10. Renewable energy in Morocco

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Morocco's national energy strategy has evolved rapidly to meet the policy challenge of increasing energy demands, environmental commitments and reliance on energy imports. As an emerging economy with limited fossil fuel resources, Morocco has focused on developing sustainable and local energy sources and has set ambitious targets to spur investment in renewable electricity. This is exemplified by the successful development of the world's largest concentrating solar power (CSP) plant in 2016, as well as a range of efforts in energy efficiency. As Morocco has moved into new technology fields, including solar PV, hydrogen and batteries, it has been guided and supported by new institutions, including the Institute for Research in Solar Energy and New Energies (IRESEN), which focuses exclusively on R&D and innovation related to renewable energy.

IRESEN has ensured that the strategic goal of technology leadership has received sufficient attention in alignment with the national vision for renewable energy. It has come to play a central role in research and innovation in renewable energy in Morocco and also in international co-operation. It develops pilot projects and facilitates collaboration between academia and industry. This institutional innovation has been highly successful and demonstrates the value of fostering technical expertise within government and co-ordinating the actions of academic and private actors. However, this model has also raised challenges of financial continuity.

Country context

Morocco is the third-largest economy in North Africa by GDP and the third-largest in terms of population. It is classified as a lower middle-income country, and has per-capita national income 45% higher than the average of all lower middle-income countries and just 18% lower than the upper middle-income threshold. Its economy has expanded robustly in the past two decades at an annual average rate of 3.8% between 2000 and 2021, although the rate has been below that average for the period since 2010 at 2.8%.

Progress in diversifying the economy and boosting growth has been hit in recent years by several crises, including the global pandemic, inflationary pressures, commodity price volatility and the Al Haouz earthquake in 2023, as well as tightening global financing conditions. Nonetheless, Morocco has demonstrated a

capacity to respond to shocks in recent years. It managed the humanitarian response to the earthquake and has a development plan to unlock the development potential of the most affected provinces.

More broadly, foreign direct investment has consistently flowed into Morocco in recent years and is increasingly directed towards the manufacturing sector. Various modern industrial niches well connected to global value chains have emerged and the country maintained access to international capital markets despite the ongoing tightening of global financial conditions. Exports of cars rose 27% in 2023 to USD 14 billion.

The European Union is Morocco's largest trading partner. In 2022, 56% of Morocco's exports went to the European Union and 45% of Morocco's imports came from the bloc. EU imports from Morocco amounted to EUR 22.9 billion, and were led by transport equipment (23.5%), machinery and appliances (21.2%) and textiles (14.3%). EU exports to Morocco amounted to EUR 33.3 billion. They were led by machinery and appliances (21.2%), followed by mineral products (15.5%) and transport equipment (11.1%).

In the global context, Morocco's human development index score is relatively strong and has risen continually since 1990. It ranks 120 out of 189 countries on this measure, just one place below the "high human development" category. Morocco is a parliamentary constitutional monarchy, whereby the king has some powers to appoint the prime minister and guide policy, in addition to the elected government.

Energy sector context

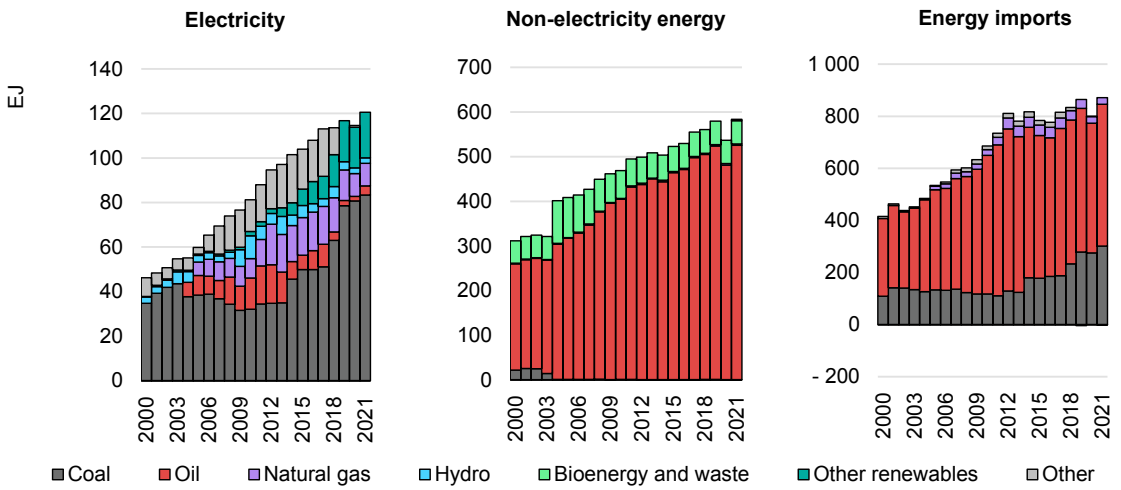
Morocco's energy system is dominated by coal and oil, and it imports more energy each year than any other African country. In 2021, 89% of Morocco's final energy needs were met by imported fossil fuels, mostly oil. This makes its economy particularly vulnerable to fluctuations in global oil and gas prices. The country's energy demand has risen steadily over the past two decades, with electricity demand rising faster than GDP, at an annual average rate of 4%, and other energy uses rising at 2%, more slowly than GDP. As a result, Morocco's CO_2 emissions from fuel combustion are on an upward trend, rising at an average of 3.5% per year since 2010 and reaching 67 million tonnes in 2021. These CO_2 emissions come almost exclusively from the burning of imported fuel, which is often used in inefficient conversion technologies – coal-fired power plants and internal combustion engines. This means that significantly more energy content is imported than is required to replace the same fossil fuels with domestic electricity sources, including for use in electric vehicles. This brings a double dividend of lowering import bills as well as emissions.

The Ministry of Energy Transition and Sustainable Development (MTEDD) is responsible for Morocco's energy policy. It is accountable for security of supply, energy market rules and authorising and supervising projects. It has a mandate to promote energy efficiency and renewable energy. MTEDD oversees the Office National de l'Électricité et de l'Eau Potable (ONEE), which is a legally and financially autonomous public entity with monopoly ownership of the electricity transmission system. It generates around one-third of the country's electricity and is involved in the purchase and sale of all electricity sold via the national grid. In 2008 a law was passed to create an Energy Development Fund.

Morocco has made significant strides in providing universal access to electricity, to the extent that it is no longer a major policy focus for the country. This milestone was achieved in 2017, marking a critical success in the nation's energy policy. This achievement distinguishes Morocco from several other countries on the African continent and highlights its commitment to improving living standards and fostering economic development through reliable energy access. The completion rate of the Global Rural Electrification Programme had reached 99.85% by the end of 2022.

In 2009 Morocco made the strategic decision to maximise the use of its domestic renewable resources to increase energy security and limit CO_2 emissions. The 2009 National Energy Strategy committed the country to increasing the share of renewables to 42% of electricity capacity by 2020 and improving energy efficiency by 12% by 2020 and 15% by 2030. This is in the context of the united goals of sustainable development, energy security and independence from fossil fuel imports. The renewables target was further broken down into 2 GW of solar, 2 GW of wind and 2 GW of hydropower. At the time, Morocco's installed solar and wind capacity was around 0.2 GW in total, while hydropower was at 1.8 GW. This strategic shift has led to significant changes in Morocco's electricity mix, with renewables reaching 19% of total generation in 2021 (Figure 10.1). Solar and wind electricity have almost entirely displaced the use of oil in electricity generation, which reached a high point in 2012 and declined to just 3% in 2021, and imports of electricity. However, solar and wind have not yet compensated for lower hydro output in recent years, or the lower imports of natural gas in the recent higher-price environment – these changes have so far been covered by more coal-fired power generation.

Figure 10.1 Energy sources for electricity and other uses, and imports, Morocco, 2000-2021



Notes: Electricity and non-electricity energy are shown on a final consumption basis. Imports are shown net of exports. "Other" refers to imports or exports of electricity.

Source: IEA (2024), World Energy Balances.

The 2009 National Energy Strategy has been complemented by successive legal instruments to enable investment towards its achievement:

- Law 13-09 (2009) mandated the national grid operator with facilitating the feed-in of renewable electricity and its export to other countries.
- Act 02.09.410 founded the Société d'Investissements Énergétiques (SIE) to manage the Energy Investment Funds and facilitate the diversification of energy resources and the promotion of renewable energy and energy efficiency.[1] SIE's budget is capitalised by MTEDD and the Hassan II Funds, which were created in 2000 to support social and economic development.
- Law 54-14 (2014) allows owners of capacity above 300 MW to sell electricity that they do not self-consume to ONEE.
- Law 48-15 (2015) established a National Authority for the Regulation of the Electricity Sector (ANRE). It also more than doubled the 2030 solar and wind capacity targets, to 4.6 GW for solar and 4.2 GW for wind.
- Law 39-16 (2016) established the National Agency for Energy Efficiency (AMEE) under the auspices of MTEDD, to be responsible for implementing energy efficiency policy, including regulations, incentives and awareness campaigns.

Energy price reforms are ongoing to reduce the fiscal burden of consumer energy subsidies. Since 2000 the government has covered the difference between fixed energy tariffs and the cost-recovery rates. While the subsidy was one of the lowest

[1] In 2023 the name of SIE was changed to Société d'Ingénierie Énergétique and given a narrow focus on investment in energy efficiency as a "Super ESCO" (energy services company).

in North Africa and the Middle East, it still exerted pressure on the national budget and reforms began in 2014 to partially index prices to fuel costs.

Morocco's 2021 update of its NDC, submitted as a signatory to the Paris Agreement, raised the renewables target to 52% of total installed electricity capacity by 2030. This is in the context of an unconditional target to reduce greenhouse gas emissions to 18.3% below business as usual by 2030 and a target of 45.5% below business as usual by 2030 conditional on receiving international assistance. Its conditional measures include reducing the emissions intensity of the cement industry through carbon capture and storage equivalent to 2.5% of the total reduction, or 20% of the emissions from the economically important phosphate sector. Morocco is estimated to hold approximately 75% the world's phosphate reserves.

Active areas of energy policy development in Morocco today include:

- Continuing to expand electricity capacity to meet growing demand.
- Strengthening energy links with Europe and sub-Saharan Africa, including through electric interconnection projects and strategic partnerships.
- The possibility of constructing a liquefied natural gas terminal for diversifying natural gas imports.
- Managing water stress and land degradation, which are being exacerbated by high vulnerability to climate change, as well as energy sector resilience to climate change.
- Managing urban air pollution.

Innovation context

Morocco has a well-developed research system relative to many of its peers in North Africa and among emerging economies. It is currently ranked 70 out of 132 countries in the Global Innovation Index and eighth among 37 lower middle-income countries. Within the last decade it has risen more than 20 places on this scale, partly due to an above-average ability to convert limited inputs into impactful outputs. One reason is its network of universities with science and engineering research departments that have dependable government funding. The Ministry of National Education, Vocational Training, Higher Education and Scientific Research is responsible for policy related to fundamental and applied research in universities and research centres. It works closely with other ministries, including MTEDD, to promote innovation and is subject to the financial control of the Ministry of Economy and Finance. The National Centre for Scientific and Technical Research coordinates the research programmes of universities and scientific institutions, and is also responsible for establishing and maintaining connections and collaborative programmes with research institutions in foreign countries.

The country has pursued a strategy of innovation through applied R&D since 2000, with an objective to reduce Morocco's dependence on imported technology, move up value chains to capture more of the added value and create a dynamic environment for industrialisation. To this end, the Hassan-II Academy of Science and Technology, a learned society under the responsibility of the prime minister, has been given responsibility for setting the general orientation for scientific and technological development, funding scientific and technical research programmes, and integrating scientific and technical research into national and international collaborative activities. A Permanent Inter-Ministerial Committee on Scientific Research and Technological Development is chaired by the prime minister and co-ordinates technology innovation activities across government, with the contribution of MTEDD on energy topics.

The importance of two new technology-related institutions in Morocco: MASEN and IRESEN

The 2009 National Energy Strategy sought to position the country as a leader in renewable technologies within Africa, in addition to setting energy security and environmental ambitions. This clear technology-related goal distinguishes Morocco's renewable energy policies from those of most of its peers in lower middle-income countries. By developing its expertise and capacity in this sector, the country aimed to seize the opportunity to export know-how and strengthen its economic and political ties with other nations. In addition, by positioning itself in this way, the government viewed its renewable energy strategy as a means of strengthening its attractiveness to foreign investors. The electricity sector in particular needed sizeable investment to modernise and keep pace with economic growth.

The intrinsic link between the 2009 strategy, the reduction of uncontrollable and high fuel import bills, and the nation's economic future created a strong alignment with the national vision. Compared with other countries, Morocco did not have a politically powerful incumbent fossil fuel production industry that was threatened by the turn towards renewables and this helped build consensus. In the Moroccan context, the public support of the king for this strategy was critical for generating momentum behind the targets. However, given that the costs of solar and wind technologies were at the time high compared to fossil fuels, there remained some scepticism among the public and within government departments about the risks of higher-than-expected economic costs.

One of the first acts in the implementation of the 2009 strategy was the creation of two new institutions to co-ordinate and undertake projects in the renewable energy area. It is notable that Morocco decided to use two new bodies entirely

dedicated to low-emissions energy development rather than giving responsibility for renewables to existing entities. The two new institutions were:

- The Moroccan Agency for Sustainable Energy (MASEN), which has responsibility for the deployment and operation of commercial-scale technologies.
- The Institute for Research in Solar Energy and New Energies (IRESEN), which has responsibility for technology analysis and R&D.

To bring solar electricity online on a large scale and with maximum compatibility with the existing electricity grid, MASEN was given responsibility for developing a CSP project and, one year after its creation, signed a power purchase agreement with a private sector project developer from Saudi Arabia, which also provided USD 126 million in debt and equity. The final investment decision for the initial 160 MW plant was taken quickly in 2013, with USD 800 million of financing secured at preferential rates from international partners.[2] It also secured USD 20 million in equity from the International Finance Corporation. The finished power station was connected to the grid in 2016, having cost Moroccan Dirham (MAD) 7 billion (USD 855 million), just 60% of the amount appraised by the World Bank in advance.

It has since been expanded twice with further support from international development finance. The aggregate CSP capacity is now 510 MW, making it the largest such plant in the world. In a 2014 assessment, the World Bank noted that its finance was justified in the global interest because the project could potentially contribute to halving CSP costs worldwide in the following years and because Morocco had a preference for power generation that could be dispatched in the evening as well as during the day.

Technology-related input to energy policy from IRESEN is highly valued by the government

The mission of IRESEN at its founding was to fill a gap in applied research and technological development in renewable energy in Morocco, including undertaking pilot projects and building prototypes to test and validate technologies before large-scale investment. It was a direct response to the needs identified in the 2009 strategy to develop internal skills and try to ensure lowest-cost technology choices. This function was important in the context of a lower middle-income country with high energy price sensitivity due to significant proportions of low-income households and manufacturing in the economy. Politically, an institution with a

[2] Financing partners included the World Bank. European Investment Bank, l'Agence Française de Développement, African Development Bank, Kreditanstalt für Wiederaufbau, the German Federal Ministry of the Environment, Nature Conservation, Building and Nuclear Safety, and the European Commission.

mandate to develop domestic capabilities and monitor the cost of renewables was useful to gain consensus around the overall 2009 strategy.

IRESEN is under the aegis of MTEDD and, while solar electricity was the initial priority, it has a mandate to explore technology topics relevant to all renewable energy sources and enabling technologies. It is also responsible for collaboration between national research institutes and engagement in relevant international forums. It has several means of supporting R&D and technology innovation. Its model is a hybrid between the operations of a funding agency and that of a research institute. It has a particular focus on collaboration between researchers, institutions and the private sector, with the objective of strengthening the overall energy innovation ecosystem in Morocco.

As regards knowledge management at IRESEN, it manages a network of research and innovation platforms across Morocco, equipped with state-of-the-art laboratories to foster collaboration between academia and industry on technologies well-suited to the national and continental context.

It has several resource push initiatives, which include the following:

- Operating a funding agency that organises competitive calls to finance R&D projects of around USD 0.1-0.5 million at research institutions or between universities and companies, while incorporating socio-economic factors whenever feasible (Table 10.1). Calls have included: INNOTHERM (2012, 2013 and 2014) for enhancing the efficiency and installation of CSP; INNOPV and INNOWIND (2013 and 2014) for developing designs that could fit well with Morocco's existing electricity infrastructure; INNOBIOMASS (2014) to explore more sustainable processes for bioenergy conversion; and INNOPROJECTS (2015) for high-potential early-stage technologies, including energy storage and other topics.
- Operating a funding agency that organises competitive calls for collaborative projects that take promising technologies to the stage of product development. Calls have included: GREEN INNO-PROJECT (2018) for collaborations between an academic partner and industrial entity on projects at or above technology readiness level 3; and GREEN INNOBOOST 2.0 (2018) for collaborations between a start-up, an academic partner and industrial entity on projects at or above technology readiness level 6. GREEN INNOBOOST 2.0 is notable for the creativity of funding design to target capital-constrained innovators who could choose to receive the funding either as a non-dilutive grant or an equity investment from IRESEN, in addition to access to a 1.5-year programme of business services, public procurement support, connections with Moroccan experts and access to research infrastructure including the Green Energy Park. The funding can be used for a variety of purposes: to acquire equipment, test and certify the prototype, pay staff or buy consultancy.
- Training future engineers and project managers, and funding doctorates and post-doctoral research.

- Establishing dedicated infrastructure for technology testing, including the Green Energy Park and Smart Buildings Park. The Green Energy Park, a joint venture between IRESEN and the Université Mohamed VI Polytechnique created in 2017, includes dedicated facilities for piloting solar PV and smart grid technologies and a laboratory environment that encourages interaction between researchers, project developers and the private sector.

IRESEN also undertakes actions to build socio-political support. For example, it inaugurated the Solar Decathlon Africa exhibition and competition with Mohammed VI Polytechnic University, MTEDD and the Department of Energy. It was held first in 2019 and raised public and policy maker awareness of the benefits of renewable energy and sustainable construction, leading to pilot projects, the creation of specialised research laboratories and strengthened academic collaborations. The IRESEN research infrastructure of the Smart and Green Building Park arose from this initiative. Projects inspired by Solar Decathlon Africa include work on energy management systems, next-generation PV panels, phase-change materials and energy storage. Solar Decathlon Africa boosted international co-operation, especially within Africa.

Table 10.1. Selected R&D projects funded by IRESEN to date

Project	Description and outcome
BioF2S	Development of solar hydrothermal carbonisation for converting waste from olive oil production to solid biofuels. The project proved the concept.
Ecomataf	Development of a process to produce construction blocks from local bio-based or recycled materials to achieve good thermal properties.
EV plan	Development of tools for city planners promoting EVs to identify areas with high EV acceptance and size charging facilities in line with demand and grid infrastructure. It also explores grid-friendly charging models.
Li-Sol	Development of a residential energy storage system that integrates with solar PV and has intelligent energy management algorithms connected to cloud services for customers. The result of the project has been spun-off as a start-up selling a package including a solar PV system, charge controllers, batteries and a control interface that can also enable backup power from the grid. The aim is to produce 100 units per year initially and maintain a rate of local equipment content of over 85%.
MCS Bitume	Development of an industrial-scale pilot facility to keep 40 tonnes of bitumen at 150°C using solar concentrators, and a feasibility study to scale up to 3 000 tonnes. The project proved that using solar could reduce fuel costs.
TahalaGrid	Development of a micro-grid demonstration encompassing eight public buildings for solar PV, solar hot water and load management integration.

IRESEN has provided a platform from which to explore opportunities for hydrogen energy

Morocco has high ambitions for hydrogen energy. It has multiple co-operation agreements with international partners to explore opportunities related to the country's extensive renewable resources and its proximity to export markets in Europe. When IRESEN was established, hydrogen was not a priority topic. However, IRESEN's flexibility and initiative in identifying new prospects was key to Morocco's readiness to engage internationally as the topic gathered high-level political interest in Europe from 2019 onwards.

IRESEN's first formal work on hydrogen was in 2018. Its interest in the topic was stimulated by its co-operation with Morocco's large industrial companies, of which the state-owned OCP Group is the biggest employer in the country. OCP Group is active in phosphate extraction and fertiliser production, which requires it to import large quantities of ammonia each year because Morocco does not have sufficient access to the natural gas typically used to produce the hydrogen needed to make ammonia. As OCP Group and IRESEN explored the opportunities for the company to use renewable energy, the electrolysis of water to produce hydrogen in Morocco surfaced as a potential research topic. In 2018 IRESEN and Fraunhofer IMWS – its German research partner – directed their co-operation towards hydrogen with a technical feasibility study of piloting ammonia production using renewable electricity and brought it to the attention of MTEDD. The study assessed Morocco's potential for hydrogen production from renewable electricity and its export.

In 2019 a National Hydrogen Commission was established, chaired by the minister of energy and including IRESEN alongside the Ministry of Economy and Finance, Ministry of Industry, Trade, Investment and Digital Economy, ONEE, MASEN, the National Office of Hydrocarbons and Mines, OCP Group and the National Higher School of Mines. IRESEN was charged with developing a Green Hydrogen Roadmap, which was published in 2021. With the technical capabilities and national co-ordination already established by IRESEN, the development of the roadmap did not require support from international bodies, unlike the case for hydrogen roadmaps in some other emerging market countries, and it drew on Moroccan perspectives only. The roadmap outlines Morocco's technical potential for hydrogen production from renewables and a strategic pathway to installing enough capacity by 2050 to satisfy domestic demand and establish Morocco as a prominent export hub to Europe. The roadmap also outlined stepwise R&D and pilot projects that would be needed for different applications of hydrogen, starting with ammonia production.

The roadmap identified Morocco's need to attract investment through public–private partnerships and international co-operation. In 2021 IRESEN and the OCP

Group established GREENH2A as a platform to spearhead R&D in hydrogen and related technologies to foster innovation.

From IRESEN's initial exploration into hydrogen, it took just four years to achieve full alignment with the national vision of the future. In November 2022 King Mohammed VI announced a significant investment programme by the OCP Group, including USD 13 billion to enhance the country's renewable energy capabilities towards production of hydrogen and ammonia. This initiative is part of Morocco's broader efforts to end reliance on imported ammonia, which became much more expensive in the aftermath of Russia's invasion of Ukraine in 2022. The programme aims to support local industries by requiring 70% of the components, materials and services to produce hydrogen and ammonia to be sourced from within Morocco, creating 25 000 direct and indirect jobs and involving 600 Moroccan companies. In 2023 King Mohammed VI announced a further initiative called The Morocco Offer to speed up the deployment of hydrogen technologies and create incentives for investment. Reaching these high-level announcements was undoubtedly facilitated by the foundation that the government had built from 2011 with the creation of IRESEN, which had the flexibility to pursue and explore arising topics related to renewable energy.

IRESEN continues to pursue this area and has recently launched a project call with French research institute SATT Paris-Saclay. The call is dedicated to fostering innovation in hydrogen from renewable electricity between 2024 and 2027 by jointly supporting two to three consortia of three research partners from both countries. It will draw upon SATT's specific expertise in bringing the fruits of research to market.

Battery-related R&D could lead to investment in the EV supply chain and use of local resources

Battery R&D for high-performance lithium-ion designs was among the first projects funded by IRESEN in 2012. The projects undertaken have tested the use of Moroccan mineral resources (especially phosphates, of which it has the world's biggest resources), creating laboratory prototypes, scaling up production to semi-pilot levels, and comparing the performance of these batteries with commercial counterparts in solar PV systems.

As with hydrogen, electric mobility was not a priority topic when IRESEN was created in 2011. However, as the EV market has expanded globally, there has been dramatic market growth for lithium iron phosphate (LFP) batteries, the type that was researched by IRESEN and which could rely on domestic phosphate as a raw material. These batteries may not have the same energy density as other designs, but they have long lifespans and less reliance on mineral inputs from countries about which there are supply chain or sustainability concerns. IRESEN's

early work in the area of LFP batteries showed that Moroccan designs had promising properties. This led to the OCP Group launching several initiatives, including R&D to further enhance efficiency and durability, as well as partnerships with international companies and research institutions. The outlook for the EV market has strengthened – it is now projected that global sales will pass USD 1 trillion per year by the early 2030s, with batteries representing the largest single cost component. Consequently, IRESEN started pilot projects to explore the feasibility of LFP battery production in Morocco, which could support a transition to EVs for the existing producers of internal combustion engine vehicles and components in the country. Renault, Stellantis, Sumitomo, Varroc Lighting Systems and Valeo operate in Morocco, and Hyundai may join them. Chinese electric carmaker BYD has been considering opening a factory in Morocco since 2017. In 2023 LG Chem, a Korean chemical company, and Hauyou Group, a Chinese industrial company, announced an agreement to make LFP batteries in Morocco, including conversion of imported raw lithium. This is in part because, since 2022, Morocco's free trade agreement with the United States makes Moroccan-produced batteries eligible for US sales subsidies when exported to the United States. In 2024 Chinese firm Gotion, backed by Volkswagen, confirmed investment in another battery factory in Morocco, which could potentially use cobalt mined in Morocco, and another Chinese firm BTR New Material announced plans for a LFP battery component factory in Morocco.

The OCP Group plays a crucial role in Morocco's industrial development and has recently shown interest in the production of LFP batteries due to the increasing demand for sustainable energy solutions. This interest is driven by the abundance of raw materials, particularly Morocco's significant phosphate reserves, a key component of LFP batteries. The OCP Group has launched several initiatives to enter this market, including investment in R&D to enhance the efficiency and durability of LFP batteries, and strategic partnerships with international companies and research institutions to leverage their expertise. Pilot projects are also underway to test the feasibility of LFP battery production in Morocco.

IRESEN was closely involved in producing the roadmap for electric mobility in Morocco, which outlines a plan for a charging network, charging standards, incentives for vehicle uptake and international co-operation to learn from experiences overseas. Alongside market pull policies, the roadmap highlights the importance of funding R&D for technology innovation. It also proposes socio-political support policies such as public awareness campaigns about the benefits of EVs. In 2023 the World Bank published Unlocking Electric Mobility Potential in the Middle East and North Africa (MENA), with a focus on Morocco and input from IRESEN. The report broadly supports the roadmap recommendations and could lead to further World Bank finance to tackle challenges including technical standards, electricity sales regulation, charging station profitability and a technical platform for integrating the various stakeholders' data needs.

While much of the work on LFP has shifted to OCP Group-led projects (via Innovx, an OCP Group subsidiary established for the purpose), IRESEN's R&D in the area has focused strategically on charging technologies. This is in part because the market in Morocco is not yet big enough to attract any of the major international EV charging providers. The R&D has resulted in the creation of a start-up, iSmart, to commercialise a charging station fully designed and developed by IRESEN at the Green Energy Park. It includes technical advances in charging infrastructure. iSmart started its first production line in 2021 and now has two production lines to meet growing demand. The startup plays an important role in IRESEN's Green Miles project, which aims to identify optimal locations for these stations to maximize their utility and accessibility. Sale of iSmart's business could help IRESEN reinvest in new projects in new technology areas.

IRESEN has become a strategic foundation for clean energy knowledge and international co-operation

IRESEN initially received a budget for ten years of operation and this was extended for an additional 6 years in 2021. This reflects the value it has created for Morocco's policymaking and its success in raising complementary funds. Between 2012 and 2019 most of IRESEN's resources came from foreign donors (57%), comprising 60% bilateral funding and 40% other foreign co-operation agreements. The remaining 43% is from the national budget. The public grant was mostly used towards the project calls, while the money from external fundraising went mostly to establishing the research infrastructure.

IRESEN's notable contributions to solar, hydrogen and electric mobility in Morocco are all considered to be of national strategic importance for local businesses and foreign direct investment. Its projects have led to 34 patent applications since 2017, and since IRESEN's foundation in 2012, Morocco has built a much stronger clean energy technology ecosystem and has proven it can react to changes in the international technological landscape. One of the success factors has been the co-ordination of networks of excellence through dialogue with universities and industrialists to identify needs and challenges.

In the last few years, IRESEN has initiated international projects with governments in Africa. The first of these is in Côte d'Ivoire. The Green Energy Park – Morocco Côte d'Ivoire is a platform for testing solar energy technologies under semi-tropical climatic conditions at INP-HB in Yamoussoukro, Côte d'Ivoire. It will build on the Green Energy Park platform in Morocco and focus on the agricultural sector. As well as calls for projects to be undertaken at GEP-MCI, it will fund students from INP-HB and train industry professionals in the field of solar energy.

However, with the possibility that its public grant will not be fully renewed, and the culmination of many R&D projects without commercial products, IRESEN is

exploring a new orientation to ensure its financial viability. It is developing a 2030 vision to become Africa's leading centre for applied R&D and innovation in renewable energy by 2030. This vision foresees IRESEN organising itself around a set of core themes aligned with national priorities and IRESEN's capabilities. Continued government funding is likely to be essential until 2030 to realise the vision, especially for the operational costs of infrastructure, but also to ensure partial financial autonomy and reduce reliance on the state. Several options are under consideration:

- Entering the business of selling services to private entities or international bodies. New commercially oriented activities could include certifying renewable components according to European and other standards (for example for solar PV technologies, batteries and electrolysers), feasibility studies, detailed engineering, site monitoring and inspection, and training. Given that the public sector is still present in most investments in renewable energy technologies in Morocco, these activities could also help to build essential private sector competences, help manage excessive financing costs and foster public support. IRESEN already has many contacts within industry that may wish to use such services.
- Generating revenue from supporting and investing in start-ups that emerge from the IRESEN ecosystem, including the Green Energy Park. The incubation and strategic support elements of GREEN INNOBOOST 2.0 could be expanded and equity could be offered, either with or without direct management involvement.
- Expanding the level of support for technologies at higher technology readiness levels, i.e. those that need specific resources to move from the laboratory to the market. Calls for projects would continue, but with extra emphasis on the part of the original mandate aimed at developing innovative products, services and processes that can create jobs in Morocco in solar PV wind, bioenergy, energy storage, hydropower, smart grids, sustainable mobility and energy efficiency. In some cases, this could involve continued support to ideas already explored at an early stage in the first decade of IRESEN.
- Licensing or selling intellectual property. To date, IRESEN has overseen projects that fully own patents and projects where a consortium shares the rights. It may be possible to raise money in future through a more strategic intellectual property strategy.
- Continuing to diversify funding sources via international co-operation, applying to overseas project calls and sharing some costs of R&D centres with the host regions than benefit from them.

Findings

The experience of IRESEN reveals several insights that are relevant to the encouragement of clean energy technology innovation in other emerging market and developing economies.

Firstly, local know-how is highly valuable when evaluating or procuring a new energy technology. As was discovered in Morocco for CSP, solar PV and EVs, products and projects often need adaptation to local conditions to be smoothly integrated with local infrastructure and the local context. IRESEN was able to play the role of "informed consumer" and develop complementary technologies to accelerate uptake, such as home electricity storage systems and EV chargers.[3] It is difficult for a government to support the achievement of an ambitious renewable energy target without informed opinions and expertise among decision-makers and in the domestic scientific community. While international partners can be very helpful, they may not always agree with each other or may not appreciate local nuances. Furthermore, international consultants can be very expensive.

While it may seem a bold move and requires a budget commitment, the creation of a dedicated institution for clean energy innovation can bring significant value. IRESEN was established at arm's length from MTEDD with a long-term mission to pursue technology in the interest of Morocco's national vision for economic development. IRESEN regularly evaluates the outcomes of its projects to inform policy makers and relevant institutions, enabling them to improve and see the benefits of investing in R&D.

A dedicated institution can become a focal point for a new network of researchers, companies and experts who have common interests and can work together. This tends to lead to expansion of this network, especially when backed by a government agency like IRESEN and an ambitious target for energy transitions that lends weight and credibility to the projects. The result in the case of IRESEN has been the creation of a strong national innovation ecosystem in the space of a decade. It can also act creatively in its design of interventions in a way that a government ministry might not be able to – IRESEN has developed smart new approaches to equity investment, international co-operation and research infrastructure.

Having a strong foundation in clean energy technologies has been shown to afford Morocco the opportunity to quickly enter new areas, such as solar, hydrogen and electric mobility. However, the impressive developments in these areas were conditional on IRESEN's flexible mandate and good alignment with national resources, including the strategic orientation of a major state-owned company (OCP Group) and domestic resources (solar radiation and phosphate). In cases where these capabilities align, it can be possible to rapidly develop new co-operative R&D projects and infrastructure with the industrial sector. In

[3] There is significant value in being an informed buyer of technology. The next 800 MW expansion of Morocco's CSP power plant, which was due to start operating in 2024, has yet to enter construction after MTEDD and ONEE rejected the proposed technology of the supplier. With a USD 2 billion price tag, it is worth getting the technology choice right in advance.

Morocco, this was helped by the support that renewable energy investors have given to local content and the creation of jobs and local industries.[4]

The case of IRESEN in Morocco demonstrates that many of the theories of technology innovation policy that have been developed around advanced economies apply equally as well in a lower middle-income country. Clean energy technology development in Morocco has responded to a combination of resource push, market pull, knowledge management and socio-political support policies. However, in a resource-constrained context, it is shown to be particularly important to ensure alignment with dominant national visions, foster international partnerships and focus on technologies that do not need to be developed from scratch, but where value can be added by adapting them in line with a clear national strategic benefit. In the case of IRESEN, this had particular impact when new information shifted an incumbent company towards more radical innovation and away from incremental development of known processes where they had only marginal international advantage. The OCP Group's pivot to hydrogen from renewable electricity and the potential tie-ups between Moroccan automakers and a new battery supply chain encapsulate this dynamic.

[4] At the same time, good practice on individual projects and strong technological capabilities are insufficient on their own. In Morocco, further work is needed to ensure that smaller-scale renewable projects receive the same opportunities as utility-scale projects, including enabling new entrants in the market and more community ownership. There remain opportunities to improve co-ordination between the various stakeholders, political groups and ministries to reach a common vision of how best to implement the renewable energy targets.