4

# **Going forward:** Six actions for the uptake of agrivoltaics

# Going forward:
## Six actions for the uptake of agrivoltaics

As seen in the previous chapter, many of the basic enabling conditions for the application of agrivoltaics in the Mediterranean are in place. However, it is possible to move forward in the deployment of this solution. To identify the success factors for the agrivoltaics, a benchmark analysis has been performed. The aim was to identify the replicable common elements and requirements, the existing gap between international best practices and the current situation in the Mediterranean countries considered in the report, and the actions needed to spur the agrivoltaics deployment. The benchmark analysis covered **France, Germany, Japan, Italy, the United States of America (USA), Chile, Taiwan and South Korea.**

First of all, **deploying agrivoltaics in the Mediterranean cannot happen without a political commitment from governments to develop agrivoltaics**. France, the USA, Korea, Germany and Japan, among others, have politically declared their interest in the agrivoltaics to boost renewable energy production as well recalling its benefits to co-locating solar and crop production on the same land. The strategic commitment enabled the speedy applications of the system in the country and embedding agrivoltaics across national strategies, plans and policy tools and instruments while improving public support to using the land for crop and energy production.

Findings show that the agrivoltaics is a growing practice in these countries. Some countries have (1) clearly defined the agrivoltaics standards and requirements in the national context as did France and Italy (2) and introduced it in the National Strategies and Plans as in Japan, South Korea and Italy. Agrivoltaics was (3) introduced in the energy policies, regulations and laws as in Germany, France, USA, Taiwan and Japan. The (4) dual-use of the land for agriculture and energy production was allowed in Japan, Italy and USA. While the majority of these countries have (5) set financing instruments and incentives to encourage agrivoltaics deployment particularly by amending the feed-in Tariff, (6) and raised awareness on agrivoltaics promoting partnerships among farmers, energy producers and State.

**This chapter highlights the six actions that brought forward the agrivoltaics in the best practices countries.**

*Figure 18: Six actions to accelerate the uptake of agrivoltaics. Source: Author's own elaboration.*

## 4.1 Clearly define agrivoltaics standards and requirements in the national context

Agrivoltaics standards are clearly defined in France and Italy. In 2021, the French Environment and Energy Management Agency (ADEME) published a series of documents[57] that defines the agrivoltaics embedding the notion of synergy between agricultural and PV production on the same land. The aim is to help achieve the objectives set by the Energy Transition Law and considers that the development of photovoltaics in the agricultural sector cannot be done without taking into account the need to preserve agricultural soils. ADEME defines Agrivoltaics as follow:

> "An agrivoltaics installation is a PV system whose modules are located on the same surface of an agricultural production, to which they bring the following services, without causing a significant qualitative and quantitative degradation of the agricultural yield, as well as a reduction of the revenue generated from the agricultural activity. Service of adaptation to climate changes, service of protection to extreme weather events, service of improving animal welfare, agronomic service for specific cultures."

When it comes to specific technical requirements, it has been specified that agrivoltaics projects must always imply the presence of a farmer. Such installations must also be reversible and adaptable to new and local conditions, without damaging the environment. Furthermore, ADEME emphasised that PV installation must provide a service in response to an agricultural problem. This means, for instance, that the PV modules above a plant production could, while producing energy, provide a beneficial service to the agricultural production protecting from excessive sunlight, limiting water stress through a shading effect, or reducing the risks associated with climatic conditions such as hail or frost.

In Italy, the Ministry of Ecological Transition (MITE) has defined the agrivoltaics systems in the 2022 Guidelines on Agrivoltaics. It defines the system according to two categories: simple and advanced.

A simple agrivoltaics system is

> "A photovoltaic system that adopts solutions aimed at preserving the continuity of agricultural and pastoral cultivation activities on the installation site."

While an advanced agrivoltaics system is

> "A complex system that adopts innovative integrative solutions with assembly of the modules elevated from the ground, also providing the rotation of the modules in a way that does not compromise the continuity of agricultural and pastoral cultivation activities, also possibly allowing the application of digital and precision agriculture tools.
>
> A complex system allows the creation of monitoring systems to verify the impact of the photovoltaic installation on the crops, water saving, agricultural productivity for the different types of crops, the continuity of the activities

[57] ADEME, 2021.

of the farms concerned, the recovery of the fertility of the soil, microclimate, resilience to climate change;

A complex system ensures the continuity of the agricultural activities (...) and integrates agricultural activity and electricity production, and aims to enhance the production potential of both subsystems."

Depending on the agrivoltaics system installed, MITE defines five requirements: the first is adoption of spatial configurations and technological tools that enhance both agricultural and energy production. The second defines the need for a synergistic production of electricity and agricultural products and non-compromise of the continuity of agricultural and pastoral activity. The third promotes the adoption of innovative integrated solutions with modules raised off the ground, aimed at optimising performance in both energy and agricultural terms. The fourth states the need for a monitoring system to verify the impact on crops, water savings, and agricultural productivity. The fifth covers the need for a monitoring system that verifies the recovery of soil fertility, the microclimate and the resilience to climate change.

## 4.2 Recognise agrivoltaics in the national strategies and plans

Among the countries that greatly recognised agrivoltaics in their mid and long term National Plans and Strategies, we can find Italy, South Korea and Japan.

Italy integrated the agrivoltaics in their National Recovery and Resilience Strategy (PNRR) which supports the green transition with key investments in energy efficiency, sustainable mobility and development of renewable energies. Agrivoltaics is one of them with a dedicated 1.10 billion of Euro. The plan envisages deploying agrivoltaic systems with a total capacity of 1.04 GW to generate around 1300 GWh per year. In August 2022, Italy launched the call for tenders to access the incentives of the PNRR for the agrivoltaics park (sviluppo agro-voltaico). The measure is part of the Green revolution and ecological transition mission and is aimed at supporting investments in hybrid agriculture-energy production systems that do not compromise the use of land dedicated to agriculture, but contribute to the environmental and economic sustainability of the farms involved. Other than decarbonising the agricultural sector, the measure also aims at making the sector more competitive, reducing energy supply costs.

South Korea Renewable Energy Plan (2017) indicates the target of 10 GW of agrivoltaics by 2030, while the country aims to produce 20% of its energy from renewable energy by 2030.[58] The plan aims to support small-scale PV developers and farmers to advance the energy transition and provide the ageing and low-income farmer population with additional income. Japan announced in the 2019 Follow-up on the Growth Strategy[59] stating that farming-photovoltaics - PV equipment installed on farmland - will expand nationwide to strengthen the agricultural sector.

[58] IEA, 2020.

[59] KANTEI, 2019.

## 4.3 Introduce agrivoltaics in the energy policies tools, regulations and laws

Several countries have introduced Feed-in Tariffs (FiT) to enable a rapid expansion of renewable energy, especially solar energy and have amended FIT Laws to adapt to the dynamic progress of the energy sector.

In 2021, Germany[60] introduced agrivoltaics in the Renewable Energies Act (EEG) categorising it as special solar systems and made them eligible for funding as a system combination via solar innovation tenders for projects with capacity superior to 750 KW, whereas smaller PV installations received a set FiT. The EEG entitled agrivoltaics operators to both a priority grid connection to the existing grid and a priority purchase of the electricity produced, with grid expansion and grid connection costs borne by, respectively, the grid operator and the system operator.

In the same year, Taiwan announced the new Renewable Energy FiT scheme and one of its aims is to encourage dual-land-use: agricultural or aquacultural management combined with solar energy facilities. Japan first enforced the FIT scheme in 2012 facilitating a ten-fold increase of solar PV from 7600 GWh in 2012 to 77 000 GWh in 2019[61] and it amended the FiT scheme including the preferential treatment for agrivoltaics in its provision. To benefit from the FiT, small-scale PV -between 10 and 50 kW have to allocate 30% of generated electricity for regional use.

In the USA, Massachusetts is the first state to offer financial compensation for agrivoltaics under its Solar Massachusetts Renewable Target (SMART) program[62] that regulates incentives for different kinds of grid-connected solar PV including projects under the Agricultural Solar Tariff Generation Unit (ASTGU). The provisions of ASTGU have been updated in 2022 to promote sustainable, cost-effective and innovative solar development in a tariff-based system for capacity for small-scale projects (<25 kW), small commercial projects (25 – 500 kW) and projects that bring benefits to low-income households.

Beginning 2023, France adopted the Law on the acceleration of renewable energy production[63] including the deployment of agrivoltaic installations. Section 7 of the Law introduces a special provision for agrivoltaics and defines it as an installation based on the sustainable development of an agricultural activity and contributes to the improvement of its agronomic potential and adaptation to climate change. In addition, the Law provides special support for agrivoltaic projects in terms of the obligation to purchase the electricity generated, and makes them eligible for the EU-funded Common Agricultural Policy subsidies for farmers.

[60] Fraunhofer report, 2022.

[61] Tajimi, 2021.

[62] https://www.mass.gov/info-details/solar-massachusetts-renewable-target-smart-program.

[63] https://www.senat.fr/petite-loi-ameli/2022-2023/268.html.

## 4.4 Allow the dual-use of the land for agriculture and energy production

An agrivoltaics system comprising a nexus of energy and agriculture would require the dual utilisation of agricultural lands. In our best practice analysis, we found that many countries do not allow dual-use of farmland or the temporary use is considered a major obstacle for the deployment of agrivoltaics.

For instance, South Korea grants 8 years of temporary use of farmland (under the Farmland Act), meaning that the solar PV - which usually has a 25 years life-span - must be removed after 8 years of use. South Korea is currently reviewing its Farmland Act for greater efficiency.

Agrivoltaics in Germany falls under the category of ground-mounted solar PV systems and follows its requirement. In the permission process, applicants wishing to deploy agrivoltaics on farmland - must specify in the development plan Special Area Photovoltaic. In 2022, Fraunhofer Institute for Solar Energy Systems (FraunhoferISE) published the Agrivoltaics Guidelines for Germany[64] which proposes a Special Agrivoltaic Area to solve this problem.

Among the countries that regulated the dual-use of the land for agriculture and energy production is Japan. In 2013, the Agricultural Land Act 2657 granted the temporary conversion of the farmland for agrivoltaics use for a maximum of 10 years[65] under the following conditions:

- the mounting structure is only temporary and easily removable,
- the shading rate ensures enough sunlight penetration for plant growth,
- the minimum panel height is 2m except for vertical agrivoltaics,
- the instalment does not hinder agricultural practice in surrounding areas,
- the reduction of yield must be under 20% compared to the average level of the surrounding farmland with the exception of projects on devastated land.

Also, the Solar Massachusetts Renewable Target (SMART) program allows dual-use under certain conditions and mandatory obligation to submit an annual report about the productivity of crops or herd, crop management, and potential changes for future years. The conditions include:

- agrivoltaics are installed on property officially defined as Land in Agricultural Use or Prime Agricultural Farmland,
- the capacity of the system must be under 2 MW,
- the lowest edge of the panel must be at least 8 feet above the ground for fixed-tilt panel systems or 10 feet (at the horizontal position for tracking systems),
- the shading rate during the growing season must not exceed 50%, and

[64] Fraunhofer report, 2022.

[65] The permit was valid for three years, but this was extended to 10 years in the 2nd directive in 2018 (30 Noushin No. 78.

- the system must be designed to optimise the balance between electrical and agricultural production over the 20-year program period.

In Italy, Legislative Decree 199/2021, which implements EU Directive on the promotion of the use of energy from renewable energy sources (RED II) classifies the areas suitable for PV installation as agricultural, regardless of landscape constraints and should be enclosed within a perimeter whose points are no more than 300 meters away from areas of industrial, artisanal and commercial uses.

## 4.5 Set financing instruments and incentives to support agrivoltaics deployment

Besides the incentives under the feed-in tariff in place in several countries, different states in the USA have set solar incentives to help farmers reduce the upfront cost of installing a solar energy system, making it more accessible and affordable. Solar incentives include: tax credits, rebates, grants and loans.[66]

- Tax credits: A tax credit is a dollar-for-dollar reduction in the amount of income tax a person or business owes. Many states offer solar tax credits to encourage the adoption of agrivoltaics systems.
- Rebates: A rebate is a direct payment to a person or business that has installed a solar energy system. Rebates can be offered by states, utility providers or other organisations, and can be used to help cover the cost of installing agrivoltaics systems.
- Grants: A grant is a financial award that does not need to be repaid. Grants can be used to help cover the cost of installing agrivoltaics systems.
- Loan programs: Loan programs can provide financing for the installation of agrivoltaics systems. These loans may be offered at a reduced interest rate or with other favourable terms.

France has been the first country in Europe to offer financial incentive schemes through tenders for innovative PV projects. In 2017, innovative solar PV tenders were launched to support the agrivoltaics deployment in France under which winners would benefit from a feed-in-tariff guaranteed for 20 years. The contracts were awarded on the basis of the offered price and on how innovative the project is for a maximum project size of 3 MWp. By highlighting agrivoltaics in the tenders, the government also sparked the interest of developers and energy generators, paving the way for a deal between Total Quadran (the French renewable power production unit of Total SA) and InVivo (the leading French agricultural cooperative group) for the deployment of 500 MW of agrivoltaic projects by 2025.[67]

[66] Agritecture, 2023.

[67] INVIVO, 2020.

The Italian government has committed €1.1 billion to establishing 1.04 GW of new agrivoltaic generation capacity as part of its National Recovery and Resilience Plan. In Chile, the Santiago Metropolitan Region government offered financial support to several agrivoltaic pilot projects through its Competitiveness Innovation Fund (Fondo de Innovación para la Competitividad). Research findings from pilot projects were then used to optimise land-use efficiency by identifying the best locations and configurations for PV systems to coexist with agricultural activities.

## 4.6 Raise awareness on agrivoltaics and promote partnerships between farmers, energy producers and State

If the deployment of agrivoltaics is to succeed, it must be anchored in the society through social acceptance. Taking into consideration the interests of farmers, energy producers and the communities, social acceptance is therefore fundamental. Among the benchmark countries, there were several efforts to raise awareness and promote partnerships.

For instance in France the Agrivoltaisme Association is an important actor of the agrivoltaic ecosystem. The association brings together more than 50 members and 10 000 affiliates from the industry, farmers, energy companies, researchers and investors. Its mission is to establish a balanced dialogue between the different actors and promote the social acceptance of the uptake of agrivoltaics. In 2022, France Agrivoltaisme organised meetings at the MED'AGRI exhibition in Avignon with actors from the agricultural realm (Chambers of Agriculture, Unions, Associations, training organisations, etc.), the energy sector, government and local authorities.

Similarly, the German Federal Ministry of Education and Research funded the APV-RESOLA project with the aim of gathering early-impressions of agrivoltaics involving citizens and stakeholder groups on the site of the pilot system in the Lake Constance region.

In the USA, Agrisolar Clearing House[68] is actively working on connecting businesses, landowners, and researchers with trusted resources to support the growth of co-located solar and sustainable agriculture. The network also provides technical assistance and evaluates innovative financing options for agrivoltaic projects.

[68] https://www.agrisolarclearinghouse.org/about/.

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