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POLICY PAPER

Sustainable Solar-Powered Irrigation Systems

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EXECUTIVE SUMMARY

Despite their relative novelty, solar-powered irrigation systems (SPIS) have earned a reputation for contributing to multiple Sustainable Development Goals (SDGs) as a single technology. Pumping water irrigating fields by harnessing the sun's power seems like a viable contribution to the goals of zero hunger (SDG 2), clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), as well as climate action (SDG 13). Irrigation improves agricultural productivity and therefore income, food security and nutrition. Ultimately, irrigation can make a decisive contribution to reducing food imports and thus strengthening independence from a volatile world market in times of crisis. However, SPIS must be implemented sustainably to reap all of its potential benefits. By considering the interdependencies between achieving water, energy and food security for human well-being, it can benefit from the synergies between these often-competing sectors.

Even though the potential of SPIS seems obvious – especially the increase of agricultural productivity and rural incomes, but also the possibility to generate off-grid electricity and its use for own consumption – it makes sense to furtherly support and promote its extension. The paper presents different business models, but also financial instruments to lower one of the biggest barriers to entry, the initial costs for the technical setup. From an economic point of view, it also gives important hints on how to strengthen the market for SPIS as a whole. Since there are currently a large number of technical options and standards for SPIS, a standardisation should take place or binding specifications should be created that will increase the quality and service life of such systems in the medium term. Along the entire value chain from production, installation, operation, maintenance and disposal of SPIS, actors must be trained accordingly to enable efficient and comprehensive use of the technology.

However, a comprehensive dissemination of SPIS can also harbour risks that should be addressed as early as possible. These include, in particular, the overuse of water resources, as the low operating costs of solar pumps offer little incentive to save water. At the water governance level, special focus should be placed on integrated water resource management, which, on the basis of consistent monitoring of the surface waters or aquifers concerned, implements equitable distribution, but also, if necessary, restrictions on use. Regarding the energy sector, it is recommended that SPIS users be given the legal and technical opportunity to either feed their generated electricity into the grid in return for remuneration, or to use it for other purposes such as cooling, in order to have an incentive to switch off the pumps. From an agricultural perspective, how SPIS are used to irrigate is ultimately crucial – increasing irrigation efficiency is of utmost importance here in order to conserve water resources in the long term. Cross-sectoral planning and regulation in line with the water-energy-food security nexus approach should therefore play a central role in the planning and use of SPIS.

1. INTRODUCTION

Despite their relative novelty, solar-powered irrigation systems (SPIS) have earned a reputation for contributing to multiple Sustainable Development Goals (SDGs) as a single technology. Pumping water irrigating fields by harnessing the sun's power seems like a viable contribution to the goals of zero hunger (SDG 2), clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), as well as climate action (SDG 13). However, SPIS must be implemented sustainably to reap all of its potential benefits. By considering the interdependencies between achieving water, energy, and food security for human well-being, it can benefit from the synergies between these often-competing sectors.

At this point, many countries have defined climate adaptation and mitigation measures in their Nationally Determined Contributions (NDCs) concerning their agricultural production, land use management and water resources management. At the same time, the economic development in rural areas remains a priority, facing population growth, urbanisation, and food insecurity. Income generation, transformation of agricultural production systems, protection of ecosystems and natural resources are but a few different targets in a context of different stakeholders – farmers and other end users, manufacturers, and investors with relatively little understanding of water resources management or agricultural production – which forms a complex setting of potentially conflicting interests in the topic of SPIS.

With many actors with different objectives and sector perspectives, the approach to SPIS often still lacks an integrated perspective. The development of SPIS is still driven by a multitude of objectives. These may be the creation of climate-smart solutions, reduction of carbon emissions and energy costs for irrigation, increasing independency of diesel or energy supply, securing or increasing food production, supporting water access for smallholder farms, but also multisectoral policy alignment and coordination. Contrastingly, unregulated use of the technology can lead to overextraction of groundwater and depletion of aquifers; other challenges are the handling of photovoltaic panel wastes, appropriate financing mechanisms and technical standards. The global trend of going solar especially for water pumps in the field of irrigated agriculture has raised a considerable interest from development actors. What can be done to foster solar powered irrigation systems, build up markets, train capacities, minimize damages to aquifers and ecosystems, and to profit from benefits? This paper aims to give a first guidance.

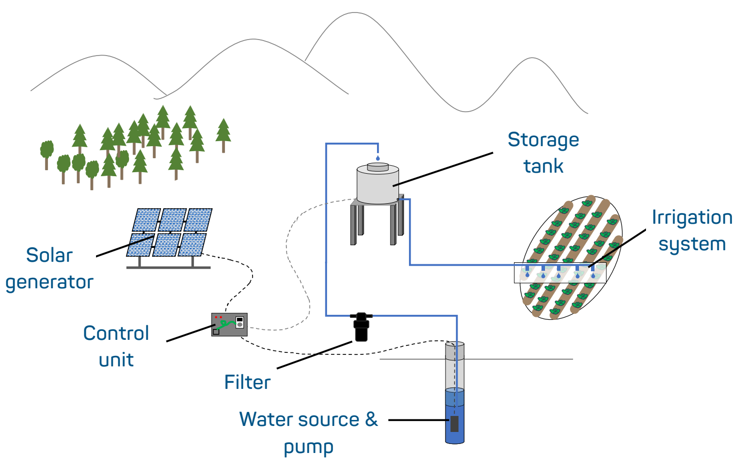
2. TECHNICAL CHARACTERISTICS OF SPIS

A solar-powered irrigation system (SPIS) is a clean-energy, low-emission option for irrigation. The technologies (figure below) rely on the use of solar energy to operate pumps for the abstraction, lifting or distribution of water for irrigation. The electricity is generated by solar photovoltaic (PV) panels. A SPIS consists of

- A solar generator (e.g. PV panel or array of panels)
- A mounting structure for PV panels
- A pump control unit
- A surface or submersible water pump, ideally with an integrated monitoring system to measure the water flow, pressure and performance
- A distribution or irrigation system, which is often combined with a storage tank or water reservoir

The water pump or storage tank is connected to a distribution and/or irrigation system. The most common SPIS irrigation systems are drip, micro-sprinkler, or flood irrigation. The solar generator can be connected to a battery and inverter technology to store and use surplus energy for additional on-farm uses, such as electrification of households or other productive uses. In addition, the generator can be connected to an existing grid, so energy can be fed in for a compensation. The exact configuration of SPIS components depends on the local biophysical and socio-economic situation, including the environmental, climate and hydrogeological conditions, and should be evaluated by a qualified expert to ensure correct matching, dimensioning and use of the solar-powered irrigation system components.

Figure 1: Components of a solar-powered irrigation system



3. AREAS OF APPLICATION

3.1. PRECONDITIONS FOR APPLICATION

From a technical perspective, SPIS technology depends on the following requirements:

- Altitude
- Sufficient solar irradiation
- Land availability to install the SPIS components
- Water availability meets water requirements of the respective crops
- Sufficient water quality, including appropriately low levels of salinity, heavy metals, and pathogens

From an ecological perspective, areas of application exclude drinking water and groundwater protection zones, nature or ecosystem protection zones both on land and water surfaces, regions with high groundwater scarcity, and areas with non-suitable topography or soil conditions for sustainable use of the water (e. g. steep slopes with high water runoff, very thin soil layers that dry out quickly). Solar water lifting technology cannot be decoupled from the availability and sustainable use of surface water and groundwater resources. Water resources are highly variable throughout regions, and the latest climate scenarios show that many of them will be affected by increased variability and uncertainty. From a legal perspective, SPIS technology requires a set of legal framework conditions in place before running and operating the SPIS in large numbers.

The power to lift water resources by using SPIS technology is still limited. SPIS is often used for drip or sprinkler irrigation in agricultural production schemes and for watering animals. However, it is not yet suitable for very energy-intensive water cannons used for irrigation in fruit and vegetable production. The technology generally depends on the water depth or depth of the well, on technical quality of the system and on the size, number and quality of the panels and pump.

3.2. APPLICATION SCENARIOS

SPIS technology may be operated in various and multipurpose use scenarios either for agricultural production, water supply and consumption, off-farm use, solar cropping, or watering livestock. The different scenarios emerge from context-based needs and demands. This paper will focus on the needs and application scenarios of small-scale farmers as one of the key stakeholder groups of food and agricultural production in the development context. The SPIS technology can be applied to adapt to climate change scenarios where lifting of ground or surface water is used for irrigation of crops, vegetables, fruits or fodder. This applies especially if rainfed agriculture is not possible, or as an addition to rainfed irrigation, potentially addressing changing rain patterns, droughts, heatwaves or the intensification of climate-smart cash crop production or extended cropping periods (2–3 harvests instead of one). SPIS technology may be used to generate additional income for farmers, and the creation of jobs around services, maintenance and financing. Solar-powered pumps are also supporting water supply with household boreholes in remote, mostly rural areas (including emergency aid and transitional aid), but also for emergency preparedness in urban areas in case of power cuts. Other applications include decentralised cooling by irrigating green spaces within cities, and establishing urban farming (e.g. hydroponics) to help to ensure a diverse food supply and healthy nutrition. As mentioned before, it serves the idea of connecting farmers to the grid and incentivizing them to pump less groundwater by paying them for excess power generated by "solar cropping".

4. POTENTIALS OF SPIS

Using solar power for irrigation pumps can cut the carbon footprint of many countries by switching existing diesel pumps to solar, and preference of solar pumps in new purchases. SPIS can reduce greenhouse gas (GHG) emissions by replacing fossil fuels with solar energy. Beyond curbing GHG emissions, SPIS lowers farmers' expenses for diesel and its transport, as well as their dependency on diesel availability, and proves beneficial for the environment by reducing diesel spills.

Solar-powered pumps foster energy independence in remote areas that are not yet connected to the grid and can thus guarantee access to water resources in remote areas, proving an asset for agropastoral communities relying on groundwater for watering their livestock in water scarce or dry areas. Many countries in Sub-Saharan Africa still have a large potential to develop groundwater resources for their socioeconomic development: only 3% of the total cultivated land is irrigated, and mere 5% of that with groundwater. Solar powered pumps could be an important component to unlock that potential, while increasing the farmers' resilience to climate change impacts through access to water in dry seasons or year-round, expanding winter and summer cropping. Irrigation improves agricultural productivity and therefore income, food security and nutrition. Ultimately, irrigation can make a decisive contribution to reducing food imports and thus strengthening independence from a volatile world market in times of crisis.

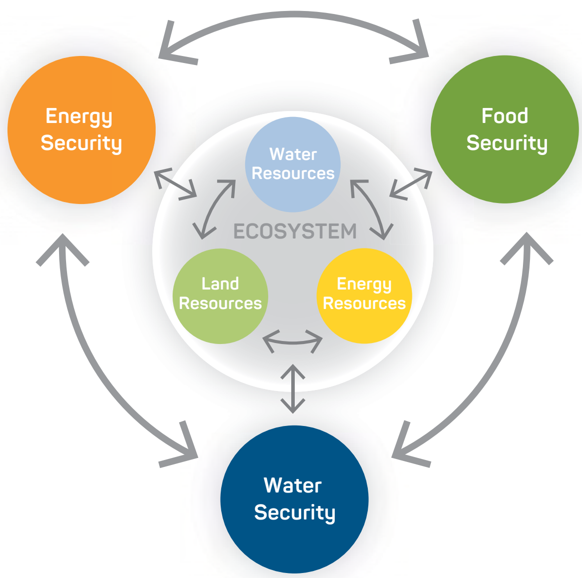
Solar energy can also offer some additional off-farm benefits such as cooling or drying, which reduces post-harvest losses and allows produce to be sold profitably in the off-season, recharging of electrical devices, or daytime power supply for other activities like food processing, cooking, sewing, internet access, home schooling, radio, TV, etc. Farmers whose SPIS is connected to a grid may have the opportunity to generate electricity for their captive consumption and may be able to sell excess electricity to energy providers, effectively earning extra income ("solar cropping"). This is a promising solution that has the potential to solve the power supply problem without exacerbating groundwater depletion while increasing farmers' incomes and food security.

SPIS can enable a variety of new jobs in the area of technical services and maintenance, training of installation and use, waste recycling, development of market and business models around its technology, monitoring and modelling of water resources, data management and other off-farm activities and effects.

5. ESSENTIALS FOR SUSTAINABLE SPIS

5.1. WATER-ENERGY-FOOD SECURITY NEXUS APPROACH

The switch from diesel to SPIS and here the large-scale expansion of SPIS based water lifting represents a relevant intervention in the existing system of water resources. Apart from improved access to water for irrigation, and therefore the possibility to expand agricultural land, the amounts and locations where water is extracted may increase and shift. These circumstances can lead to an overuse of water resources, bearing risks unsustainable use in the medium and long term for the future development of respective regions. The Water-Energy-Food (WEF) Nexus approach addresses this potential trade-off and recognises that water, energy, and food security can only be achieved through safeguarding, protecting and upholding natural resources. For this reason, the intersectoral coordination is paramount when employing SPIS technology and promoting it further. Since mandates for the implementation of SPIS (e.g. financing, planning, construction, water permits) will likely be with different authorities, close coordination and strategy alignment are essential.



Just as future small-scale water users learn to deal with the new technology, the actors responsible for overall water resource management – authorities, water user organisations, cooperatives, and others – must be familiarised with it. Efficient processes and effective water resources management institutions ensure that the economic benefits of SPIS are accompanied by social and ecological improvements. The higher the share of used water in the total amount of available water resources, the more potential distribution conflicts must be anticipated and avoided.

For this, a detailed study of current and future water availability, demand, accessibility, and use is essential for multisectoral planning of SPIS. Conflicts on the allocation and accounting of water may develop and may be avoided in looking at land use, climate change scenarios, land and water tenure rights, developing relevant and related regulatory framework, guidelines for (ground-)water abstraction as well as modelling and monitoring before introducing SPIS technology in a country or region at large scale.

5.2. WATER RESOURCE MONITORING

Water resource monitoring is fundamental to long-term sustainable water management in general and to the employment of SPIS in particular. It allows governments or other dedicated institutions to understand, control and potentially adapt water extraction if it exceeds the respective groundwater or surface water body's recharge rate. Monitoring and subsequent water accounting eventually support informed, data-based decision making about the water management and allocation among users.

Water resource monitoring should always be target-oriented and serve a specific purpose in the context of SPIS. Monitoring objectives may refer to

- Resource monitoring, i.e. capturing the characteristics of a groundwater system, its recharge, discharge, interaction with surface water etc.
- Compliance monitoring, i.e. tracking the effectiveness of governance/management measures
- Protection monitoring, i.e. observing impacts on critical water bodies or ecosystems that depend on them
- Pollution monitoring, i.e. capturing information to prevent potential pollution hazards such as intensified agricultural land use

Depending on the objective, monitoring can yield static data with no variation over time, e. g. from hydrogeological logs or well pumping tests or dynamic data with variation over time, e. g. from groundwater level monitoring or well abstraction monitoring. Monitoring water resources can happen directly, by measuring abstraction, which can be an expense factor and dependent on the water users' cooperation. It can also happen indirectly, by using indicative data, for example calculating abstraction from energy consumption and the average pumping rate, or remote sensing with satellite or airborne sensors. Depending on the technical setup, monitoring can be coupled with immediate adjustment of the extraction, e.g. switching off pumps remotely if water levels fall below a pre-determined level, or indirect adjustments, e.g. charges or penalties.

5.3. REGULATORY FRAMEWORK

The application of SPIS technology at small farm level is on the rise globally, showing an upwards trend likely to continue. The increased application of SPIS technology has put a spotlight on the topic and has opened various sectoral perspectives, especially from water, energy, and agriculture, leading to sectoral distinction. Hence, there are different systems, a lack of common technology standards, multiple and complex finance modalities, and eventually a demand for regulatory frameworks. The investment in solar irrigation also follows competing orientations and objectives along the various sectors. The current situation creates complexity for technology producers and distributors as well as for end users and political decision-makers. Besides technological aspects, sector strategies and policies, guidelines, laws and regulatory roadmaps concerning sector policies (e.g. protection, management of resources, water rights, feed-in tariffs, waste management policies) still form an uncharted landscape, full of gaps, sometimes opaque, with numerous unclarities concerning enforcement. Uncoordinated investment programmes, and the absence of policies and regulations for the management of new solar-powered technologies, conventional energy subsidies, combined with an insufficient availability of valid information on rainfall, water availability, depletion or recharge, jointly form a negative scenario for the long-term sustainability of water resource use. Any resource that becomes easily accessible bears the risk of being overexploited, unless access and use of this resource is controlled through regulations and policies, and concerned sectors institutionalise integrated planning approaches (e.g. WEF Nexus approach). While groundwater use can be expanded in some regions to address water scarcity, water resources are heavily overexploited in other regions. In both cases, the impact of SPIS on groundwater abstraction in the absence of regulation should be considered. The need to prevent groundwater depletion, while becoming more important, is still not a major main policy driver, but should be factored in consistently. Ideally, quality control of imported SPIS systems, including certification and standardisation, formulated regulations on e.g. water tenure arrangements, pumping depth, volumes, catchment areas and user areas, irrigation efficiency, restrictions to diesel and electrical pumps are planned and implemented with the participation of local communities.

Smallholder farmers may have intrinsic motivations to introduce SPIS on their fields, but policy makers should incentivise it further. On the one hand, there is a need to cover up-front expenditures for the technical setup and potentially operating costs, on the other hand, there are other

objectives, such as sustainable water management and life cycle management of the SPIS, that might be incentivised. The promotion of SPIS should include all relevant actors from the sectors of water, energy, and agriculture. Currently, most policies concerning SPIS are strongly driven by governmental energy authorities. This is reasonable concerning major aspects of energy subsidies or potential feed-in tariffs, yet the inclusion of water and agricultural authorities would benefit the integrated planning process. The overall application of SPIS, including water pumping and the actual cultivation of crops, can be managed more sustainably and with less trade-offs when the entire process is considered.

Incentives involving appropriate financing instruments and business models are the first step to make SPIS more attractive in the first place. Additionally, they can be complemented with favourable framework conditions, the standardisation of SPIS technology and services, as well as clear regulations concerning water management. Water accounting, allocation and monitoring have to be incentivised or at least consistently supervised with the involvement of qualified authorities. Regulations are less likely to play an effective role in fragile contexts where state institutions are weak or on the verge of collapse and where the state performs core roles inadequately. In that case, non-governmental, community- or user-driven regulation mechanisms might be a better option.

5.4. BUSINESS MODELS

Business models should decrease up-front costs for the end user and thus lower the entry barrier to SPIS, provide incentives for limiting water abstraction by putting a price on it, and create flexibility both for the service provider and the end user.

The pay-per-use (PPU) model is a contractor model where a service provider owns the SPIS, and farmers are charged each time they use its service. Typically, payments are made to the contractor depending on the amount of water delivered from the pumps, which can be monitored through basic water meters in combination with GPRS. This allows farmers to account both for their alternative sources of water (i.e.: rain) and their financial capabilities. PPU models can include the mobile service providers that transport their equipment to cover larger areas. In this case, irrigation can be scheduled and pay for remotely, but it requires an infrastructure that grants regular, quick access to the customers, as well as a suitable surface water body.

Similar to the PPU model, a pay-as-you-go scheme can be established. Here, a contractor builds the SPIS, and grants use to farmers. The difference lies in the fact that this model transfers ownership to the customer over time. The farmer pays small, monthly instalments – functionality of the service can be cut off if payments are not made on time. Payment is typically made via a mobile micropayment or scratch card.

Another viable business model is the agricultural service cooperative, an autonomous, jointly owned enterprise that can facilitate and manage either the financing of SPIS for its members or provide the entire service within its structure. In principle, cooperatives can offer the same services as third-party contractors, but for considerably less costs because of their non-profit structure.

5.5. FINANCIAL INSTRUMENTS

SPIS costs have significantly decreased over the past decades making it an economically viable solution for many and has been widely adopted for agricultural practices. However, access to such technology remains challenging to low-income, small and marginal farmers, including women, due to limited and limiting financing schemes. Subsidies, loans, grants and leasing agreements are some of the most commonplace financial instruments geared toward SPIS promotion.

Appropriate subsidy schemes can provide an enabling environment for smallholder farmers that usually wouldn't be able to afford SPIS. Government subsidies are the most common means of SPIS procurement via production subsidies, encouraging increased output by offsetting production cost. Governments offer subsidy schemes to promote the use of SPIS by offsetting the cost of SPIS PV pumping system, water tanks or the system as a whole. To ensure the sustainable use of SPIS, drip-irrigation installation is often a condition within the subsidy schemes, helping to avoid over-abstraction of ground water. Many states subsidise agricultural electricity connections and consumption, making solar-powered irrigation systems more uneconomical in comparison. Although subsidies can be used strategically to stimulate the development of the SPIS market, careful attention to context is necessary. Subsidies may undermine the market for SPIS in the long run, since they decrease incentives for manufacturers to innovate and competitively price their products. In many countries, the private sector development of SPIS is hindered by government subsidy programmes which make up the large majority of the SPIS business.

As alternatives to subsidies, there are a number of policy interventions and financing measures. They can include

- Lower import duties and tariff exemptions
- Bulk purchases
- Local production and assembly
- Access to finance products specifically designed for farmers

Subsidies oftentimes do not finance the entirety of the investment whereby farmers can seek out a long-term loan. Agrarian development banks generally offer low interest rate loans and flexible repayment schemes to borrowers when compared to commercial banks. Leasing is also a business financial model which offers farmers who do not have the option of credit schemes the opportunity to make use of SPIS technology and equipment. Grants are also be provided but are less common and come with certain conditions, e.g.: extraction limits or grouping of smallholder famers for collective ownership and operation.

To maximise SPIS as a sustainable financially viable means of irrigation several aspects should be taken into consideration: state agencies and financial institutions should design subsidies both for SPIS as well as conventional energy and pumps carefully. There is a need for increased awareness of SPIS technology and financing potential among financial institutions. Raising awareness of financial schemes among small holder farmers can encourage marginalised stakeholders to seek out financially viable subsidies or loans. Tailoring sustainable financial instruments to smallholder famers will increase SPIS use. Gender-based financing consideration is necessary as many women have limited access to financial resources and land ownership. Women farmers' exclusion can be minimised through tailored credit assessment tools pursuant to asset-based financing or through (non-collateralized) financing plans offering affordable, low monthly instalments by which customers eventually own the SPIS product.

5.6. TECHNOLOGICAL STANDARDS

Due to the enormous growth in the range of solutions for SPIS in recent years, it is becoming increasingly difficult for smallholders to identify good quality products that are suitable for their intended use. This has led to the need for quality and technological standards for SPIS equipment. When end-users invest in a new technology, this is associated with relatively high financial risks. Good and reliable products prevail in the long run, whereas bad products tend to make users turn away from the entire technology. Standards are also advantageous for public actors and technology providers. As a result, criteria can be defined more precisely in public tenders and funding programmes, and providers can adapt to market requirements.

International norms for individual components of SPIS can be a first indication of adequate quality. Additionally, standardization allows damaged systems to be repaired with the aid of spare parts, which, hence makes the system more sustainable and creates business opportunities. Eventually, international norms and standards should be adopted, implemented and monitored by national authorities.

The International Electronical Commission (IEC) is an organization that prepares and publishes standards for all electrical, and related technologies. Among others they published norms for solar pumps (IEC 62253:2011) and photovoltaic (PV) modules (IEC 61215:2021; IEC 61730:2016), which includes that PV modules need to meet the Low Voltage Directive 2014/35/EU in Europe. Further standards exist regarding smaller components

such as cables and connectors. Depending on the country and region, different requirements may have to be met. Standards for entire SPIS, however, do not exist yet, as the systems need to be variable to adapt to different local conditions.

5.7. CAPACITY DEVELOPMENT AND SERVICE PROVIDERS

Capacity building is key to unlocking the potential of SPIS. Expertise in SPIS design, installation, operation, maintenance and repairs, as well as knowledge of efficient, productive and sustainable use of water and good agricultural practice is needed to ensure sustainable use of water as an input and management of water sources in agriculture. Improved skills of service providers, practitioners, and farmers will prevent water and yield losses and pollution. Moreover, informing and training extension agents and multipliers is critical to empower them to provide comprehensive practical guidance to end users, policy makers, and financiers on technically viable and suitable SPIS business and finance models. Regulatory frameworks can only be successful when institutions and end-users have a shared understanding of sustainable resource management. It is most important that governments, regional basin authorities, and financial institutions better understand farmers' and end-user needs and water management requirements to ensure inclusive and climate-resilient smallholder agriculture and global water-efficient food system development. Thus, institutionalising SPIS capacity development interventions in agricultural VET centres is critical. Trainings should be tailored to their target group, e.g. bankers, farmers, or policy-makers, and can be held in innovative formats from TV shows to radio podcasts or telephone hotlines.

In addition to the required capacities of smallholders to use SPIS and the knowledge and structures for sustainable dissemination of SPIS by the public sector, the existence of service providers is also essential to ensure the long-term operation of SPIS facilities. This can be a crucial challenge, especially in rural regions that are further away from economic centres. However, particularly in the context of the widespread distribution of SPIS, income opportunities and attractive jobs arise at the same time. Service providers can be supported through funding programmes to expand into other regions, and Technical and Vocational Education and Training (TVET) programmes also offer an opportunity to use knowledge about SPIS to make a modern and promising technology known and to anchor the necessary capacities in the labour market in the long term. It is even possible to enable SPIS service providers to become one-stop shops that provide technical services around SPIS, but also soil testing, weather forecasts, or agribusiness planning.

5.8. WASTE MANAGEMENT OF PV SYSTEMS

As the rate of global PV installation increased exponentially in the past decades, the growing amount of decommissioned PV panels presents a new form of waste to be considered along with its environmental impacts. The two most common PV panel technology groups are silicon-based, i.e. crystalline silicon (c-Si) and thin-film based, i.e. cadmium telluride (CdTe). Silicon modules are primarily composed of recyclable materials such as glass, plastic and aluminium, however, the process through which materials are separated requires advanced machinery. CdTe PV modules are recycled by first shredding and then separating the glass, cadmium and tellurium, seeking to reuse of glass and cadmium. Cadmium, being a highly toxic carcinogenic element, requires sound life cycle management to minimise environmental contamination.

The quality of the PV panel will determine its lifespan. A poor-quality PV panel can lead to decreased efficiency, eroding or malfunctioning of microwires, and a higher annual degradation rate which eventually decreases the solar power output. Modern solar panels include a 25-year warranty from the solar company. Thin-film panels, although economical, tend to have a shorter lifespan (10–20 years) than silicon-based panels (averaging on 25–30 years). The 1990s saw the start of large-scale PV module deployment; as they have an estimated lifespan of 25–30 years, the PV waste stream is expected to increase in the coming years. Projections indicate that by 2050, there will be a total global volume of 60–78 million tonnes of PV panel waste. As such, the proper waste disposal and recycling of PV systems becomes a salient issue.

The European Union has developed a comprehensive regulatory approach dictating the end-of-life-management of PV panel waste as part of its Waste Electrical and Electronic Equipment (WEEE) Directive which has been subsequently incorporated into national legislation. This EU legislation sets out baseline rules and targets regarding proper PV panel disposal at the end of their life cycle which each Member State incorporates into national law. "Extended Producers Responsibility" is applied through which producers (manufacturers, resellers, distributors, importers and distant sellers) are financially responsible for the disposal of PV modules. The directive encourages cooperation between producers and recyclers to facilitate re-use, dismantling and recovery of EEE. WEEE including PV panels must be correctly sorted through municipal waste to ensure proper treatment of collected WEEE. PV panels are included as part of Member State collection rate i.e.: 65% of the average weight of EEE placed on the market in the 3 preceding years in the MS must be collected.

Policy action is needed to address the challenges ahead, with enabling frameworks being adapted to the needs and circumstances of each region or country. Rapidly expanding PV markets such as Japan, India and China still lack specific regulations. Countries with the most ambitious PV targets are expected to account for the largest shares of global PV waste in the future. With the exception of the EU, there remains a lack of specific legislation and regulatory frameworks for the PV panels, as they fall under general waste classification. This holds an enormous economic potential: preliminary projections suggest that raw materials recovered from PV panels could yield a total value of up USD 450 million by 2030.

5.9. GENDER INCLUSIVITY

As SPIS technology becomes increasingly accessible to smallholder famers, considering a gendered lens could increase inclusivity of women farmers within the agricultural sector and accelerate the energy transition. Current governance and land/water tenure systems often limit women's and young people's decision-making power regarding

natural resources and hinder their ability to own agricultural land. Household water management (e.g.: sanitation, drinking and homestead irrigation), on the other hand, is generally a task delegated to women. Gender equality on sustainable SPIS requires a systemic change in land and water tenure to ensure equitable access to natural resources.

Female farmers currently have limited access and awareness of technologies, financial services, and information. However, an increasingly common solution to overcome such systemic hurdles are collective approaches to SPIS financing models. These have been developed to strengthen women's land rights through joint leasing and decrease the risk to lenders. Likewise, capacity development and TVET programmes on SPIS with a focus on female professionals would help to both build expertise and to integrate woman in an emerging market.

Recognising the gender dimension of the WEF Nexus acknowledges the power differentials between men and women within the various sectors. Doing so encourages a bottom-up local-level approach to ensure marginalised voices are heard and considered in policy and decision making to produce gender tailored strategies.

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