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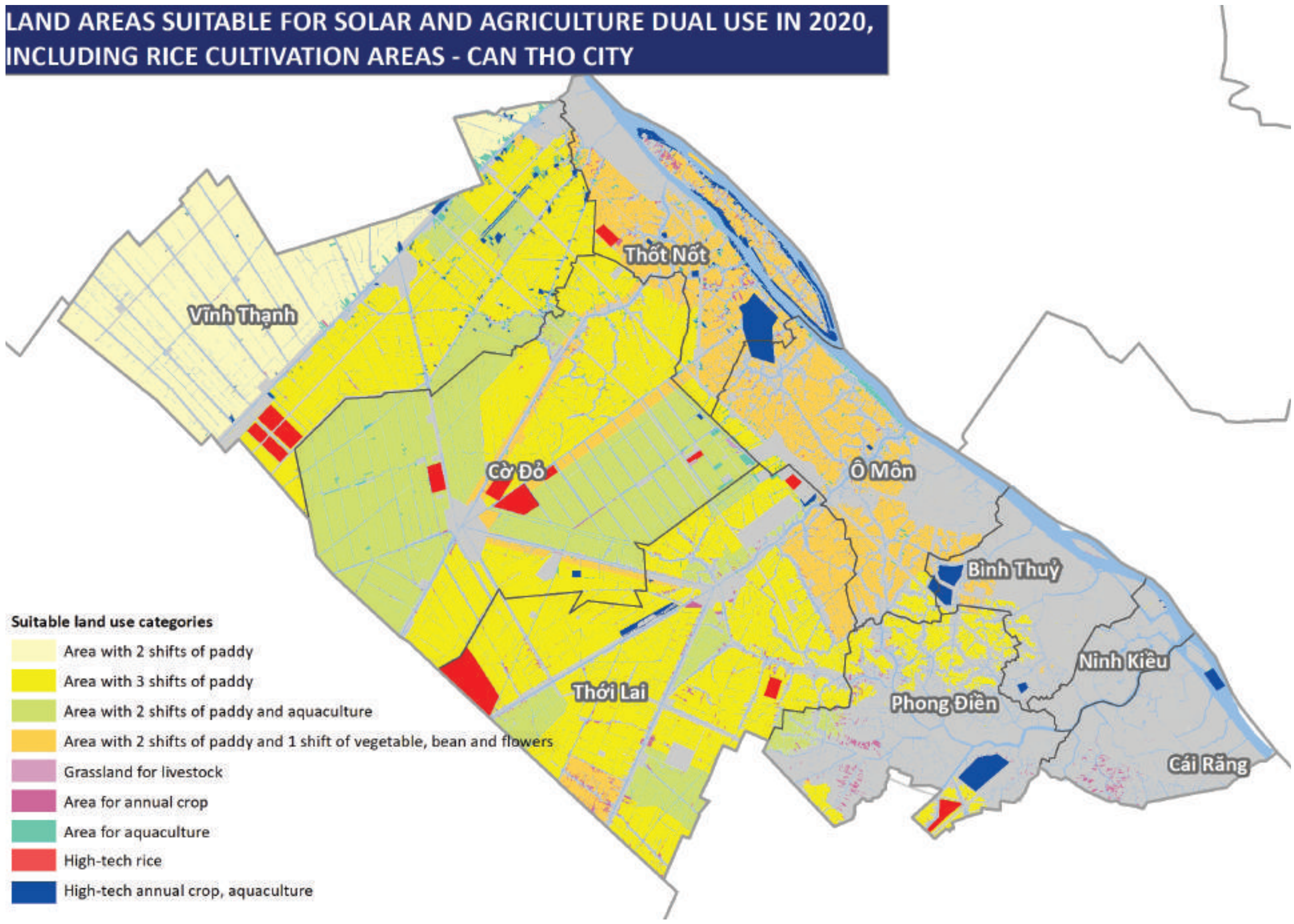
GreenID

# DUAL-USE APPROACHES FOR SOLAR ENERGY AND FOOD PRODUCTION

# INTERNATIONAL EXPERIENCE AND POTENTIALS FOR VIET NAM


LAND AREAS SUITABLE FOR SOLAR AND AGRICULTURE DUAL USE IN 2020, INCLUDING RICE CULTIVATION AREAS - CAN THO CITY
Vĩnh Thạnh
Thốt Nốt
Cờ Đỏ
Ô Môn
Bình Thuỷ
Ninh Kiều
Thới Lai
Phong Điền
Cái Răng
Suitable land use categories
Area with 2 shifts of paddy
Area with 3 shifts of paddy
Area with 2 shifts of paddy and aquaculture
Area with 2 shifts of paddy and 1 shift of vegetable, bean and flowers
Grassland for livestock
Area for annual crop
Area for aquaculture
High-tech rice
High-tech annual crop, aquaculture

# TABLE OF CONTENTS

# ABBREVIATIONS

| | |
|---|---|
| DARD | (Provincial) Department of Agriculture and Rural Development |
| DoNRE | (Provincial) Department of National Resources and Environment |
| DoIT | (Provincial) Department of Industry and Trade |
| ERAV | Electricity Authority of Viet Nam (under MoIT) |
| EU | European Union |
| EVN | Electricity of Vietnam |
| FiT | Feed in Tariff |
| GDP | Gross Domestic Product |
| GW(p) | Gigawatt (peak) |
| GWh | Gigawatt-hour (=1 million kWh) |
| kW(p) | Kilowatt (peak) |
| LER | Land Equivalent Ratio |
| MARD | Ministry of Agriculture and Rural Development |
| MoIT | Ministry of Industry and Trade |
| MoNRE | Ministry of Natural Resources and Environment |
| MW(p) | Megawatt (peak) |
| MWh | Megawatt-hour (= 1,000 kWh) |
| PM | Prime Minister |
| PPA | Power Purchase Agreement |
| PPC | Provincial People´s Committee |
| PV | (Solar) Photovoltaic |
| TWh | Terrawatt-hour (=1 billion kWh) |

# EXECUTIVE SUMMARY

- Over the last 30 years, Viet Nam has managed a remarkable development of its agricultural sector and its energy sector. However, challenges remain in both sectors. Low productivity, a lack of market development and communication as well as pressure on the income security of farmers are persisting challenges in the agricultural sector. Furthermore, climate change poses an ever - increasing threat to agriculture production, necessitating the development of more renewable energy sources in the sector to reduce its Greenhouse Gas emissions.

- Recently, a new challenge has arisen at the nexus of both sectors, involving land-use conflicts caused by the increasing influx of wind and solar energy investments in particular. Viet Nam's renewable energy resources are vast and largely untapped. With the new support schemes for wind and solar energy, around 300 renewable energy projects are under development, among them 285 solar projects representing 23,000 MWp of capacity.

- The already large and growing number of new solar PV investment projects in particular has raised concerns particularly in the Vietnamese "food basket "provinces in the South with regard to potential land-use conflicts. Provincial leaders of the Mekong Delta are now seeking solutions for the combined use of renewable energy and agricultural or aquacultural production on the same land or water area.

- Solar PV dual-use or agrivoltaic concepts can resolve this land-use conflict between energy and agriculture production, by combining both on the same site. Developed in the early 1980's in Germany, the concept has been implemented in a number of countries with hundreds of (mainly small scale) projects and applications. Recently, a growing number of larger, commercial projects have been implemented in countries such as China, Japan, Italy or France.

- Solar dual-use provides multiple socio-economic benefits that are mainly based on the key concept of the increased land productivity of the combined system, compared to the single-use of the same area of land. The increase of this Land Equivalent Ratio (LER) through dual-use applications has been proven by pilot projects in different countries.

- Further benefits of solar dual-use for farmers and the public include energy cost savings (solar self-consumption), additional income of local farmers with potentially higher investments and tax revenues, improved marketing opportunities and competitiveness (sustainable production/ supply chain), potentially improved agricultural practices, the reduction of (peak) energy demand, a reduction of $CO_2$ and hazardous local emissions from conventional thermal power plants (such as coal), and the development of a more competitive sustainable agricultural sector in general (for domestic and export markets).

- The analysis of international best practice and scientific monitoring of pilot projects provides the necessary background to identify a number of crops and aquacultural products in Viet Nam suitable for dual-use applications. Among them are popular crops such as rice, corn/maize, cassava, vegetables of various kinds, soybean, coffee, tea, low growing fruit trees and fish / shrimp production in ponds.

- The application of this concept in a case study for Can Tho shows great potential for solar dual-use. Suitability for solar dual-use (agrivoltaic) applications could be identified for nine agricultural and aquaculture products (rice, corn/maize, soybean, sesame, vegetables, cassava/starch roots, livestock, fish and shrimp).

- Based on these crops, an overall "realistic" technical potential (as such realizable within the next 5-8 years) could be calculated for Can Tho. Excluding rice production, this potential is in the range of 700 to 1,100 MWp, equaling an electricity potential of 1 to 1.5 TWh. This solar electricity generation would cover 46% to 70% of Can Tho's annual electricity demand.

- Including dual-use application on rice production areas, the "realistic" potential would increase to 7,500 to 11,300 MWp or 10.5 to 16 TWh. This amount of clean electricity far exceeds the city's electricity demand and could thus contribute to the demand of the wider Mekong Delta region and further neighboring provinces.

- Regarding the costs of solar power from dual-use applications, a conservative assessment was made based on assumptions derived from the limited available international data. According to this assessment, the solar dual-use LCOE are estimated at 9.07 USct/kWh in a base case scenario, with a range between 8.40 USct/kWh (low cost case) and 9.81 USct/kWh (high cost case) and therefore roughly within the range of the current FiT in Viet Nam (9.35 USct/kWh) or about 1.5 USct/kWh above the current avoided cost tariff for Southern Viet Nam (7.48 USct/kWh).

- International experience shows that with the dramatically decreased costs of solar PV technology, the growing number of agrivoltaic best practice projects and the development of the dual-use application, this approach is a viable option for Viet Nam to avoid or reduce land-use conflicts related to the increased influx of solar energy investments and the pressure on land owners that comes with it.

- To develop solar dual-use in Can Tho and Viet Nam in general, the development of a Dual-Use Roadmap is suggested. The most important element of such a roadmap would be the implementation of a Vietnamese solar dual-use pilot project to verify the suitability and potential of selected crops in the local agro-ecological context. Furthermore, a development strategy should include an institutional foundation such as regional Steering Committee or Working Group to integrate important stakeholders, to undertake advocacy work towards regulators or financing institutions and to raise awareness among farmers and other sector stakeholders.

- On the regulatory side, it is suggested to further identify potential barriers in the regulatory framework, in particular in land-use regulations. On the national level, the FiT needs to be opened for solar dual-use applications. This includes basically two aspects, the eligibility of dual-use applications for the support measures and the amount of financial support necessary to trigger market development and pilot projects in the first place (a small FiT premium for solar dual-use applications could help to mobilize investments in an early development stage of this technology). Furthermore, solar dual-use could be considered and acknowledged in national and international strategic planning and policy instruments such as the National Power Development Plan, the Viet Nam Green Growth Strategy or the climate change target framework (NDC).

# INTRODUCTION

Over the past three decades, Viet Nam has undergone a remarkable development. Spurred by the economic and political reforms launched under Đổi Mới (engl. change/renewal) in 1986 the country has developed from being one of the poorest nations worldwide to a lower middle-income status, with strong regional and international economic integration. The country as achieved significant advances in meeting the Millennium Development Goals, including lifting more than 40 million people out of poverty, placing the country number 116 out of 189 on the Human Development Index 2017.[1]

Economic growth today is strong, with an estimated GDP increase of 7.1% in the first half of 2018.[2] This growth is primarily driven by a strong manufacturing sector but secondly, by an **increasing agricultural production** that shows an ever-stronger export orientation. Currently, the sector represents around 15% of the national export value and contributes 18% to national GDP.[3] Agriculture is a central pillar of the Vietnamese economy and large parts of the population depend on the production of agricultural products. Around 66% of the more than 92 million people in the country live in rural areas and 47% of jobs (25.6 million people) are in primary production agriculture.[4]

In the same time, Viet Nam has managed a similarly impressive development of its **energy sector**. Between 1990 and 2015 the electrification rate, i.e. the ratio of households that are connected to the national power grid, increased from below 30% to 98% - a rate unprecedented in the entire Southeast Asian region. In the same period Viet Nam added almost 40,000 MW of mainly state budget funded power generation capacity, predominantly hydro and coal power plants. Over the last years, the government initiated a process to transform the energy market from a centrally planned and SMO dominated public sector with political price setting to a more liberalized market with competitive price setting mechanisms. Furthermore, the government included renewable energies, mainly wind and solar energy, to their power development strategy and introduced support mechanisms such as Feed-in-Tariffs (FiT) and preferential tax treatment for wind and solar energy investment projects.

Despite these undeniable success stories, Viet Nam is facing substantial challenges in both the agricultural and the energy sector. And, as this study will further highlight, there are new challenges that arise at the nexus of the two sectors, which can be addressed with innovative solutions.

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1 See UNDP (2018)

2 See World Bank Vietnam (2018), http://www.worldbank.org/en/country/vietnam/overview

3 Regarding current data and further analysis of the agricultural sector in Viet Nam, this report and the following section in particular strongly draws on research done by a consortium of Vietnamese and international institutions that include (among others) the International Center for Tropical Agriculture (CIAT), the Food and Agriculture Organization of the United Nations (FAO), the Viet Nam Institute of Policy and Strategy for Agriculture and Rural Development (IPSARD) and the Viet Nam Ministry of Agriculture and Rural Development (MARD). See Nguyen et al. (2017).

4 See Nguyen et al. (2017), p.3

## WHY NOT DO BOTH? - THE IDEA OF COMBINING AGRICULTURE AND ENERGY PRODUCTION

Substantial differences between employment share and GDP share of agriculture indicate a large gap in productivity between agricultural and non-agricultural sectors. Unstable market prices for certain agricultural products, and regularly occurring oversupply situations due to shortcomings in planning and a lack of communication among market stakeholders cause pressure on farmer`s incomes and livelihoods in general.[5] This in turn often hinders farmers in improving their productivity or investing in new technologies. Thus, farmers and communities in the rural parts of the country are more likely to struggle with improving their livelihoods compared to urban communities or to people working in the industrial or newly developing services sectors.

In addition to that, a new challenge arises with the surging number of wind and solar energy investment projects and their land requirements, which increasingly compete with agricultural land-use in the Southern and central regions of the country.

A large number of solar PV projects, exceeding even the capacity targets for the year 2030, have reached an advanced development stage and have been included in the official power master plans as of mid-2018. And there are ever more requests from investors approaching local authorities for land availability and clearance. A similar development can be expected in the wind energy sector with the revised wind Feed-in-Tariff (FiT) and persisting investor interest in the Southern coastal and highland regions.

Given that Viet Nam still is in the very early stages of developing renewable energy, and both wind and solar energy show declining cost curves, it can be expected (as is desirable for multiple reasons) that power generation in Viet Nam will follow the world trend and rely more and more on wind, solar and other renewable sources.

Thus, more renewable energy investments on a multi-Gigawatt scale can be expected over the coming years and decades with the mentioned potential for surging land-use conflicts in the agricultural production regions of the country.

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5 See e.g. https://e.vnexpress.net/news/business/vietnamese-farmers-should-study-market-demand-to-avoid-oversupply-losses-pm-3734796.html

Source: Fraunhofer Insitute for Solar Energy Systems ISE, Freiburg/Germany.

*194 kWp Agrophotovoltaic pilot project in Southern Germany. The German Fraunhofer-Institute for Solar Energy Systems (Fh-ISE) has been a pioneer for solar dual use research. Its founder and long-time Director, Prof. Adolf Goetzberger, started to publish on solar dual use in the early 1980's (see Goetzberger/Zastrow, 1982).*

With these current developments and future prospects for Viet Nam in mind, a key question comes into focus. If there is the need to improve the income situation and livelihood of farmers on the one hand and a potentially serious conflict of land-use between agricultural production and clean energy generation on the other hand, why not find a way to combine the two? Or in other words, why not use the same plot of land for agricultural and energy use simultaneously, following a "dual-use" approach?

The idea to develop an elevated solar power system that allows agricultural (or aquacultural) use underneath it with a specific operational scheme has already been discussed for almost 30 years.[6] Only now, with the drastic cost reductions that photovoltaic (PV) technology has undergone over the past 10 years in particular, this application comes into a new perspective and the development of economically viable solutions becomes a realistic option as first international best practice projects show.

[6] One of the pioneers of the dual use approach was the founder of the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg, Germany who started to publish on solar dual-use in the early 1980's. See Goetzberger/Zastrow (1982)

## KEY OBJECTIVE
## OF THE STUDY

This study analyses new concepts and applications of renewable energy use – with a main focus on solar energy – that aim to combine agricultural production and clean power generation on the same land area, and thereby to reduce land-use conflicts between these two essential sectors.

Over the past years, various local stakeholders, such as representatives from provincial governments in Viet Nam´s Southern Mekong Delta, have expressed strong interest in developing renewable energy solutions in harmony with their agricultural development strategies and in a way that improves the livelihood of farmers and farming cooperatives. With these objectives, *dual-use* concepts came into perspective and have been discussed for the first time in workshops such as the annual R*enewable Energy Week Viet Nam* organized by the Viet Nam Sustainable Energy Alliance (VSEA) and the Green Innovation and Development Center (GreenID) Viet Nam.[7]

However, the dual-use approach is still a relatively new concept with limited international application, and the idea itself has not gained much attention in Viet Nam so far. In response to this, the overall objective of this study is **to develop a "vision"** for a renewable energy development in Viet Nam that strives to utilize synergies in land-use and *dual-use* potentials for energy and food production, and that removes barriers for renewable energy development related to real existing or perceived land-use conflicts. The study is intended to initiate a discussion on *dual-use* as an alternative approach with multi-faceted socio-economic benefits that could become an essential part of the overall renewable energy development strategy of Viet Nam. Such a strategy could also address questions of social inclusion of local people and communities, as well as fairness and justice within the ongoing process of energy transition in Viet Nam.[8]

On a more concrete level, the study tries to assess and outline the **general feasibility of dual-use approaches** for solar power (solar photovoltaic, PV) generation and food production (agriculture and aquaculture) and the specific **benefits for Viet Nam** in general.

7 See e.g. http://en.greenidvietnam.org.vn/vietnam-renewable-energy-week-2018.html

8 See also the discussion on social-ecological transformation processes and its implications for the development of energy systems. See e.g. Danso-Dahmen/Degenhard (2018)

# KEY APPROACH AND METHODOLOGY

This study aims to initiate the discussion of dual use approaches and applications for Viet Nam, mainly in the field of solar energy, by citing international experience and assessing the general feasibility and potentials for Viet Nam.

There is of course much potential for other renewable energy sources in a dual use approach that are outside the scope of this report. Firstly, **Bioenergy, although** eminently suitable for dual use, addresses another kind of potential land-conflict ("food crop" vs. "energy crop"). Secondly, **wind energy** can be used for dual use power generation and agricultural production with much less potential for land-use conflicts due to lower land area covered by the wind masts compared to the larger solar PV fields.

With this in mind, the study focuses on the **dual use potentials of ground-mounted solar energy** projects that, particularly in Viet Nam, are often referred to as "solar farms" which already makes a direct semantic link to the key topic of this study.

In the following two sections the study will introduce firstly, the status, current developments and challenges in the **agricultural sector** of Viet Nam. The following chapter will highlight the current **development of renewable energy in Viet Nam** with a primary focus on solar energy, and will introduce the emerging land-use conflicts due to increased solar energy investments in the rural and agricultural areas of the country.

Following this, the study will introduce and discuss **international best practice in solar energy dual use** applications in different regions of the world. The aim of this is to identify successful technical applications and suitable crops and agri- or aquacultural products that could be used for the dual-use approach in Viet Nam but also to show the concrete socio-economic benefits for farmers, communities and eventually the society in general that might arise from such a development strategy.

Following that the study develops a **case study for Can Tho City**. With available data on land-use and agricultural production in Can Tho, and the key parameters for solar energy dual use applications derived from international best practice projects, the case study identifies and highlights the potentials for solar energy generation in dual-use application with the help of GIS Mapping and the related social-economic benefits for farmers and the province in general. In a further step, a conservative estimate for the overall potential for dual-use in Viet Nam will be developed based on the findings of the case study.

The concluding chapters will then **explore future strategies and necessary action** at different levels and for different political and society stakeholders to develop the solar energy dual use approach in Viet Nam.

# VIET NAM'S AGRICULTURAL SECTOR
# OVERVIEW AND KEY CHALLENGES

This section gives an overview of the key agricultural production systems in Viet Nam and the current situation and challenges of the sector.

## THE AGRICULTURAL SECTOR
## KEY PRODUCTION SYSTEMS

The total land area used for agricultural has remained stable over the last 10 years, reaching 10.23 million ha, which accounts for almost 35% of total national land area (including arable land, permanent crops land and permanent meadows land). Forests land, including an increasing share of plantations, accounts for 15.8 million ha in 2013, representing 46.8% of the total land area.[9]

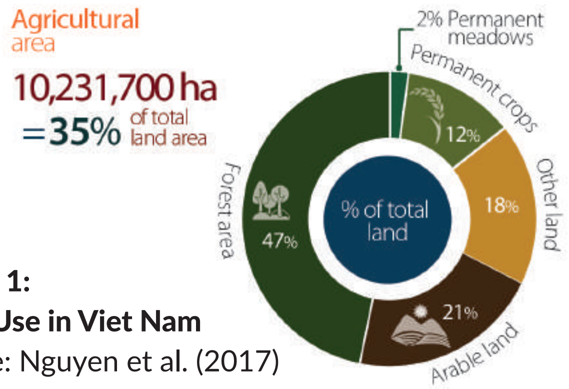


**Figure 1:**
**Land-Use in Viet Nam**
Source: Nguyen et al. (2017)

Due to the specific geography and climate (the country stretches over 15 latitudes and climate varies from the North to the South with different seasonal patterns) Viet Nam's agricultural production systems are specialized by agro-ecological zones. The two river deltas (Red River Delta in the North and Mekong River Delta in the South) mainly concentrate rice and livestock production while other cash crops are produced in the Central Highlands and the Southeast. The Northeast and Northwest are mountainous areas with only limited and mainly subsistence agricultural production, except those areas where conditions allow for forestry plantations and industrial crops such as tea and rubber.

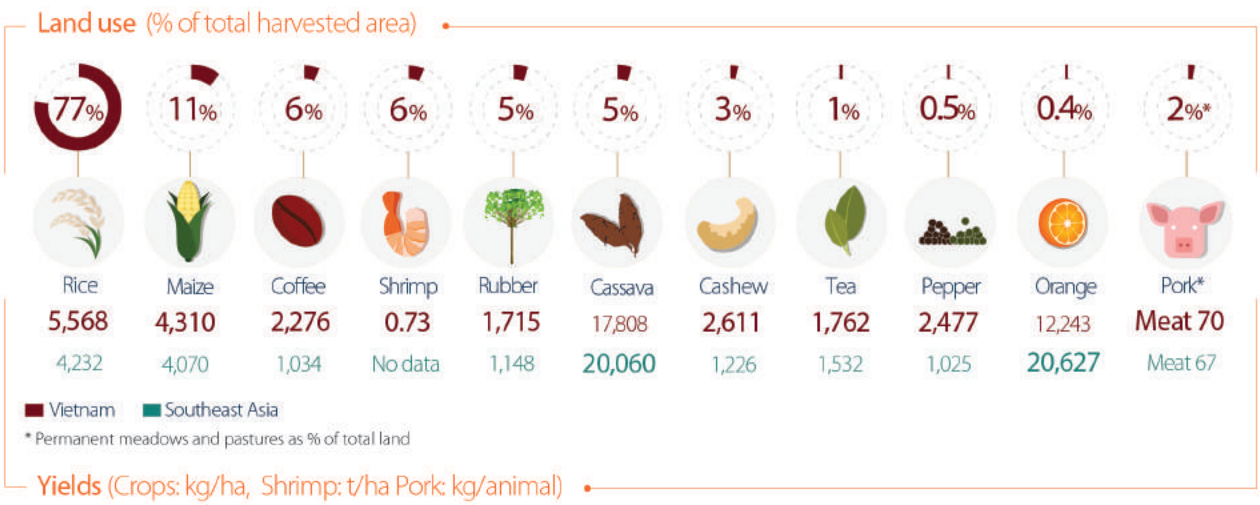


**Figure 2: Production Key and Agricultural Land-Use in Viet Nam-** Source: Nguyen et al. (2017)

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9 All figures from Nguyen et al. (2017) based on data from Viet Nam General Statistics Office (GSO) and FAO from 2015. Most current available data from 2016 show a slight increase of total agricultural production area with 11.5 million ha but no change in the general structure and shares of land-use (see www.gso.gov.vn/default_en.aspx?tabid=773). For the reason of consistency, this report further refers to the analysis of CIAT/MARD in Ngyuen (2017).

The growth in agricultural and aquacultural productivity has been a key driver of GDP in the 1990´s and afterwards. Currently, the sector represents around 15% of the national export value and contributes 18% to national GDP.[10] Viet Nam has become a leading global exporter of a number of relevant agricultural products such as rice, coffee, cashew nuts, vegetables, and rubber. Due to this development, agriculture, forestry and fishery are the only sectors with a trade surplus, thereby making a contribution to limiting the country's trade deficit. Rice, with its importance in ensuring food security, is not only the important crop (occupying 77% of total harvested area) but also a political commodity. Rice production has been and still is a prevailing economic and political priority for Viet Nam, and particularly in the Mekong Delta.

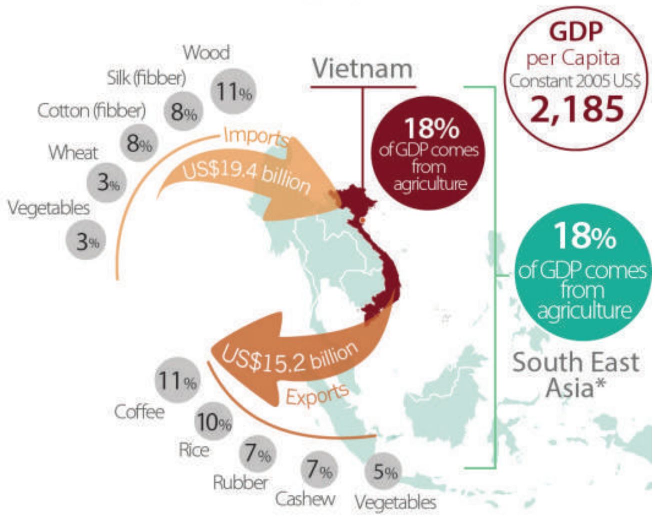


**Figure 3: Economic Relevance of Agriculture in Viet Nam**
Source: Nguyen et al. (2017)

## KEY CHALLENGES OF THE VIETNAMESE AGRICULTURAL SECTOR

About 66% of the almost 93 million Vietnamese population live in the rural areas and 44% of the total population are reliant on agriculture, fisheries and forestry as their main livelihood.[11] Despite the strong development of the agricultural sector over the past decades and the increase in productivity in general, there still are substantial differences between employment share and GDP share of agriculture indicating a large gap in productivity between agriculture and non-agricultural sectors. This also explains the already mentioned concentration of poverty in agricultural and rural areas.

Furthermore, the agricultural sector in Viet Nam is dominated by small-scale family-owned farming. Almost 70% of all farms are small-scale (below 0.5 ha) and only 6% of farms are large-scale with an area larger than 2 ha.

Traditionally, control over land and assets has been dominated by men. Women were not previously entitled to rights over assets or to secure credit.[12] However, significant efforts have been made over the past decades to facilitate women's empowerment, such as the Land Law 2003, which improved gender equality by including the names of women on land tenures certificates. Today, women and men are equally involved in agricultural production with 51% of female versus 49% of male agricultural labour force. However, with only 13% of land titles held by women, the ownership of land is still dominated by men.[13]

[10] See Nguyen et al. (2017).
[11] Nguyen (2017)
[12] See Oxfam (2017) for an analysis of inequality in Viet Nam.
[13] GSO data from the 2011 rural, agricultural and fishery census, see www.gso.gov.vn

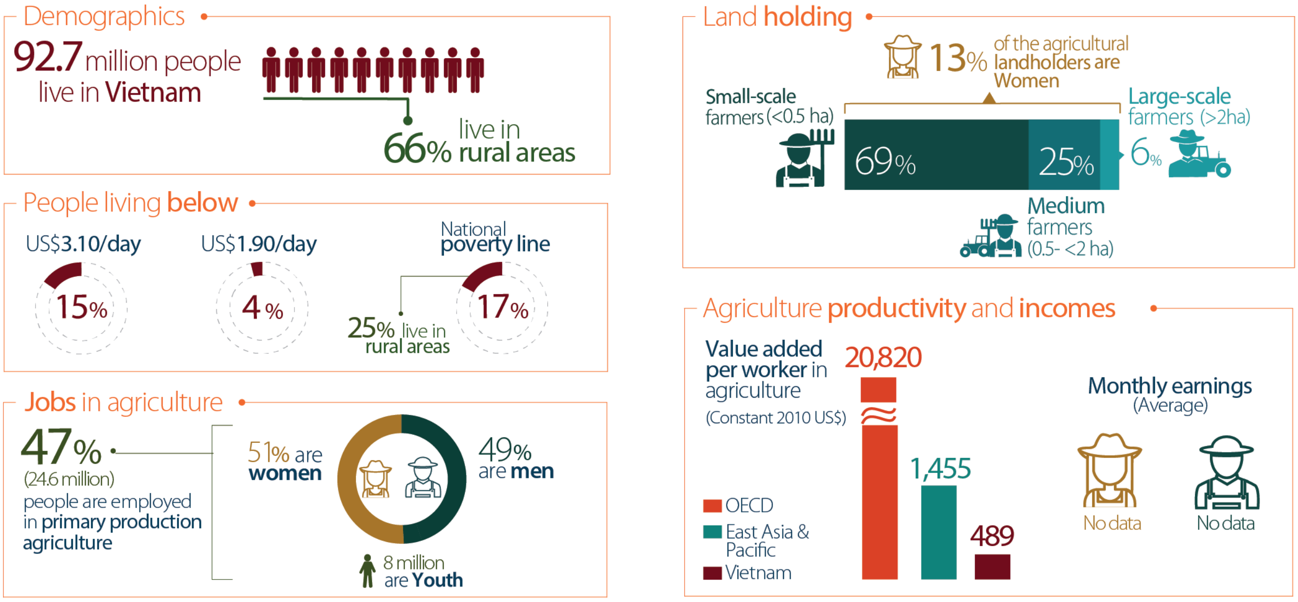


**Figure 4: Demographics and Productivity Indicators for the Agricultural Sector Viet Nam**
Source: Nguyen (2017) based on data from GSO, World Bank, FAO

The general income situation of farmers seems also rather low compared to the regional average if available data on agricultural productivity is taken into account.[14] Figure 4 compares the level of agriculture productivity in Viet Nam to the average in East Asia & Pacific region and to OECD countries. As mentioned in earlier, recent years have seen unstable market prices for certain agricultural products and regularly occurring oversupply situations caused pressure on farmer`s incomes and livelihoods in general. In short - farmers and communities in the rural parts of the country often struggle with improving their livelihoods and with increasing the productivity of agricultural production in general.

## CLIMATE CHANGE IMPACTS IN THE VIETNAMESE AGRICULTURAL SECTOR

Climate change is increasingly apparent in Viet Nam. According to the 2014 report of Viet Nam to the UNFCCC, the sea level along the coasts of Viet Nam has risen by more than 20 cm over the past 50 years. Annual rainfall decreased in the north and increased in the south, leading to different patterns of drought across climate regions and agro-ecological zones. Severe saltwater intrusion in the Mekong Delta and increasingly serious recent droughts in the Central Highlands provided clear examples of adverse impacts on agricultural production due to climate change.[15] Predictions of climatic changes until the end of the 21st century draw a pessimistic perspective regarding further sea level rise and change of weather and seasonal patterns.

Climate change represents a major challenge for agriculture production. Rising temperatures, increased pest incidence, and droughts are expected to lower rice yields by 4.3% over the 2016–2045 period, below the level it would be in the absence of climate change. Rising sea levels and salinity intrusion are expected to reshape the geography of rice production. The changing climate will probably drive rice production to areas that are especially suitable

[14] Data on real income/earnings of farmers could not been accessed within the research of this study.
[15] MoNRE (2014)

for multi-cropping. Coffee production, which is concentrated in the Central Highlands, could be hit hard by intensive droughts, higher temperatures, more temperature extremes, and increasing frequency of heat waves that cause increased evapotranspiration, and increased pest incidence.[16]

Agriculture is not only a sector affected by climate change, but also a major source of greenhouse gas (GHG) emissions that increase global warming. Globally, key sources of GHG emissions are rice cultivation, enteric fermentation, agricultural soils, and manure management, burning of savannas and burning of agricultural residues. The agricultural sector represents a key source of GHG emissions, estimated at about 43% of total national emissions in 2000.[17] However, while agricultural emissions are likely to continue to rise, rapid economic growth would cause energy-related emissions to rise even more rapidly. Within the agricultural sector in Viet Nam, paddy rice is a key source of GHG emissions and accounts for 57% of all agricultural emissions, mainly in the form of methane and nitrous oxide. Thus, any reduction of GHG emissions in the sector, e.g. by implementing solar dual-use concepts, would decrease the energy-related emissions from the sector (e.g. energy used for pumping, irrigation etc.) by substituting fossil fuel based electricity consumption of farmers.

[16] World Bank (2016)
[17] IMHEN/GIZ (2018)

# VIET NAM'S RENEWABLE ENERGY DEVELOPMENT AND THE LAND-USE CHALLENGE

This section will highlight current developments in Viet Nam's energy sector and its implications for the agricultural sector. In particular, it will explore the upcoming land-use conflicts that are triggered by strong domestic and international renewable energy investor attention and related wind and solar energy project development in the country.

## THE DEVELOPMENT OF RENEWABLE ENERGY AND SOLAR PV IN VIET NAM

The ongoing strong growth of the Vietnamese economy is fueling a steadily increasing power demand of more than 10% per year. This poses a real challenge to the country's energy supply security, the generation of long-term cost-efficient electricity and the provision of energy services. Simultaneously, Viet Nam must secure its energy sector's sustainable and green development, and contribute to its international commitments to tackle climate change (according to Viet Nam's Nationally Determined Contribution: 8% reduction of GHG by 2030 compared to the Business-as-Usual scenario, 25% conditional with internal support).[18] In addition, international partners and multilateral institutions such as the UN and the World Bank continuously highlight to the Vietnamese government the necessity of reducing the country's dependency on unsustainable and increasingly costly fossil energy production.[19] Viet Nam has become a net-importer of coal, which not only increases the country's dependency on foreign fuel imports but also increases the costs of power generation.[20]

The **socio-economic impacts of coal power** development in particular – the current Power Development Plan (PDP VII revised) foresees an expansion of coal power capacities from 10 GW today to 55 GW by 2030 – will be tremendous and the burden for society extremely high.[21]

There is a great risk for Viet Nam and its core state-owned energy sector giants such as EVN, PetroVietnam and Vinacomin, to face a situation where there are **stranded assets of enormous value**. A recent study of the Carbon Tracker Initiative found that coal power asset owners in Viet Nam are at great risk of **losing 11.7 billion USD** within the coming 10-15 years due to increasing unviability of coal. This is based on the trend-based assumption that by 2027 and 2028 respectively, it will be cheaper to build new solar PV and wind power plants than to operate existing coal power plants.[22] Higher coal prices have already increased the cost of power generation, currently placing a great financial burden on EVN, and could further compromise EVN's financial status, if it remains committed to coal. The existing plans to create a wholesale electricity market and a fully competitive retail market by 2023 will allow consumers to purchase power from those utilities less exposed to coal price (and offering cheaper tariffs).

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[18] MoNRE (2015)

[19] See e.g. UNDP (2015). Green Growth and Fossil Fuel Fiscal Policies in Viet Nam. United Nations Development Programme. Hanoi, Vietnam

[20] According to the project "Vietnam Coal Industry Development Planning to 2020 and 2030", by 2020 coal demand for domestic production will reach about 75 million tons. Since domestic coal resources can only meet about half of this demand, coal imports will reach approximately 120 million tons by 2030. See www.langnuongvietnam.vn/news/en/coal-mineral/vietnam-begins-to-strongly-increase-coal-import

In addition to this, **environmental and health concerns** have been receiving growing attention among Vietnamese scientists and also in public forums. Air pollution, with associated increasing levels of respiratory disease, has becomes more and more an issue of concern for people not only in urban areas, but also in regions with coal power plants. Just recently, authorities of the Mekong Delta provinces of Bac Lieu and Long An have opposed plans for the construction of coal power plants in their provinces with strong support from scientists, medical experts, local residents, farmers and other enterprises.[23]

In the light of these challenges, Viet Nam can draw on **abundant renewable energy resources.** With around 3,500 km of coastal lines and highland regions in the Central and North of the country, Viet Nam has great potential for **wind energy** that is largely untapped. Current estimates for medium-term potentials for wind energy range around 27,000 MW. [24]

Furthermore, Viet Nam has **extensive solar resources** that could be used to successfully develop the solar energy sector. Current scientific estimates of the overall solar resources in Vietnam state an average Global Horizontal Irradiation (GHI) of 4-5 kWh/m2/day in most regions of Southern, Central and partially even Northern Vietnam (totaling 1,460-1,825 kWh/m2/year) and average peak irradiation levels of up to 5.5 kWh/m2/day in some Southern regions (totaling up to 2,000 kWh/m2/year). [25]

These solar irradiation levels are comparable to most countries in the region, including developed solar markets such as China, Thailand or the Philippines, as well as to international solar markets, such as Spain and Italy. They allow solar yields of 1,300-1,500 kWh/kWp in Central and Southern Viet Nam with current standard PV technologies.

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[21] For an analysis of social-economic impacts of coal-fired power in Viet Nam see Ha-Duong et al. (2016)

[22] Grey et al. (2018)

[23] See www.vietnamnews.vn/society/466493/long-an-province-says-no-thermal-power-plant-proposals

[24] GIZ Support Programme for Wind Energy in Vietnam, see www.gizenergy.org.vn

[25] See CIEMAT/MoIT (2015)

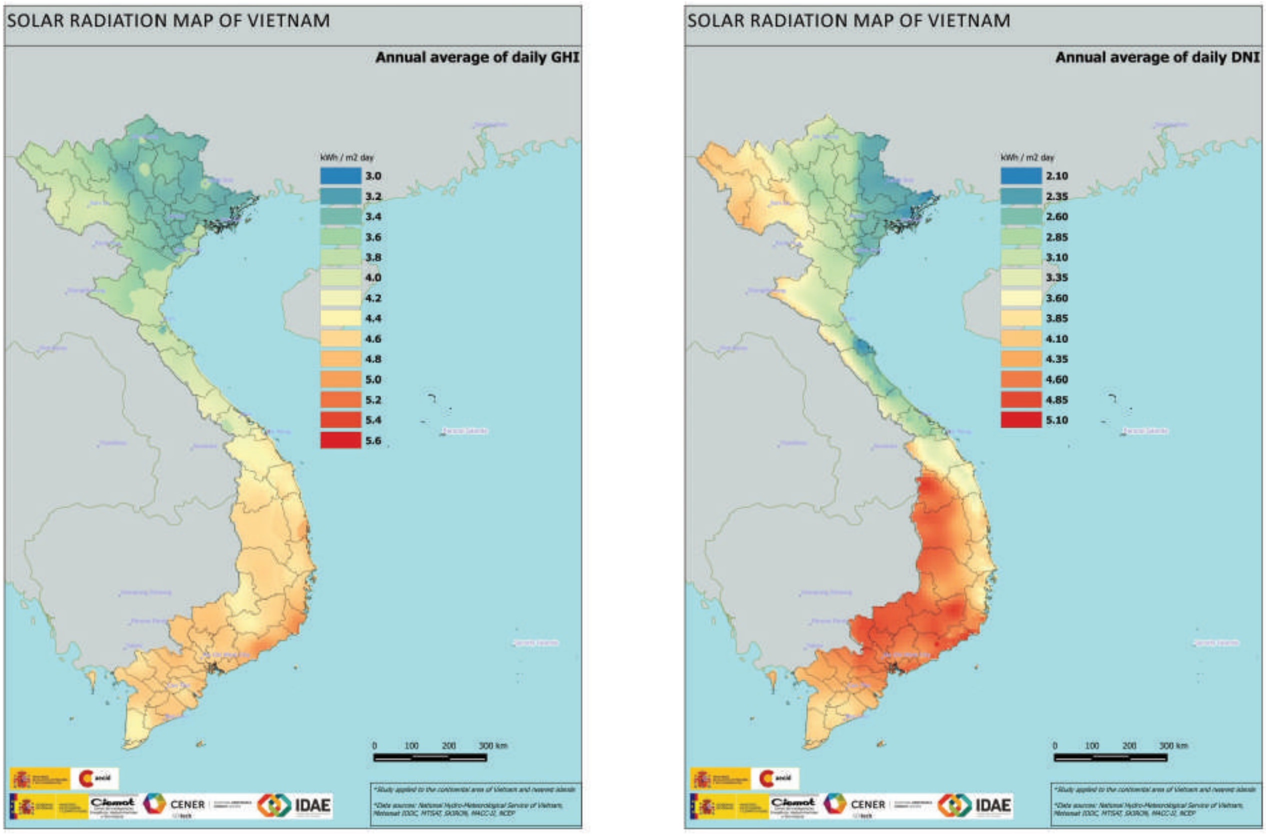


**Figure 5: Solar Irradiation Maps of Vietnam – Annual Average of Daily GHI and DNI**

Source: CIEMAT et al. (2015)

Long-term solar energy potential will easily reach hundreds of Gigawatt in the long-term. The Viet Nam Energy Outlook Report 2017 e.g. foresees more than 100 GW in its 2050 scenarios.[26] The medium-term technical potential was estimated in the GreenID Renewable Energy Capacity Scenario as 56,000 MW.[27] This potential does not include agricultural land-use areas.

The Vietnamese government is aware of the potential of renewable energy in general, and of solar PV in particular, and has incorporated respective development targets in the recent power development planning and further key strategies such as the Green Growth Strategy from 2012[28] or the Renewable Energy Strategy introduced in 2015.[29] In the currently effective Power Development Plan VII (PDP VII revised) from March 2016, the government targeted for wind energy 800 MW until 2020 and 6,000 MW until 2030. For solar PV the plan targets 850 MW until 2020 and 12,000 MW until 2030.[30]

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26 Danish Energy Agency (2017)

27 GreenID (2018)

28 See Prime Minister Decision 1393/2012/QD-TTg of 25 September 2012.

29 See Prime Minster Decision 2068/2015/QD-TTg of 25 November 2015

30 See Prime Minister Decision 428/2016/QD-TTg of 16 March 2016. Currently, the government prepares the PDP VIII, planned for implementation in 2020.

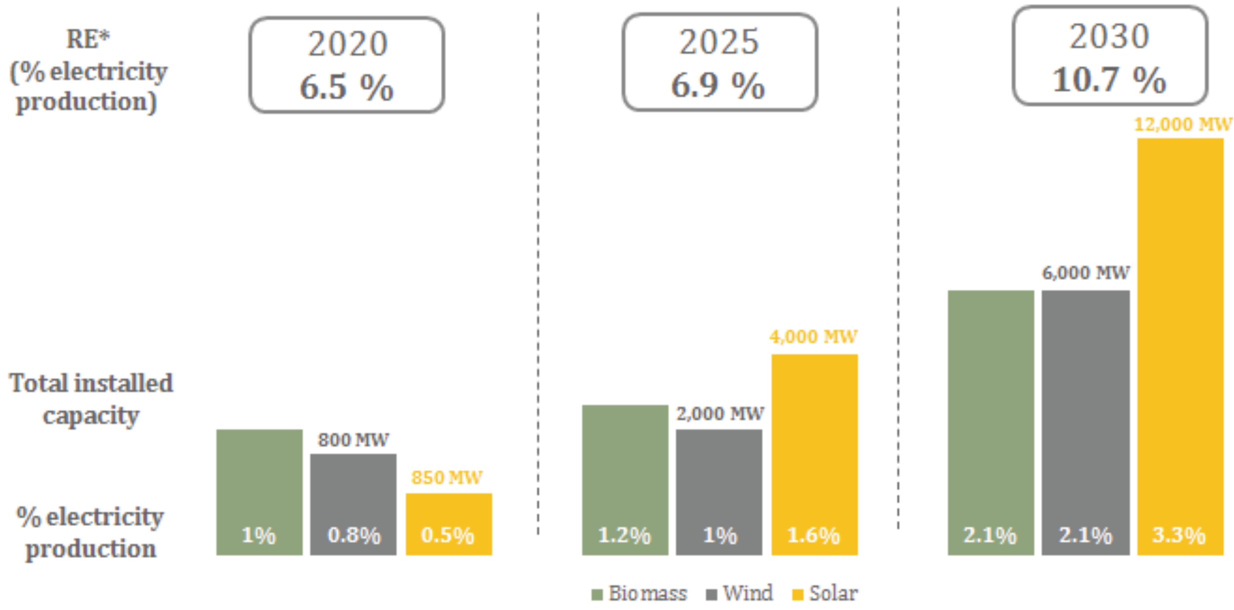


**Figure 6: Renewable Energy Targets for 2020/2025/2030 (PDP VII revised, 03/2016)**
Source: GIZ Energy Support Programme Vietnam

Consequently, the Vietnamese government also introduced support schemes for wind energy and solar PV investments in form of Feed-in-Tariffs (FiT). For wind energy the FiT was already introduced in 2011 (then 7.8 US cents/kWh).[31] It was recently adjusted, as the initial tariff did not trigger substantial investments and market development (now 8.5 US cents/kWh for onshore wind power and 9.8 US cents/kWh for offshore projects).[32]

For solar PV investments the government introduced a FiT for ground-mounted PV systems and a net metering scheme for rooftop applications on households or commercial-industrial buildings in 2017. The following table gives an overview of the regulation that was introduced in July (Prime Minister Decision) and September 2017 (MoIT Circular with more detailed regulations for implementation) after almost two years of preparation and consultation processes. [33]

31 See Prime Minister Decision 37/2011/QD-TTg of 29 June 2011

32 See Prime Minister Decision 39/2018/QD-TTg of 10 September 2018

33 See Prime Minister Decision 11/2017/QD-TTg of 21 July 2017 and MoIT Circular 16/2017/TT-BCT of 12 September 2018

<table>
<tr><th>PV Application</th><th>Support Mechanism</th><th>Further (indirect) Support</th></tr>
<tr><td>Ground-Mounted PV (grid-connected)</td><td>• Feed-in-Tariff (FiT) via a Standard Power Purchase Agreement (SPPA): 9.35 US cent/kWh<br>• PPA duration: 20 years<br>• Specific land-use requirement: Projects are only eligible for the FiT when the used land area does not exceed 1.2ha/MWp</td><td rowspan="2">• Corporate Income Tax: tax exemption (year 1-4) and 50% reduction (year 5-13)<br>• Import Tax: Varying levels of reduced import tax, depending on type of imported goods, exemption on goods forming fixed assets, which cannot be produced locally<br>• Waiving of land-use/lease fees: Land is provided for free or lease fee is reduced as part of the licensing agreement</td></tr>
<tr><td>Rooftop PV</td><td>• Net metering mainly for self-consumption (balancing with bi-directional meter). Applicable for PV systems installed on roofs or “near” buildings.<br>• Annual remuneration of excess solar power generation (via annex to existing EVN electricity retail contract).<br>• Net metering credit for excess sales: 9.35 US cent/kWh<br>• Contract duration: 20 years</td></tr>
<tr><td>Solar Dual-Use / Agrivoltaic</td><td colspan="2">• Not mentioned / no specific regulation<br>• But: Land-use requirement for ground-mounted PV systems de facto excludes solar dual-use applications (usually 2-3 ha/MWp land-use for Agrivoltaic systems)</td></tr>
</table>

**Table 1: Support Scheme for Solar PV Systems in Viet Nam (valid until June 2019)**

As Table 1 shows, there currently is no explicit regulation for solar dual-use applications. In fact, this approach and a potential specific incentive for dual-use projects were never discussed during the consultation process of the Decision and related ministerial Circular. Unfortunately, the land-use requirement for ground-mounted PV systems de facto (but most probably unintentionally) excludes solar dual-use applications (usually 2-3 ha/MWp land-use for Agrivoltaic systems - see the following chapter). For aquaculture solar dual-use applications on building-like structures built over ponds, this requirement would not apply since such systems could claim the net metering support scheme for rooftop PV. However, the full implementation of the net metering support has been delayed due to unresolved questions of taxation and a lack of standardized procedures and grid-connection regulations. Thus, in the short-term – i.e. before the planned revision of the solar energy support regulation – such aquaculture systems would still face challenges in their implementation.

The support scheme for solar PV investments implemented in 2017 only valid until 30th June 2019. As of October 2018, the Ministry of Industry and Trade of Viet Nam is preparing a follow-up regulation for solar energy that is intended to extend the incentive for solar PV investments for a further period (currently planned) of two years. This represents an opportunity to include solar dual-use approaches in the FiT scheme in a way that fosters the development of this new approach, and incentivizes investments in pilot and demonstration projects (see also concluding chapter).

## THE EMERGENCE OF LAND-USE CONFLICTS BETWEEN AGRICULTURE AND RENEWABLE ENERGIES

By June 2018 around 285 solar power investment projects in over 30 provinces accounting for nearly 23,000 MWp of capacity had been submitted to the government for formal approval.[34] To build all of these solar power plants, a land area of up to 27,600 ha would be needed, and with traditional methods of solar power plant development solely utilized for clean power generation.[35]

This might seem relatively little when compared to more than 10 million ha of agricultural land area in Viet Nam. However, since 70% of those projects are planned in only five provinces in Southern Viet Nam, this already creates serious land-use conflicts in some rural and agricultural regions of the country. And apart from already licensed projects, there are many more requests from investors that approach local governments for land availability and clearance for further projects.

Furthermore, Viet Nam still is in the very early stages of developing renewable energy. Wind and solar energy will soon take over the role of not only the cleanest, but also the most economic choice for power generation in Viet Nam and the world. The long-term potentials for wind and solar energy in Viet Nam are much higher than today's investment project pipeline. And there is an urgent need to shift Viet Nam's power planning from a heavily coal and fossil fuel based strategy to a cleaner and more climate friendly path based on renewable energies as well.

Thus, more renewable energy investments on a multi-Gigawatt scale can be expected for the coming years and decades with the mentioned potential for increased land-use conflicts in the agricultural production regions of the country.

The already large and growing number of new solar PV investment projects has **raised concerns** particularly in the Vietnamese "food basket "provinces in the South with regard to **potential land-use conflicts**. Recent developments have seen examples of de facto planning of PV solar systems on rice paddy land such as in An Giang province. Thus, the long-term conversion of agricultural land-use for paddy rice production to "energy use", with the result of a long-term loss of rice production on this plot of land. This officially contradicts the prevailing political priority of rice production for food security reasons, and seems to be the result of the high investor pressure.

Provincial leaders of the **Mekong Delta** are now seeking solutions for the combined use of renewable energy and agricultural or aquacultural production on the same land or water area and initiated the discussion of the concept of dual-use and the combination of food production and solar energy generation.[36]

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[34] MoIT Report No. 4614/BCT-DL on the development of solar power as of June 11, 2018

[35] The current regulation on solar energy investments allows for a land-use ratio of 1.2ha/MWp. See MoIT Circular No. 16/2017/TT-BCT.

[36] For example, the discussions at the Renewable Energy Week Vietnam 2018 and the "Workshop on Dual-Use Approach of Solar Energy and Agriculture / Aquaculture" in Can Tho on September 24, 2018. See: http://en.greenidvietnam.org.vn/vietnam-renewable-energy-week-2018.html

# SOLAR PV DUAL-USE
# CONCEPT AND INTERNATIONAL PRACTICE

Long before the discussion of potential land-use conflicts caused by renewable energy development came up, initial ideas on combining solar power generation with agricultural production developed within the early solar energy expert community of the 1980's. Based on existing concepts and methodological approaches from forestry or agriculture on mixing different crops on the same area of land or intercropping certain crops in forests, the question was if the overall productivity of such a mixed production system that shares the resource 'sunlight' – for photosynthesis-based biomass production and for photovoltaic power generation – could be higher than in a mono-production system.

This chapter outlines the general concept of solar dual-use, its socio-economic benefits and main technical applications. Furthermore, the chapter highlights international developments and shows selected best-practice examples. The analysis of international best practice will then identify key parameters for the case study on Can Tho and the related assessment of solar dual use potentials and will eventually lead to initial conclusions for the application of the concept in Vietnam.

## DEFINITION AND GENERAL CONCEPT OF SOLAR DUAL-USE

In Germany, the researchers and solar energy pioneers Adolf Goetzberger, founder of the Fraunhofer Institute for Solar Energy Systems in Freiburg, and Armin Zastrow published a first theoretical study in 1982 showing that there is enough radiation underneath elevated PV arrays to permit cultivation of many different crops.[37] The result of this first theoretical assessment was that for a combined solar PV and agriculture system 2/3 of solar radiation would still be available for plant growth even if the arrangement of solar modules was optimized for solar power generation. Further the authors illustrated that this radiation distributes almost uniformly over the day so that homogeneous plant growth could be realized. The preliminary conclusion was that this amount of radiation would be sufficient to grow a variety of crops such as rye, barley, oats and sugar beets as well as maintaining livestock underneath the PV system.[38]

Later, with first ground-mounted PV power plants being installed, there was practical evidence for the fundamental feasibility of this approach in the abundant growth of weeds under those existing PV installations and the fact that "undesired" vegetation has to be controlled and is thus contributing to maintenance costs.[39] And with this, the foundation of the solar dual use concept was provided and thereafter triggered much interest in the solar energy community and first practical research and pilot projects when solar PV technology costs had been reduced dramatically by international mass production and large market developments some 20 years later. Recent years have seen revived interest in the concept with increasing land-use conflicts in a number of rapidly growing solar PV markets

[37] Goetzberger/Zastrow (1982)

[38] The simulation was based on solar radiation at a site of 40° latitudes with weather data from Germany

[39] Beck et al. (2012)

So for the purpose of this study a **simplified definition of Solar Dual-Use** will be:

> **"**
> **The simultaneous use of the same area of land for photovoltaic and agricultural production (which includes aquaculture also).**

With a broader consideration on the key objectives and benefits related to the **concept Solar Dual-Use** can be defined as:

> **"**
> **A form of land-use in which solar power generation and agricultural or aquacultural production are deliberately combined on the same land plot to reduce land-use conflicts and to achieve socio-economic benefits compared to the single-use of both applications (i.e. realizing 'double revenues' from a) agri-/aquacultural production with no or not substantially reduced yields compared to no dual-use production and b) power savings (self-consumption of the generated solar energy) and/or power sales (e.g. via a feed-in-tariff, net metering or power purchase agreement with a power offtaker). These social-economic benefits will be introduced in the following sections of this chapter in more detail.**

Different terminologies have been used for this concept: "Dual Use" and "Agrophotovoltaics" (APV) in the German research context,[40] "Agrivoltaic" or "Agrovoltaic" in the French and US research context, [41] "Photovoltaic Agriculture" in the Chinese context,[42] and "Solar Sharing" in the Japanese context.[43] Further used terminologies relate to double-cropping or double-harvest.[44] For the purpose of this study the terms "Solar Dual Use" and "Agrivoltaic" will be used. Solar dual use would translate to Vietnamese in: Sử Dụng Kết hợp Năng Lượng Mặt Trời.

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[40] See www.agrophotovoltaik.de/english

[41] See e.g. Dupraz et al. (2011) as well as Dinesh/Pearce (2016)

[42] See e.g. Xue (2017)

[43] See for an overview: www.solar-sharing-japan.blogspot.com

[44] See e.g. Haugwitz (2018)

## LER OR HOW TO MEASURE THE PRODUCTIVITY OF COMBINED AGRI-PHOTOVOLTAIC SYSTEMS

A fundamental idea regarding solar dual-use it that the main benefit of the combined production of agricultural products and clean electricity comes from **a higher overall productivity** of the combined system compared to the single-use or mono-production of either agriculture or solar PV on the same area of land. To validate this assumption and actually measure the effect, the dual-use research has used the concept of Land Equivalent Ratio. Since this is key to the understanding and assessment of solar dual-use, the concept is introduced and explained in more detail here:

The LER (Land Equivalent Ratio) was originally introduced as an indicator of the productivity of a certain plot of land used to assess the value of mixed cropping systems.[45] Thus LERs allow comparing the productivity of mixtures of crops on the same land area versus monocultures, and are used for both mixtures of annual crops or mixtures of trees and crops in agroforestry systems.

The concept of LER can then be applied to the agro-photovoltaic system (solar dual-use system) as it combines two types of production on the same area of land.[46] The LER of an agrivoltaic/solar dual-use system is then defined as:

LER = (Yieldcrop in dual use / Yieldmonocrop)
+ (Yieldelectricity in dual use / YieldelectricityPV)

Here the monocrop system refers to the sole production of the crop and electricityPV refers to a standard ground-mounted PV system. If LER is >1 that means that the solar dual use system is more effective than the pattern of separate crop and PV arrays for the same land area.

Usually, mixed cropping systems have LERs between 1.0 and 1.3, while agroforestry systems have LERs between 1.1 and 1.5. A LER of 1.4 means that, by adopting a mixed system, the production of a 100 ha farm will be as high as the production of a 140 ha farm with separate productions. Such substantial increases of productivity are explained by a better use of resources in the mixed system, resulting from complementarity in resource needs (in the solar dual-use system this relates to the shared sunlight). Additionally, there can also be other processes involved where one component benefits from the other (such as the reduction in water evaporation due to the additional shading).[47]

Figure 7 shows a schematic explanation of this concept for a solar dual-use system that increases the overall productivity by 60% as first results from a German pilot system monitored by the Fraunhofer Institute for Solar Energy Systems (ISE) indicate. The LER in this case would be 1.6.

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[45] Mead/Willey (1980)

[46] Dupraz et al. (2011) introduced the LER concept to agrivoltaic/solar dual use systems.

[47] For an extensive discussion of the LER concept for solar dual-use systems see Dupraz et al. (2011)

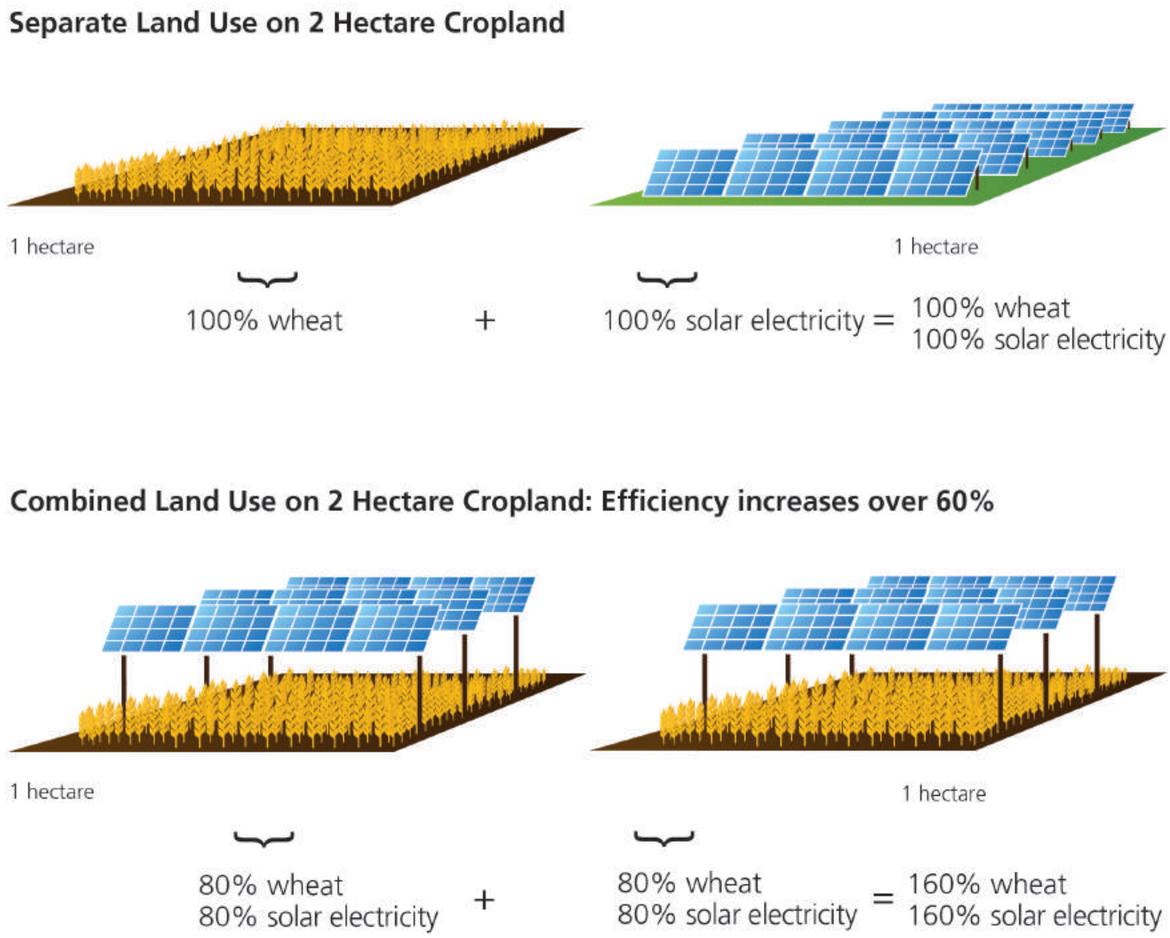


**Figure 7: Schematic Concept of the Land Equivalent Ratio (LER)**
Source: Fraunhofer Institute for Solar Energy Systems (Fh-ISE)

The predicted LER for solar dual-use systems that have been developed with the help of advanced simulation tools are at impressive values that have never before been reported or predicted for any mixed systems of crops or agroforestry systems, they indicate LERs of up to 1.7.[48] Such an LER would mean that a 100 ha dual-use farm would produce as much electricity and food crops as a 170 ha farm with separate productions.

So these simulation-based results on land productivity of solar dual-use applications were surprisingly high, suggesting that it would be very efficient to produce electricity and to harvest food crops on the same land unit. The following sections will further highlight the socio-economic benefits as well as the international development of the concept including first empirical evidence and validation from pilot and best-practice projects in different regions of the world.

[48] See Dupraz et al. (2011), the authors have been using the STICS crop model developed in France (Simulator multidisciplinary pour les Cultures Standard) to simulate the crop development in response to environmental and technical forcing variables. The simulations were mainly based on durum wheat as a test crop.

## GENERAL BENEFITS OF SOLAR DUAL-USE

The benefits and potentials of solar PV for economic growth, local job creation, and enhancement of human health and welfare have been discussed and acknowledged widely.[49] The following list gives just an overview of the main benefits that also apply to the integration of solar PV in dual-use concepts:

Distributed solar PV **can be developed quickly** to add needed power capacity and contribute to meet (increasing) electricity needs of societies and economies;

With the dramatically reduced PV technology costs over the last 10-15 years (and further declining), solar PV is currently becoming the **most cost-effective (cheapest) way to generate electricity**;[50]

Solar PV is a **domestic energy source** that increases energy security and energy independence;

Solar PV can **replace expensive peak power demand** (coal/gas) and reduces needs to invest in **transmission power grids**;

Solar PV is **clean, safe** and as **no negative** environmental or social **impacts** locally. In contrary, it reduces harmful local emissions and air pollution by replacing fossil power generation from coal, oil, gas or nuclear sources;

Solar PV helps to meet national **green growth** and **climate change** (CO2 emission reduction) goals;

Solar PV development can **mobilize** vast amounts of **private investments**;

Solar PV **creates local added value** and **jobs** in manufacturing, operation, and maintenance.

Solar PV creates **opportunities for local communities and people** to develop a clean, safe and independent energy supply on the local level.

[49] For a good overview of the socio-economic benefits of solar energy see IRENA (2017) and further IRENA publications at www.irena.org/benefits

[50] For mid-2018 data from actual PV projects and from PV capacity auctions worldwide show, that solar PV is already cheaper than any fossil-based electricity generation when looking at new power capacity investments in many world regions and developed solar energy markets. For actual data see IRENA (2018).

## THE REDUCTION OF LAND-USE CONFLICTS AS A KEY BENEFIT OF SOLAR DUAL-USE

Apart from all these benefits that solar energy creates for national or local communities and the economy in general, a key benefit of the solar dual-use approach relates to **the reduction of land-use conflicts** and all negative impacts that are linked to this. The potentials for land-use conflicts caused by increased renewable energy investments for Viet Nam have been outlined in the previous chapter already.

In general, this potential land-use conflict arises when **solar PV electricity generation replaces food production** on a specific land area. Thus, on this particular plot of land food production will be terminated in favor of renewable energy generation. In the case of solar energy, the land is likely to be used for power generation over decades (most projects driven by FiTs or long-term power purchase agreements (PPAs) are designed for 15 to 20 years). The lifespan of a well-maintained PV system goes even beyond that, data from PV systems built in the 1980's show still high performance from these systems that produce costs close to their low variable (O&M) costs.

Furthermore, on a strategic and planning level, many governments might prioritize **food security** or certain **agricultural export** targets over renewable energy development. Solar dual use offers a solution for this.

Of course, on **a global level** the land-use conflict of (mono-use) solar PV versus food production is more of a **long-term perspective**. Currently, the total area globally covered by solar PV systems accounts for less than one per million of arable land.[51] And land-use of solar energy is much less compared to fossil energy based power generation (including the extractive processes of coal and oil e.g.).[52]

However, the land-use conflict related to increased solar PV development can arise **already on the short and medium-term** in certain areas with high investor interest and competing agricultural land-use. The above discussion for Viet Nam has shown this.

## BENEFITS FOR FARMERS AND LOCAL COMMUNITIES

Most prominently, solar dual-use applications will create an **additional revenue** stream for farmers in form of solar electricity sales to the grid (**"second harvest"** from the same field). In the short-term, in Viet Nam that would most likely be the sale of excess solar energy (after the consumption of solar power for own uses such as water pumps, irrigation systems etc.) to EVN via a FiT or special power purchase agreement (PPA).

With the discussion on Land Equivalent Ratio (LER) in mind, we can assume that the **overall productivity** of the land **will increase** through solar dual-use. However, the concrete economic feasibility of such projects needs to be investigated more carefully as well as the potential of different stakeholders in the agricultural sector (farmers, cooperatives, farming corporations etc.) to actually invest in such systems. The case study on Can Tho will shed some light on this question and try to explore the economic feasibility and potential of solar dual-use for Viet Nam.

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51 IEA (2015)

52 UNCCD (2017

International experience has shown that some crops even **benefit from additional shading and improved agricultural practise** (i.e. they have a higher yield, see following section). Other crops show minor **reductions in yield** that can be **compensated** by the additional revenues from solar generation. Both cases would result in a higher total income from the agricultural production plus the additional solar energy sales compared to the single production of the crops.

Furthermore, solar dual-use could contribute to better **business marketing** and **improved competitiveness** of the agricultural products since they could meet demands of **sustainable supply chains** (especially for export markets). Interviews with shrimp farmers in the Southern coastal provinces indicate that questions of sustainable production become more and more relevant for international market access of Vietnamese products.[53]

On the **level of local municipalities and provinces**, solar dual-use could result in higher local investments and tax revenues. In addition, the local or regional **energy demand from the agricultural/aquacultural sector** would be reduced, as well as demand for power grid extension. The sector could realize energy savings and $CO_2$ emission reductions and therefore contribute to meet the **national energy efficiency and climate change targets.**

## BENEFITS OF SOLAR DUAL-USE FOR IMPROVED AGRICULTURE

Incorporating solar PV into agriculture with the dual use approach can be beneficial for crops in different ways. The shading caused by the solar PV modules can help to **alleviate water evaporation** during summer and dry seasons especially. It was observed that shading resulted in water savings in the range of 14-29% depending on the level of shade in a European climatic environment.[54] It can be assumed that the general effect will also apply to tropical or subtropical environments and specifically in regions with dry seasons.

The PV modules have also been shown to **alleviate soil erosion** by reducing the moisture evaporation in experimental settings in China.[55] Furthermore, fresh water can be saved through the recycling of water used for solar module cleaning, for further use of irrigation.

Solar dual-use can also lead to **improved aquacultural production** (shrimp or fish production). The additional shading and coverage of aquaculture ponds can allow better **control of water temperature**; reduce **water evaporation** and limited **growth of algae** (in case that is intended).

Fish and shrimp farming are particularly sensitive sectors regarding environmental impacts. Due to the increasing contamination of water in rivers and canals in the Mekong region, more and more ground water is used for shrimp farming. In addition to water subtraction for domestic for domestic and agricultural uses, this result in a steady lowering of land levels.

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[53] See e.g. the plans and activities of Viet Uc shrimp company in different Southern provinces that aim at reducing the $CO_2$ footprint of production and improving the overall sustainability of their products for domestic and international customers (Viet Uc has built a first solar PV system at an An Giang production facility and is planning a first dual-use pilot project, based on own exchange with company representatives, see also Fraunhofer ISE 2017).

[54] Marrou (2013a)

[55] Wu et al. (2014)

According to the Master Plan for Development of Aquaculture and Fishery towards 2020 by the Vietnamese Directorate of Fisheries,[56] the expansion of shrimp farming in Viet Nam will be mostly concentrated in the Mekong Delta, which is a specifically sensitive area and expected to be severely affected by climate change. This has been the motivation for increased requirements of sustainable shrimp farming practices and activities to mitigate climate change in the region.[57]

| Benefits for Farmers and Agricultural Practice | Benefits for Municipalities/Provinces and the Economy in General |
|---|---|
| • **Own energy supply** (self-consumption) and **energy savings**;<br>• Additional income **from solar power production (sale to the grid)**;<br>• **Improved marketing opportunities/ competitiveness** (sustainable production);<br>• **Reduction of land-use conflicts** (pressure from investors or indirectly from authorities who want to support renewable energy development);<br>• **Aquaculture (shrimp/fish):** Better c**ontrol of temperature**, **reduced** water evaporation, **limited** growth of algae **(in case that is intended);**<br>• **Agriculture (vegetables, crops etc.): Some crops** benefit from additional shading **(higher yield), some have minor** reductions in yield **that are** compensated **by additional revenues from solar generation;**<br>• **Business marketing and improved competitiveness of products (sustainable production), meeting demands of** sustainable supply chains **(especially export markets).** | • Reduction **of land-use conflicts**;<br>• **Additional income** for farmers with potentially higher **investments** and **tax revenues for municipalities and provinces;**<br>• **Reduction of energy demand** from agricultural/ aquacultural sector and benefits from decentralised power generation (less demand for power grid extension);<br>• **Reduction of CO2-emissions and hazardous local emissions** from conventional thermal power plants (such as coal);<br>• Development of a more competitive **sustainable agricultural sector** (for domestic and export markets). |

**Table 2: Summary of Key Benefits of Solar Dual-Use Applications**

[56] Prime Minister Decision 124/2012/QD-TTg of 2. February 2012

[57] See Fraunhofer ISE (2017)

# MAIN TECHNICAL CONCEPTS AND FORMS OF APPLICATION

This section gives an overview of different technical concepts and approaches of solar dual-use. The general concepts will be mainly categorized in **1. "Full" solar dual-use concepts** that apply an equal focus on agricultural production and solar energy generation or even prioritize agriculture over energy generation; **2. "Add-on" concepts** that prioritize solar energy generation (mostly to generate revenues from Feed-in-Tariffs) with an add-on agricultural component; **3. Solar PV greenhouses** and **4. Dual-use concepts for aquaculture.**

## "FULL" SOLAR DUAL-USE (AGRIVOLTAIC) SYSTEMS

The core concept of solar dual-use or agrivoltaic systems is that of an **elevated mounting structure** that carries solar PV modules. The elevation of these "full" solar dual-use systems that aim at an equal focus on agricultural production and solar energy generation usually is 3-5 meter to allow extensive or intensive, mechanized farming methods (including e.g. machine harvesters/tractors) underneath the solar modules.

Secondly, solar dual-use applications include a less dense area coverage (**less PV capacity density**) of the solar modules compared to roof-mounted or conventional ground-mounted PV systems to allow a higher ratio of irradiation to reach the ground (i.e. the plants, crops). The space between the module rows differs from project to project and is actually a key parameter of the dual-use set up. It largely depends on the shading-tolerance of the crops and plants that grow underneath. Pilot projects and scientific test sites usually experiment with differing shading-ratios created by differing densities of the solar modules.

**First Scientific Dual-Use Project near Montpellier/France (50kWp)**
Source: Dupraz et al. (2011)

PV modules can be **fixed** on the mounting structure or **single- or double-axis** (2D or 3D) tracked (thus the tilt angle of the PV modules can be adjusted). Single-axis tracked solar systems are in general more to be found in regions closer to the equator (sunrise and sunset are very short), double-axis tracking more in regions further away from the equator.

The dynamic control of the module tilt angle in tracked systems can be utilized to a) **increase the solar yield** of the system (more kWh generated per kWp installed) and b) to allow more sunlight to reach the crops or to **create a more stable shading effect,** which benefits soil humidity and micro-climate on the ground.

**Tracked Solar Dual-Use Systems in Italy (Piacenza/Mantua, 6.7MWp in total)**
Source: RemTech S.r.l.

Initial scientific experience with these tracked systems has shown that it can be beneficial for some crops to allow more sunlight to reach the plants in early stages of plant growth when shading-sensitivity is higher than in later plant life. The sunshine needs in different stages of plant growth vary from crop to crop and the adequate distribution of sunlight/shading over the lifetime of an agricultural crop needs careful scientific monitoring. However, the effect of PV module management seems to have less effect on available radiation for the crops and plant growth than the density of the modules.[58]

## "ADD-ON" SYSTEMS WITH MAIN FOCUS ON SOLAR ENERGY GENERATION

Over the last 2-3 years some very large Chinese solar dual-use projects were realized where the agricultural production seems more like an "add on". Some of these systems are not highly elevated and leave more space in between the module rows for vegetable production. In these cases, it appears that the systems are more optimized for solar energy generation to maximize revenues from the local FiT. However, these projects reach impressive sizes of more than 100 MWp capacities.[59]

A more traditional type of "add-on" dual-use concept is the grazing of livestock in between or underneath the modules. This has been practiced for many years and often has the objective of cost-efficient control of undesired vegetation and growth of weeds.

**Livestock Grazing and Vegetables (150 MW, China) under Conventional Solar Systems**
Source: https://twitter.com/thibaultfrisson/status/986892522063572992

[58] Amaducci et al. (2018) have monitored the dual-axis tracked RemTec Agrivoltaico systems in Northern Italy

[59] Haugwitz (2018)

## SOLAR PV GREENHOUSES

A specific form of solar dual-use that has been applied in different world regions already is the integration of solar energy technologies (mainly solar PV but also solar thermal technologies) into the environmental control systems (cooling, heating, lighting etc.) of greenhouses.[60] Here, different PV technologies have been applied ranging from traditional silicon-cell based modules to flexible cell concepts, and different types of semi-transparent module concepts that allow a higher transition of sunlight to the plants.

**Example of Solar PV Greenhouse Concept in Italy**
Source: Marucci et al. (2018)

Larger solar PV greenhouse applications have been installed in China,[61] but also in other regions of the world. In general, the experience with those projects shows that the integration of solar PV and solar thermal (ST) technologies in greenhouses can be very beneficial in terms of energy and cost saving, and in the reduction of the environmental impacts of greenhouse production (water demand, CO2 emissions etc.).[62] Key challenges are specific crop management, the selection of the most suitable crops and the use of most beneficial solar PV technologies such as semi-transparent cells/modules to reduce impacts on plant growth.

**Solar PV Greenhouses in Japan**
Source: Thibault Frisson

For the further discussion of the topic in this context, the study will mainly focus on the above mentioned elevated solar dual-use approaches for free-field agriculture applications that are most common in Viet Nam. However, in some regions in Viet Nam, such as the Central Highlands, where greenhouse technologies are common for vegetable production, these solar PV greenhouse concepts could be feasible in general and should be further explored.

60 For an overview see Hassanien et al. (2016)
61 For an overview see Wang et al. (2017)
62 Hassanien et al. (2016)

### SOLAR DUAL-USE CONCEPTS FOR AQUACULTURE

Fish and shrimp farming are particularly sensitive sectors in terms of environmental impacts. Due to the increasing contamination of water in rivers and canals in the Mekong region, more and more ground water is used for shrimp farming. In addition to water subtraction for domestic and agricultural uses, this results in a steady lowering of land levels.

In the current process of expanding shrimp farming in the Mekong Delta, there are increased requirements of sustainable farming practices. Here, solar dual-use concepts could offer solutions and synergies in multiple ways. The coverage of fish or shrimp ponds can substantially **reduce water evaporation** and **reduce algae growth** where this is not intended (see also the following chapter on suitable crops/applications for solar dual-use).

**Large-scale Solar Dual-Use Fishery Projects in China**
Source: Xiangshui Fishery Project, Jiangsu/China (120MWp); Solar Aquaculture project, China

In recent years, China developed a number of large-scale solar dual-use fishery projects on a multi-Megawatt scale. Projects with 120 MWp or even 150 MWp have been developed in the Eastern-Central coastal provinces of Jiangsu and Zheijang. Further large projects are planned, among others in the context of a joint venture of China's largest aquatic feed manufacturer Tongwei Group that announced ambitious plans to develop solar PV aquaculture over the coming years.[63]

## OVERVIEW OF THE INTERNATIONAL DEVELOPMENT OF THE SOLAR DUAL-USE CONCEPT

The scientific debate around solar dual-use / "agrophotovoltaic" initially started in **Germany** with the work of Adolf Goetzberger and Armin Zastrow at the Fraunhofer Institute for Solar Energy Systems (Fh-ISE) in Freiburg.[64] Almost 30 years later, this work entered the next stage with the 194 kWp pilot project at Southern Germany's Lake Constance area that was built in 2015.[65]

The first results of the project have been very promising. With tests on wheat, potatoes, celeriac and clover grass, it could be proved that the **overall productivity of the dual-use concept was increased by 60%** compared to the single-use of solar PV and agriculture. Based on the results from the test site, the research team estimated a realizable potential of **solar PV dual-use for Germany on 53,000 MWp**

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[63] See https://www.undercurrentnews.com/2017/01/13/chinese-firm-establishes-115m-jv-to-integrate-solar-power-aquaculture/

[64] See Goetzberger/Zastrow (1982)

[65] For more information, see www.agrophotovoltaik.de/english

(with the assumption of 430kWp/ha solar dual-use capacity and only 10% of overall technical potential realized).[66]

The first real solar dual-use pilot project, however, was installed in **France**, close to the Southern city of Montpellier. A very comprehensive study on this experimental 50kWp system with 4m elevation was conducted in 2010/2011. The authoring team developed a model for radiation intensity within a solar PV field including boundary effects. They also estimated the influence of shade on crop yield using existing models from agroforestry (interspersing crop areas with trees) and applied the concept of LER (Land Equivalent Ratio) that originally had been developed to quantify yields of mixed agricultural systems, like the combination of different crops, or trees and crops, to the combination of PV with crops.[67]

Japan is the second “birthplace” of the solar dual-use concept, here referred to as solar sharing. The pioneer of Japanese solar sharing is Prof. Akira Nagashira who started his research on dual-use / solar sharing in 2003.[68]

By understanding that too much sun would not increase further growth of plants, Nagashima came up with the idea to combine PV systems and farming. He developed and originally patented a special elevated structura l concept and created a couple of testing fields with different shading rates and different crops.

**One of the First Test Sites for ‘Solar Sharing’ in Japan**
Source: www.renewableenergyworld.com

In 2013 and 2014, the Japanese Ministry of Agriculture, Forestry and Fishery (MAFF) introduced guidelines for solar dual-use applications on agricultural farmland.[69] It basically approved the installation of PV systems on existing crop-producing farmland with the requirement that the **potential reduction of the agricultural yield** through the additional shading stays **below 20%**. Previously solar generation on farmland, productive or idle, was prohibited under the Agricultural Land Act.[70]

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66 See Beck et al. (2012)

67 See Dupraz et al. (2011) as well as Marrou (2013b) and Marrou (2013c)

68 Most of his research is only accessible in Japanese.
For an overview see: www.solar-sharing-japan.blogspot.com

69 See www.maff.go.jp/j/press/nousin/noukei/pdf/130401-01.pdf (Regulation regarding the handling and permission of photovoltaic power generation facilities on agricultural land)

70 See also https://www.renewableenergyworld.com/articles/2013/10/japan-next-generation-farmers-cultivate-agriculture-and-solar-energy.html

In May 2018, MAFF even improved the regulation on solar sharing by extending the period of allowing temporary conversion of farmland for dual-use purposes from 3 years to 10 years. By mid-2016, 775 projects had been approved for dual-use projects by the Japanese government. The majority of them are small-scale, not exceeding 50 kWp capacity.[71] At end of 2017 an estimated 1,000 solar sharing projects had been installed in the country.[72]

There are estimations on solar sharing" potential for Japan from some of the pioneers of the approach in the country: If 20% of Japan's farmland was used for solar dual-use, the combined systems could generate **457,000 GWh of electricity** which would equal to **57% of total demand** of the country.[73]

In Japan, there is also initial experience with solar **dual-use applications on rice paddy farming** which would be highly relevant for the application of the concept in Viet Nam and the Mekong Delta in particular (see the discussion on suitability of dual-use for rice in the following section).

Over the last number of years, **China** saw a number of utility-scale projects of 'Photovoltaic Agriculture' applying solar dual-use concepts to crop and aquaculture farming. Most research and market information from China is difficult to access. However, there are rough estimates that over the last 2 years approximately 1,000-2,000 MWp of dual-use projects (including solar greenhouses as well as large-scale solar dual-use aquafarms) have been installed every year.[74]

China also has the largest solar dual-use farm in the world to date. In Henan a 1,000 MWp agrivoltaic system was installed in 2017 with further plans to expand the project to 3,000 MWp. The project mainly produces goji berries, vegetables and rape seed.

71 See RTS (2018)
72 Haugwitz (2018)
73 See Batorova (2015)
74 See Haugwitz (2018) for an overview.

**Largest Solar Dual-Use System in China (Henan, 1GWp)**
Source: Thibault Frisson (Twitter)

In **France** initial projects with solar dual-use approaches have been tested for wine grapes with promising results.[75] Wine growing in almost all of the major wine regions in Mediterranean Europe, South America, South Africa and Australia are increasingly threatened by climate change mainly due to higher water stress during the summer, which drastically reduces yields or deteriorates the quality of grapes and the aromatic profile of the wines.

**Solar Dual-Use System on Grapes/Vineyard, France**
Source: Sun'Agri/Sun'R

[75] See e.g. www.sunagri.fr/en/agrivoltaics/wine-growing

Here the French test sites could validate a number of benefits of the additional shading by the elevated solar system: The reduction of alcohol content of wines, the preservation of aromatic profiles of wines, the alternative to irrigation during dry periods for vineyards with no access to water (20% water saving), and the preservation of, and even increase of yields.

Further countries have started to introduce specific solar PV support programmes for farmers that partially include concepts of dual-use applications. The **Indian** state government of Gujarat for example launched a solar power scheme for farmers enabling them to generate electricity for their captive consumption as well as to sell the surplus power to the grid and earn extra income. It is planned that around 12,400 farmers from 33 districts will be covered under the pilot project, generating 175 MWp capacity.[76] Despite the implementation of small pilot projects, there were no large-scale projects reported from India and there are no targeted policy measures or regulatory frameworks in place.[77]

Furthermore, a US based research team around Prof. Joshua M. Pearce developed a techno-economic analysis of solar dual-use applications on grape farms in India. The results show that the **economic value of the grape farms** deploying the proposed agrivoltaic system may **increase more than 15-times** as compared to conventional farming, while maintaining the same grape production.[78] If this dual-use of land is implemented nationwide, the author concludes, it could make a significant impact by generating over 16,000 GWh electricity, which has the potential of meeting the energy demands of more than 15 million people in India.

Furthermore, **South Korea** has implemented its first solar dual-use farming projects and programmes to support farmers in using solar PV and “Smart Farming Concepts”.[79] In 2016, a first 100kWp solar dual-use project was initiated by the Green Energy Institute Korea in Chungbuk Ochang, researching effects on rice, cabbage, ginseng, soybean, garlic and other vegetables.[80]

Other European countries have developed pilot projects. In **Croatia** a pilot project was built in 2016 in the village of Mecini in Slavonia region. The 500kWp system with a solar energy generation of around 567 MWh per year is used for tests with different vegetables and is monitored by the Agricultural Faculty of the University in Osijek.[81]

The Indian Ocean island **Réunion**, also hosts a larger solar dual-use project that includes both, agricultural and aquacultural production. A 7.5 MWp agrivoltaic system covers vegetables, herbs, livestock and bees, whereas a 1.5 MWp system covers Tilapia fishponds.[82]

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[76] See https://solarquarter.com/index.php?option=com_content&view=article&id=12009:gujarat-launches-sky-scheme-for-farmers-to-generate-solar-power&catid=113:featured-news

[77] Haugwitz (2018)

[78] Malu et al. (2017)

[79] See for a brief overview: http://www.industrynews.co.kr/news/articleView.html?idxno=24780

[80] Haugwitz (2018)

[81] Predragovic, L. and Radosevic, K. (2018) as well as http://www.pveurope.eu/News/Solar-Generator/Innovative-500-kW-agrophotovoltaic-installation-in-Croatia

[82] See: http://www.akuoenergy.com/en/les-cedres

## VIET NAM

Recently, first research activities on solar PV use in aquaculture started also in Viet Nam. Until now, this focused not on full dual-use concepts as outlined in this study but rather add-on or stand-alone systems.[83] However, over the last two years there has been more attention and interest in this approach among researchers and practitioners, as well as relevant professional associations of the country.

In May 2018, the Vietnam Energy Association (VEA) in coordination with MoIT and other government agencies and private sector representatives organized a conference on “Integrating Aquaculture with Renewable Energy Systems” in HCMC to discuss opportunities to develop renewable energy and solar PV in particular for aquaculture and other agricultural production areas in the Mekong Delta.[84]

Furthermore, the Renewable Energy Week 2018, organized by the Vietnam Sustainable Energy Alliance (VSEA) addressed the topic of solar dual-use with a workshop in 2018.[85] And eventually, this study project was also initiated in the light of the new level of awareness and the search for innovative solutions to tackle land-use conflicts and improve the sustainability of the agricultural sector in Viet Nam.

Currently, a **first pilot project** on solar dual-use in **shrimp farming** is under preparation. Initiated by the German GIZ Energy Support Programme Viet Nam, a consortium is led by German Fraunhofer Institute for Solar Energy Systems (Fh-ISE) is preparing a funded research project (PV SHRIMPS) including a 1 MWp test site at a shrimp farm in Southern Bac Lieu province.

The key objective of this project is to prove the technical and economic viability of an integrated dual-use PV shrimp farm in order to contribute to a more ecological and socio-economic sustainable development of Vietnam’s economy.[86] The project also aims at the subsequent diffusion of the technology by developing a concept for a rollout in the Mekong Delta that assesses all technical aspects, but also relevant economic aspects of up-scaling and market potentials with the integration of a bankable business case for small and medium-size aqua-farming units.[87]

Soure: https://www.rfa.org/vietnamese/in_depth/shrimp-mekong-delta-02142017104037.html

[83] See e.g. http://vneec.gov.vn/tin-tuc/projects/t12277/the-use-of-solar-power-in-aquaculture.html

[84] VEA (2018)

[85] See e.g. http://en.greenidvietnam.org.vn/vietnam-renewable-energy-week-2018.html

[86] Fh-ISE (2017) and Fh-ISE (2018)

[87] See also GIZ (2018)

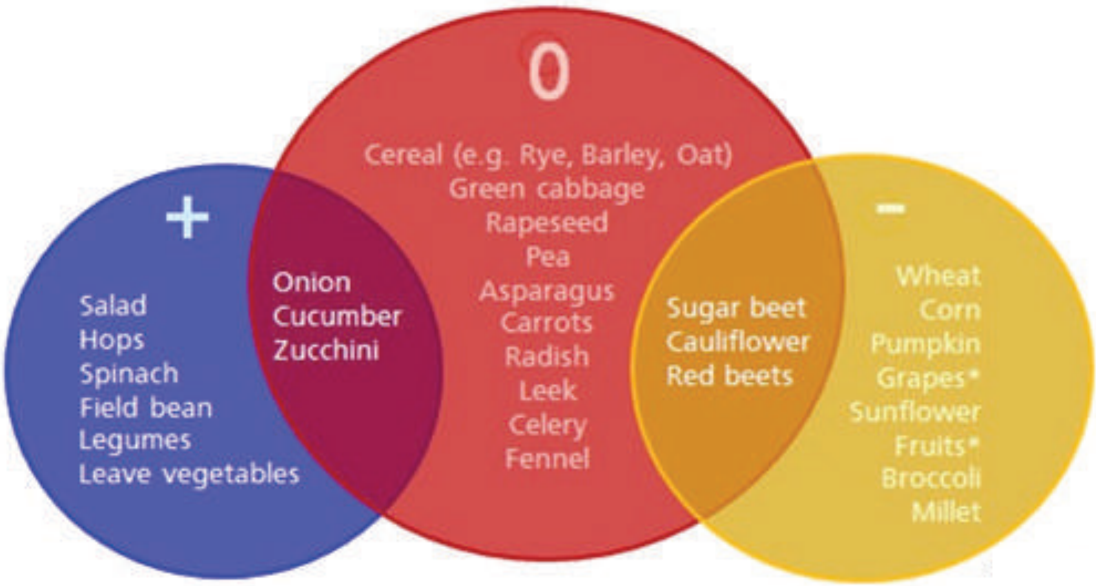
## WHAT CROPS ARE SUITABLE FOR SOLAR DUAL-USE APPLICATIONS?

The question of suitable crops for solar dual-use applications is crucial, but also a challenge to assess in the Vietnamese context without any best practice projects available. Most of the available scientific assessments on shading-tolerance and dual-use suitability have been made in Germany, France, Italy or in the USA. The most important studies and research projects have been described in previous sections of this study. However, there are already a number of dual-use projects in countries like Japan, India, Korea and China that can give indications for the application in the Asian context and in tropical or sub-tropical environments such as in Viet Nam.

A fundamental effect of the shading caused by the PV modules is reduced water evaporation from the soil. Obviously, this has a positive effect particularly in arid regions where water can be scarce. However, Viet Nam has some dryer regions and also an extended dry season in some parts of the country.

With this in mind, the following categorization of suitable crops is preliminary and rather indicative and needs to be validated in pilot projects and scientific assessments.

The German research on solar dual-use initially identified the following categories and crops for agrivoltaic suitability:[88]




**Suitable Crops for Solar Dual-Use (Case Study for Germany)**
Source: Fraunhofer ISE

Again, it has to be noted that this is based on a case study and crop simulations in the German context. However, experience with commercial and scientific dual-use systems in Asia largely confirms the above categorization. In fact, some of the crops that initially had been categorized as shading-sensitive have proven to be suitable for solar dual-use in real experiments, provided the right shading ratio (less density of the solar modules) was chosen. This applies to corn, wheat, grapes and low-growing fruit trees (such as oranges) in particular.

[88] See e.g. Obergfell (2013)

With this in mind, the following list of potentially suitable crops for Viet Nam can be developed based on different research and best practice projects (also see the following section on selected best practice projects):

| Category | Crop (+) | |
|---|---|---|
| Field crops | • Corn<br>• Green Tea<br>• Coffee | • Soy<br>• Rice |
| Vegetables | • Cassava<br>• Spinach<br>• Broccoli<br>• Legumes<br>• Beans<br>• Salad/Lettuce<br>• Herbs (e.g. Lemongrass)<br>• Peas<br>• Mushrooms | • Cabbage<br>• Asparagus<br>• Carrots<br>• Leek<br>• Fennel<br>• Celery<br>• Onion<br>• Cucumber<br>• Zucchini |
| Fruit | • Low growing fruit trees (orange etc.)<br>• Berries<br>• Grapes | |
| Aquaculture | • Shrimp<br>• Fish (Tilapia etc.) | |
| Livestock | • Chicken, Ducks, Goats etc. | |

**Table 3. Potentially Suitable Crops for Solar Dual-Use in Viet Nam**

And to add some information and reference regarding the dual-use suitability of a few of those crops:

**Maize:** Early research in China has shown that for maize, at above 50% of shading all plant growth parameters have been reduced significantly, but that this differs from variety to variety so that some varieties can be classified as shade-tolerant.[89]

[89] Cited in Dupraz et al. (2011)

However, more recent studies from pilot projects in Northern Italy show maize yields under a solar dual-use system were even higher compared to normal fields without solar dual-use in conditions of drought stress. Thus, in times of water shortage or extended dry seasons, solar dual-use applications can be even beneficial for maize production. This indicates that solar dual-use systems could increase crop resilience to climate change.[90]

Furthermore, the Italian experience showed very high Land Equivalent Ratios of 2 and up to 3 (thus, a productivity increase through dual-use application), when comparing the electricity generated from the solar PV system and biogas in the dual-use application to that produced by conventional ground-mounted solar PV systems and biogas maize in monoculture. This very high LER was even higher compared to the earlier simulation studies of Dupraz et al. and Valle et al.[91]

**Cassava:** There is experimentally verified shade tolerance for cassava and sweet potato.[92]

**Coffee and Tea:** There is positive experience with coffee and tea in the European and Asian context.[93]

## DUAL-USE AND RICE
## FIRST INTERNATIONAL EXPERIENCE

In Europe, there is positive experience with (dry) rice solar dual-use applications since 2011.[94] First solar dual-use test sites and pilot projects on wet paddy rice have been installed in Japan and China. However, in - depth scientific research on suitability of paddy rice is still rare.

A preliminary study monitoring a paddy rice dual-use project in Chiba, Japan resulted in 20% shading causing 20% of rice yield loss. However, the project did not include the flexible use of shading during different phases of plant growth (with tracking PV systems) such as other international best practice suggests. A first scientific monitoring report states, that “it seems necessary to take measures to improve the sunlight conditions in the early stage of growth that greatly affect the number of (rice) panicles”.[95] Tracked PV systems can optimize irradiation for the plant during early periods of growth and then balance more for PV generation in plant growth stages where irradiation can be less.

Apart from these early monitoring results, there are also optimistic views on suitability of paddy rice. RemTec are currently building rice dual-use projects in China and Japan and are expecting positive results from these projects.[96]

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90 Amaducci et al. (2018)

91 Dupraz et al. (2011) and Valle et al. (2017)

92 Johnston/Onwueme (1998)

93 See the pilot projects of RemTec in Italy and China/Japan (www.remtec.energy/en)

94 See e.g. the Italian projects implemented by RemTec: http://www.remtec.energy/en/agrovoltaico-2/monticelli-dongina-plant/

95 See Homma et al. (2016), p. 30

96 Personal exchange with the company director.

**Solar Dual-Use on Paddy Rice, Japan**
Source: Left: rice paddy system Izunokuni; right: rice paddy system Chiba Prefecture (Homma et al. 2016)

## SHRIMP AND FISH FARMING

Traditional technologies of aquaculture (particularly in shrimp production) rely on algae providing oxygen and food for the aquacultures. These technologies would be limited in their suitability for solar dual-use aquaculture due to adverse shadowing effects on algae growth. However, new technologies replace the function of algae with bacteria that absorb nutrients and the biomass produced in this process provides the food for the aquacultures (so-called biofloc approach). Oxygen is provided by technical means (aerators). [97]

While productivity and environmental sustainability of such innovative shrimp breeding systems usually are significantly higher than conventional systems, they have higher energy demands due to the use of aerators and pumps. Here, the solar PV system on-site offers opportunities for self-consumption and electricity cost reductions.

Furthermore, these innovative aquacultural systems usually include farmhouse structures that cover the ponds to create a controlled environment for the shrimp and to protect the breed from pathogens and predators. An additional layer of PV modules on top of the farmhouse structure would create additional benefits: Less water evaporation, improved working conditions through shadowing, and more stable water temperatures. In the South of Viet Nam were most shrimp farms are located, temperatures in farmhouses can be very high. Some shrimp farmers therefore install shading nets between the roof and the shrimp ponds to reduce passive heating effects from the solar irradiation (see picture below). PV modules covering the farmhouse structure would have a similar cooling effect.

[97] Fraunhofer ISE (2017)

**Innovative Shrimp Farming (Covered Ponds, Biofloc) in Bac Lieu, Viet Nam**
Source: Viet Uc / R. Brohm

The additional revenues from solar power generation could compensate the higher investment costs for the farmhouse structure. In general, solar dual-use for aquaculture appears to be very promising and offers multiple synergies and benefits for farmers.

## SELECTED INTERNATIONAL PROJECT EXAMPLES

This section highlights selected international best practice and pilot projects to give an overview of existing experience with the solar dual-use concept. It also identifies the key parameters of these project examples that will be used later for the development of the Can Tho case study and the assessment of technical potential for dual-use.

### AGROPHOTOVOLTAIC PILOT PROJECT IN HEGGELBACH, GERMANY (194KWP)

The pilot project in Heggelbach, Germany is part of the APV-RESOLA research project (APV = Agrophotovoltaic) under leadership of the Fraunhofer Insitute for Solar Energy Systems (ISE).[98] Key objective of the research project is to develop a market-ready solar dual-use plant for the use on agricultural land. The primary aim is a maximum impact on a resource-efficient land use in Germany and thereby mitigating land-use conflicts between food and energy security. The maximum impact is to be realized by the combination of the market-ready dual-use technology and the accompanying political and social innovations, like new concepts for approval procedures on a municipal level or adapted processes in agricultural management.

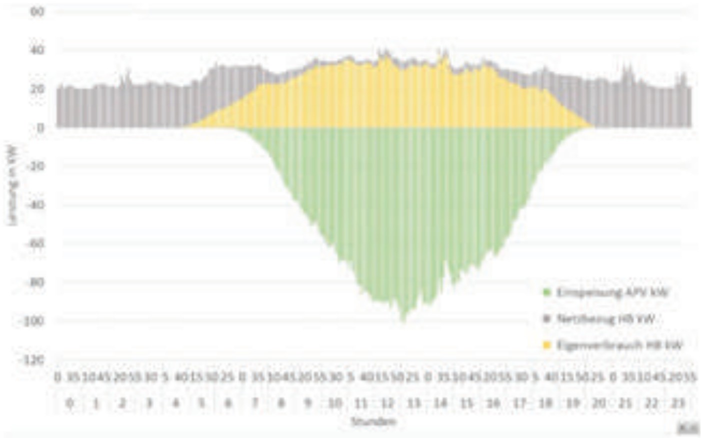
A biodynamic (Demeter) organic farm in Heggelbach in the region Lake Constance-Upper Swabia (Bodensee-Oberschwaben) was selected to be the site of the research facility. The district is facing the challenge of increasing the share of renewable energies from 10% (as in 2013) to 26 % in 2022. With 15 %, solar PV is intended to be the main renewable energy source in the region. Innovative approaches like solar dual-use are considered to be a means to reach this target.

[98] See: www.agrophotovoltaic.de/english

**Agrophotovoltaic (APV RESOLA) Pilot Project in Heggelbach, Germany (194 kWp)**
Source: Fraunhofer Institute for Solar Energy Systems (ISE)

Winter wheat, potatoes, celery and clover grass were the first crops to be tested. The Southwest orientation and the extra distance between the five-meter high rows of bifacial glass-glass PV modules ensured that the crops were exposed to uniform solar radiation. The results from the first harvest were, for the most part, promising. The crop yield of clover grass under the PV array was only 5.3 percent less than the reference plot. The yield losses for potatoes, wheat and celeriac were between 18 to 19 percent and therefore somewhat higher.

With an installed power of 194 kilowatts, the photovoltaic array can supply 62 four-person households with electricity. In the first twelve months, the array produced 1,266 kilowatt-hours electricity per installed kilowatt, one third more than the average value of 950 kWh/kWp in Germany.




**Agrophotovoltaic Project in Heggelbach, Harvest and Energy Balance**
Source: Fraunhofer Institute for Solar Energy Systems (ISE)

The power production from the experimental field matched well to the daily farm load. About 40 % of the electricity produced on the farm was used directly to charge the electric vehicles and process the harvested crops. In summer, the load demand could be almost completely met by the photovoltaic system. The surplus solar electricity is fed into the Elektrizitätswerke Schönau, an electric utility company based on 100% renewable energy and a partner in the project.

The preliminary result of the research project is that with the solar dual-use approach the **Land Use Efficiency (LER) could be increased by over 60%**. After the first year of monitoring the researchers summarized that the system proved suitable for use and costs were at the level of a small solar roof system (thus higher than conventional ground-mounted PV power plants but slightly lower than small-scale PV rooftop systems, see figure 8). The crop production was sufficiently high and could be profitably sold on the market.

| Project / Location (Year of Installation) | Capacity (PV) | Crops | Further Parameters |
|---|---|---|---|
| Heggelbach, Germany (2015) | 194 kWp | Clover, celery, potatoes, wheat (1st year) | 580 kWp/ha PV density, 5m elevation |

**Table 4: Project Example – Agrophotovoltaic System Heggelbach, Germany (194 kWp)**

One of the researchers of Fraunhofer ISE developed an **economic analysis** of the pilot system that delivers interesting insights in the cost structure of the dual-use pilot project. Some of these parameters will be used later in this study to develop the Can Tho case study.[99]

The basic outcome of this economic analysis is that a key factor for economic viability and feasibility are the costs of the elevated mounting system. In the pilot system, those costs were 109% higher compared to a conventional ground-mounted PV system. The **overall CAPEX costs** were about **30% higher** compared to a non-dual-use system. Costs for Operation and Maintenance were only slightly higher since cost-saving effects (no land-lease costs, mowing/weed control necessary etc.) and cost-increasing effects  (higher cleaning costs, monitoring of the system etc.) would be in balance.

An interesting result of the analysis is also the **calculation of Levelized Costs of Electricity (LCOE)**. The LCOE of the solar dual-use system were higher compared to the conventional ground-mounted PV system but lower than a small-scale PV rooftop system (all findings for Germany with data from 2015). Figure 8 shows the LCOE comparison and also the cost split of the system between agricultural and solar PV costs:

[99] Trommsdorff (2016)

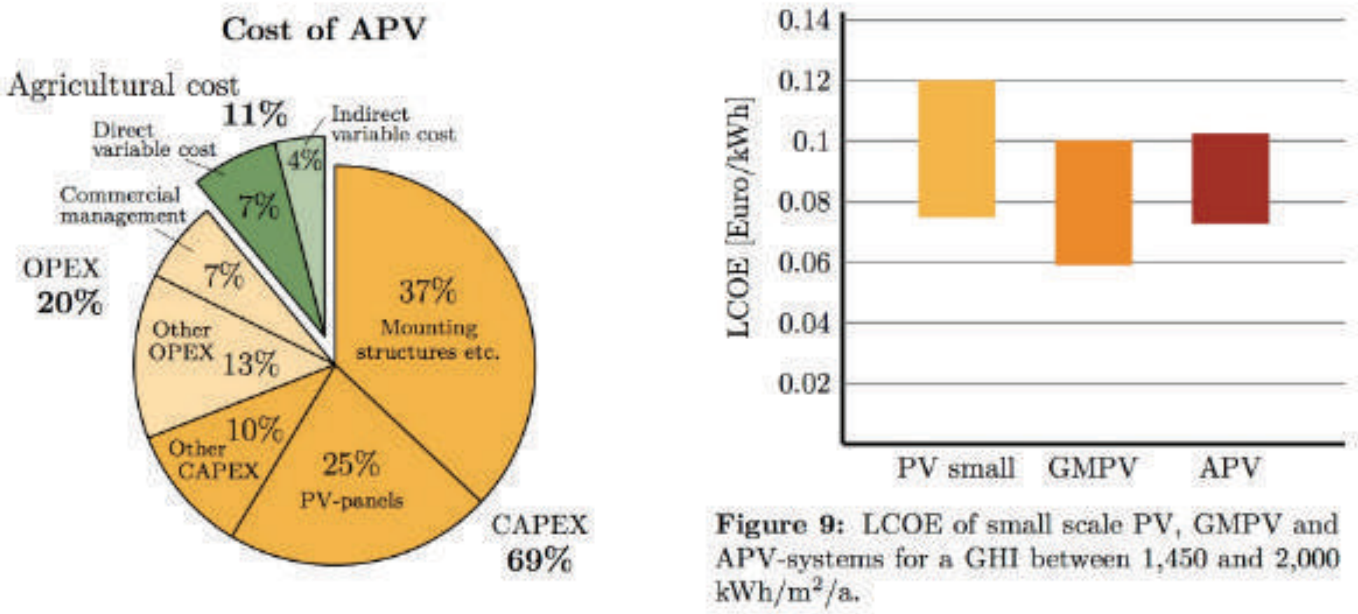



**Figure 8: Costs of Agrophotovoltaic-System (APV) in Germany and LCEO Comparison**
Source: Trommsdorff (2016), p. 30

The case study on Can Tho, developed in the following chapter of this study, will use some of these general parameters to calculate preliminary LCOE for a solar dual-use system in Viet Nam.


**KAZUSATSURUMAI 'SOLAR SHARING' PROJECT, CHIBA PREFECTURE, JAPAN (34 KWP)**

The solar sharing project in Chiba, not far from Tokyo was one of the first solar dual-use systems that took advantage of the new Japanese regulation and received revenues from the Japanese FiT. The project includes farming of different vegetables such as pumpkin, tomatoes, yams, taro, eggplant, cucumbers and peanuts but also low growing fruit trees.

**Farmer Makoto Takazawa and his Solar Sharing Project in Kazusatsurumai**
Source: www.renewableenergyworld.com

The story of farmer Makoto Takazawa's experience with his solar sharing project also tells a lot about the potential benefits of solar dual-use for farmers in general. In his conclusion, the **solar sharing can re-activate the declining farming sector.** Farmers in Japan are facing serious issues such as the reduction in farming revenues and subsequent lack of successors for the family-owned farms. Many small farmers are forced to get a second job to sustain their living. Takazawa learned the concept from the Japanese solar sharing pioneer Nagashima and found that the solar dual-use farming is a way to revitalize Japanese farmers, providing opportunities to increase income and contribute to the nation's energy need. In that sense, the countryside has a potential to create clean energy, thereby stimulating local economy.[100]

| Project / Location (Year of Installation) | Capacity (PV) | Crops | Further Parameters |
|---|---|---|---|
| Kazusatsurumai Solar Sharing Project, Chiba Prefecture, Japan (2013) | 34.8 kWp | Pumpkin, peanuts, tomato, yams, taro, eggplant, cucumber, low fruit trees | 450 kWp/ha PV density 3m elevation, 1,017kWh/kWp , 126,000USD installation costs, (3,660USD/kWp), app. 40MWh/yr |

**Table 5: Project Example – Solar Sharing Project Chiba, Japan (34.8 kWp)**

## MUSHROOM SOLAR SHARING FARM, JAPAN (4 MWP)

There are also best practice projects for non-field crops such as mushrooms in Japan. The two mushroom farms in Tome town and Miyagi town have a combined capacity of around 4 MWp and produce approximately 40 tons of black fungus mushroom and some 4,000 MWh of solar electricity.

In unusually hot weather, the researchers found, the shading from the panels actually helps the plants, and despite getting less sun, yields can be essentially the same as for plants in an open field. In more typical weather, tests so far indicate the yields may be only somewhat reduced. A farmer could make up the financial difference by selling electricity, while preserving valuable farmland.[101]

**Solar Dual-Use Mushroom Farm in Japan (4 MWp)**
Source: Sustainergy Co., project presentation

[100] See https://www.renewableenergyworld.com/articles/2013/10/japan-next-generation-farmers-cultivate-agriculture-and-solar-energy.html

[101] See https://www.fastcompany.com/40469425/these-solar-farms-have-a-secret-hiding-under-them-mushrooms

| Project / Location (Year of Installation) | Capacity (PV) | Crops | Further Parameters |
|---|---|---|---|
| Tome town and Kami town, Miyagi, Japan (2017) | 1.8 MWp / 2.2 MWp | Black Fungus mushroom | 780/970 kWp/ha Installed on abandoned farmland. Operated by local agricultural corporations in an ESCO model. |

**Table 6: Project Example – Mushroom Solar Sharing Project, Japan**

**'AGRIVOLTAICO' SYSTEM IN MONTICELLI, ITALY (3 MWP)**

Italy has developed some interesting best practice projects with profound scientific monitoring in cooperation with the University of Piacenza. This project designed and installed by the company RemTec SRL in Monticelli was already installed in 2011. The project collected data from different field crops such as rice, wheat, maize/corn and soy.

In particular this project provides data and experience with tracked solar modules and the effects on shading and crop development.[102] These results came to the conclusion that an adapted solar PV tracking operation scheme could increase crop yield by allowing more sunlight to reach the crop in early stages of plant development, when the requirements of the plant regarding sunlight exposure are higher than in later stages of plant growth.

**Monticelli Solar Dual-Use Project**
Source: RemTec SRL company presentation

[102] See Amaducci et al. (2018)

| Project / Location (Year of Installation) | Capacity (PV) | Crops | Further Parameters |
|---|---|---|---|
| Monticelli, Italy (2011) | 3.23 MWp | Rice, wheat, soy, maize/ corn etc. | 190 kWp/ha, single axis trackers |

**Table 7: Project Example – Solar Dual-Use Project Monticelli, Italy**

**AGRIVOLTAIC AND AQUAVOLTAIC PROJECT ON THE ISLAND RÉUNION (9 MWP)**

The solar dual-use farm in Les Cedrese on the island of Réunion spans two sites. The first is an aquaculture solar farm, consisting of solar PV sun-screens above 12 fish rearing pools, with a capacity of 1.5MWp. The operator of this site is Max Dyckerhoff, a pioneer in fish farming on the island, who for more than 25 years has supplied the local market, particularly with tilapia.[103]

**Aqua-PV Project Réunion, France (1.5 MWp)**
Source: www.akuenergy.com

[103] See: http://www.akuoenergy.com/en/les-cedres

The second site is an agrivoltaic farm where the PV panels have been elevated to allow mechanized farming of the whole of the 7.5 ha site. The density of the PV modules is comparatively high and the farming includes only non-shading sensitive gardening products, herbs and permaculture.

**Aqua-PV Project Réunion, France (7.5 MWp)**
Source: www.akuenergy.com

The agricultural partner for this site is Agriterra, an agricultural company partnered with Akuo Energy, which is developing a major permaculture project, mixing livestock, forestry and market gardening. Produce from these organic farms is destined for the local market, and several agricultural jobs have been created.

| Project / Location (Year of Installation) | Capacity (PV) | Crops | Further Parameters |
|---|---|---|---|
| La Réunion, France (2016) | 1.5 MWp | Red Tilapia, Sturgeons | Both systems are combined with a 9MWh battery storage system that also stabilizes the island grid. |
| | 7.5 MWp | Vegetables, herbs, livestock, bees, | |

**Table 8: Project Example – Agrivoltaic and Aquavoltaic Farms, La Réunion**

The following table gives an overview of selected international pilot and best practice projects with their key parameters and features. In particular, the parameter on PV capacity density will be used for the development of the case study on Can Tho and the calculation of solar dual-use potential (in capacity and electricity production mainly).

| Project / Location (Year of Installation) | Capacity (kWp) | Crops | Further Parameters |
|---|---|---|---|
| Germany, Heggelbach, (2015) | 194 | Agrivoltaic:<br>Clover, celery, potatoes, wheat (1st year) | 580 kWp/ha PV density, 5m elevation |
| Japan, Mega Solar Sharing No. 1 Plant, Shaoshi, Chiba Prefecture (2017) | 1,000 | Agrivoltaic:<br>Soy bean, barley | 313 kwp/ha PV density |
| Japan, Kazusatsurumai Solar Sharing Project, Chiba Prefecture (2011) | 34.8 | Agrivoltaic:<br>Pumpkin, peanuts, tomato, yams, taro, eggplant, cucumber, low fruit trees | 450 kWp/ha PV density 3m elevation |
| Japan, Awajishima Solar Farm (2015) | 87 | Agrivoltaic:<br>Onion, rice | 500-600 kWp/ha PV density, 3.5m elevation, 5m between columns |
| Japan, Tome town and Kami town, Miyagi (2017) | 1,800 / 2,200 | Agrivoltaic:<br>Black Fungus mushroom | 780/970 kWp/ha PV density, operated in ESCO model. |
| Japan, Oo Power Plant, Tsukuba, Ibaraki (2014) | 41 | Livestock:<br>Chicken, goats | 410 kWp/ha PV density, 3m elevation, 33% shading rate |
| China, Anhui, Jinzhai province (2016) | 544 | Agrivoltaic:<br>Rice, soy bean | 500 kWp/ha PV density, single axis trackers |
| South Korea, Chungbuk Ochang (2016) | 100 | Agrivoltaic:<br>Rice, cabbage, potato, ginseng, soy bean, garlic | 435 kWp/ha PV density |
| India, Gujarat Surat (2015) | 1,000 | Agrivoltaic:<br>Vegetables | 335 kWp/ha PV density |
| Italy, Monticelli (2011) | 3,230 | Agrivoltaic:<br>Rice, wheat, soy, maize/ corn | 190 kWp/ha PV density, single axis trackers |
| Croatia, Virovitica-Podravina (2016) | 500 | Agrivoltaic:<br>Vegetables | 860 kWp/ha PV density |
| France, La Réunion (2016) | 1,500 | Aquaculture:<br>Red Tilapia, Sturgeons | System combined with a 9 MWh battery storage system that also stabilizes the island grid. |
| | 7,500 | Agrivoltaic/Livestock:<br>Vegetables, livestock, bees | |
| France, Tresserre (2018) | 2,100 | Agrivoltaic:<br>Wine grapes | 420 kWp/ha PV density, tracked system |

**Table 9: Selected International Solar Dual-Use Projects with Key Parameters**

# CASE STUDY - FEASIBILITY AND POTENTIAL OF SOLAR PV DUAL-USE FOR CAN THO

The previous analysis of international experience and pilot and best practice projects has shown, that the solar dual-use approach would be applicable in Viet Nam in general for a variety of crops and aquaculture products. The following case study will apply this to a selected province in the Mekong Delta, the city of Can Tho with the aim to identify concrete potentials in regards to solar power capacity (in MW) and solar electricity (in MWh) that could be developed in the city area without land-use conflicts but with overall social-economic benefits for farmers and the province/city itself.

Can Tho was chosen for the case study since the city is a “hub” in the Mekong Delta in terms of agriculture and agricultural science (with Can Tho University as the most prominent research center in the whole region). Furthermore, albeit that Can Tho is not a large province with large agricultural areas, it does have a diversely structured agricultural sector that includes production sectors from aquaculture (fish and shrimp) to annual and perennial crops, fruits, vegetables and of course rice production in different technologies and applications (crop shift schemes).

With these framework conditions and the existence of strong institutions in the agricultural sector, the objective of this case study is also to subsequently develop a solar dual-use strategy for Can Tho or the Mekong Delta including pilot projects and further scientific research efforts.

## INTRODUCTION - CAN THO´S AGRICULTURAL SECTOR AND ENERGY SITUATION

Can Tho city is the central city of the Mekong Delta. The total population in 2015 was 1.25 million, of that 415.250 rural population, representing 33% of the total population, which is above the average of most other central cities in Viet Nam. Under these conditions, the rural area and agricultural production plays an important role in the overall socio-economic development of the city.

The agricultural land area of Can Tho occupies 80% of the land area of the city, mainly rice and perennial crops. The agricultural structure consists of three main sectors: agriculture, forestry and fishery with the largest production value coming from agriculture, which is 72.7%. 27% is aquaculture and the rest is forestry. In the agriculture sector, rice cultivation always occupies a large proportion, fluctuating around about 85% in the period 2010-2015. Apart from rice, Can Tho also cultivates fruit trees such as durian, mango and grapefruit. Further, a mix of annual vegetables is cultivated.

According to the Resolution No 45-NQ/TW of the Party Central Committee, term X, issued in 2005, the development objectives of Can Tho in the coming period are: “strive to build and develop Can Tho city into a national-level delta city of modern, green - clean - beautiful, worthy of being gateway city of the Lower Mekong River; to be a center of industry, trade - service center, tourism, education center and science-technology, medical and cultural centers; to be an important focal point for regional and international transportation.” Accordingly, the Can Tho City Party Central Committee has identified a program of building and developing high-tech agriculture as a focus, aiming to restructure the agricultural sector in the direction of enhancing added value and sustainable development, developing agricultural production and rural development to adapt to climate change and rising sea levels.

Along with the development of agriculture, the energy sector of Can Tho has also grown rapidly and made remarkable achievements. The rate of rural electrification is 100%, grid infrastructure ensuring the reliability and quality of electricity. The average annual growth rate of commercial electricity usage in 2011-2015 is 14% per year. Power supply to the city of Can Tho primarily comes from thermal power plants - renewable energy sources such as wind, solar and biomass have not been developed in the locality.

While Can Tho has not developed any solar power projects to date, the local solar power potential is substantial (as this case study will highlight) and the policy framework for solar power has been promulgated on the national level. The lack of large-scale renewable energy projects and a renewable energy development strategy in Can Tho can be explained mainly by its limited land resources, which currently are focusing on agricultural development. Thus, in Can Tho there is a land-use priority for agriculture that so far hindered the development of renewable energies in the city.

Along with the remarkable development of Can Tho in comparison with other provinces in the Mekong Delta, the impacts of climate change on this area becoming increasingly serious. The Mekong Delta is considered to be one of most vulnerable areas for climate change, due to salinity intrusion, drought and sea level rise causing significant loss of productive land. In this context, governments and communities are vigorously seeking solutions to reduce the impact of global warming, helping farmers secure livelihoods and their production.

Promoting the widespread use of renewable energy in agricultural production is therefore seen as a beneficial solution that not only brings clean & green electricity to agriculture, but also helps farmers to generate greater income from their land.

## FEASIBILITY AND POTENTIAL OF SOLAR DUAL-USE IN CAN THO: METHODOLOGY AND APPROACH

The assessment of solar dual-use potential for Can Tho will follow four methodological steps:

**01** The **identification of land area** in Can Tho for **crops that are suitable** for solar dual-use applications based on international experience and scientific research as discussed in above sections of the study.

**02** The definition of necessary **parameters to calculate the solar output** of solar dual-use systems, mainly the available solar resources (solar irradiation) and technical parameters on the performance of solar dual-use applications based on the international experience (primarily average solar PV density per ha and specific solar yield per capacity unit installed).

**03** The **actual calculation of solar dual-use potential** based on the above assumptions and parameters with the help of GIS mapping.[104] The calculation will be developed in different scenarios. One scenario with higher output (higher PV density and more shading) and one with lower output (lower PV density and less shading). One scenario includes rice production areas and one without. The calculations will be made for Can Tho and for the nine districts in Can Tho specifically.

**04** Finally, the **estimation of average costs** of electricity generated in solar dual-use systems with the help of an LCOE (Levelized Costs of Electricity) assessment. The calculated LCOE can then be compared with existing "benchmarks" such as the current FiT for ground-mounted PV systems in Viet Nam.

104 A geographic information system (GIS) is a system designed to capture, analyze, and present spatial or geographic data. GIS applications are tools that allow users among others to edit data in maps, and present the results of all these operations in a graphic and comprehensible way.

In a subsequent section, the results of the potential assessment will be discussed and concluded.

### DETERMINATION OF LAND AREA FOR CROPS SUITABLE FOR SOLAR DUAL-USE

Can Tho is divided into **nine districts** that display a variety of agricultural and aquacultural land-uses. Regarding the analysis of international experience above in this study, the following list of **crops suitable for dual-use application** can be identified in Can Tho:

- Rice
- Corn (Maize)
- Soybean
- Sesame
- Vegetables
- Starch roots (cassava, potatoes, etc.)
- Fish in ponds
- Shrimp
- Livestock (data only for whole Can Tho available, not for each district)

Table 10 shows the crops and aquacultural products with the respective land area (in ha) cultivated in the nine districts.

| | Potential by district in 2015 (MW) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai |
| **Crops** | | | | | | | | | |
| Rice | 106 | 15,428 | 3,359 | 644 | 14,038 | 67,376 | 69,773 | 10,146 | 57,080 |
| Corn | 8 | 40 | 93 | 3 | 37 | 22 | 190 | 420 | 241 |
| Soybean | 2 | 5 | 5 | - | 1 | 3 | 7 | - | 1 |
| Sesame | | 2,622 | - | - | 3,548 | 594 | 1,087 | 62 | 216 |
| Vegetables | 36 | 380 | 839 | 340 | 439 | 323 | 2,051 | 2,776 | 1,475 |
| Plants for stark root (e.g., potato, cassava…) | - | 16 | - | - | 7 | - | 4 | - | - |
| **Aquaculture** | | | | | | | | | |
| Fish in ponds | 7 | 274 | 229 | 108 | 416 | 229 | 429 | 471 | 379 |
| Shrimp | - | 2 | 29 | - | - | 25 | - | - | 4 |
| **Grassland for livestock** | - | - | - | - | - | - | - | - | - |

| | Potential by district in 2020 (MW) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai |
| **Crops** | | | | | | | | | |
| Rice | - | 12,400 | 2,000 | 500 | 11,900 | 56,050 | 60,500 | 8,800 | 52,950 |
| Corn | - | 100 | 200 | - | 150 | 100 | 500 | 500 | 450 |
| Soybean | - | 200 | 100 | - | 200 | 250 | 200 | - | 50 |
| Sesame | | 2,000 | - | - | 3,000 | 300 | 500 | - | 200 |
| Vegetables | - | 600 | 550 | 550 | 1,000 | 800 | 2,450 | 2,300 | 1,750 |
| Plants for stark root (e.g., potato, cassava…) | - | - | - | - | - | - | - | - | - |
| **Aquaculture** | | | | | | | | | |
| Fish in ponds | - | 395 | 489 | 92 | 470 | 489 | 331 | 512 | 430 |
| Shrimp | - | - | 40 | - | - | 40 | 10 | 5 | 10 |
| **Grassland for livestock** | | | | | | | 19 | | |

**Table 10: Land Area Cultivated for Crops (in ha) for the 9 Can Tho Districts (for 2015 and 2020)**
Source: Agriculture Development Plan for Can Tho until 2020, DARD Can Tho

Since **rice production** has a very high priority in Viet Nam and is a sensitive topic when it comes to land-use changes, this will be treated with as a special focus within the case study. In particular, the scenarios developed for the calculation of solar dual-use potential will be distinguished in scenarios including and excluding rice production areas. This is further justified with the still limited international experience with rice in dual-use application.

Following this determination of land-use categories and suitable crops and their respective cultivation areas in Can Tho, the following maps show the land areas in two scenarios. The first map (Figure 9) shows all land area that is generally suitable for dual-use application, including the area with rice cultivation. The second map shows all suitable areas without rice cultivation area, thus only including the other crops and aquacultural production areas.

The Annex II of this report contains further maps of all nine districts of Can Tho showing the respective land use areas and categories of suitable crops and aquaculture products including the calculated technical potential for solar dual-use.

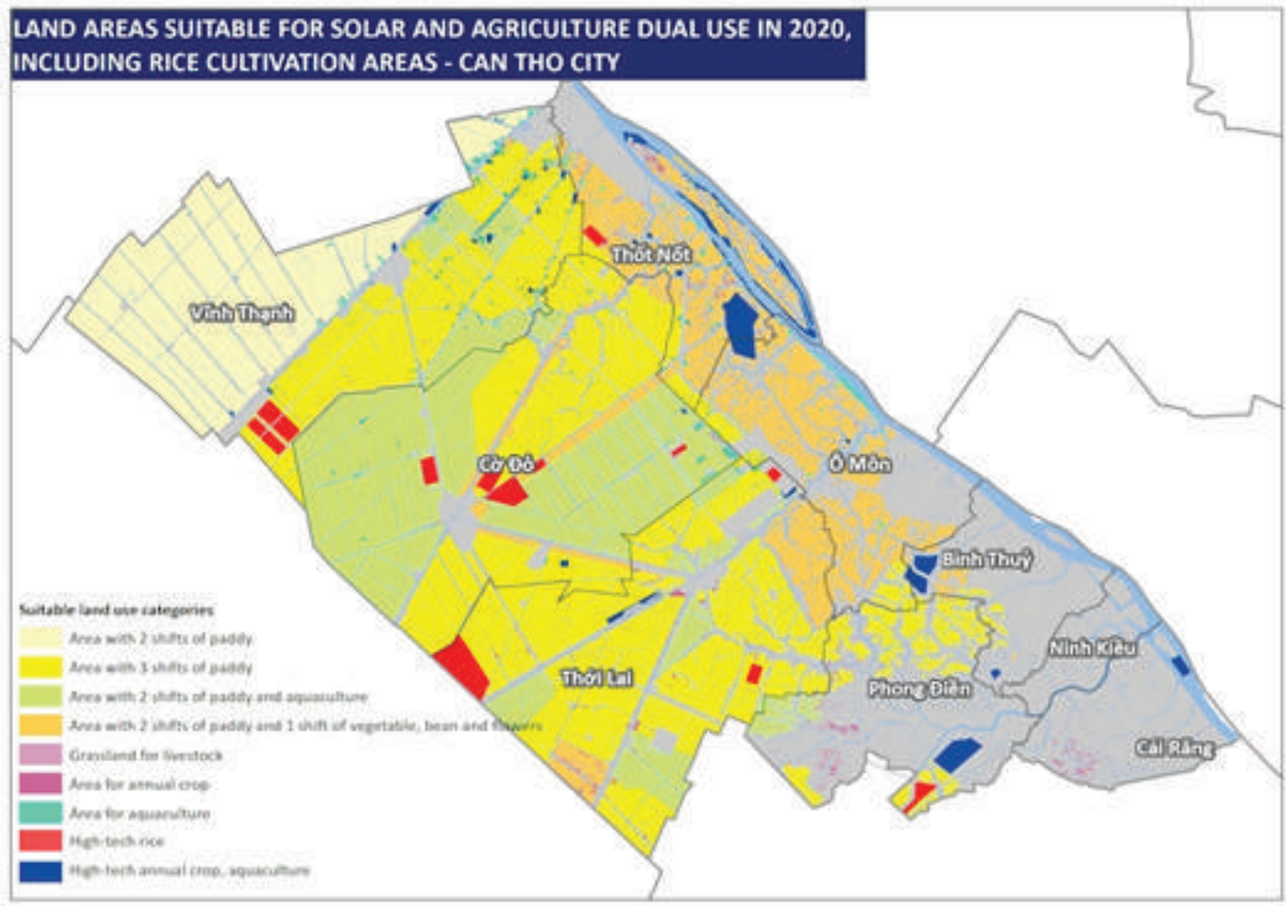



**Figure 9: Map of Land Areas Suitable for Solar Dual-Use (Incl. Rice)**

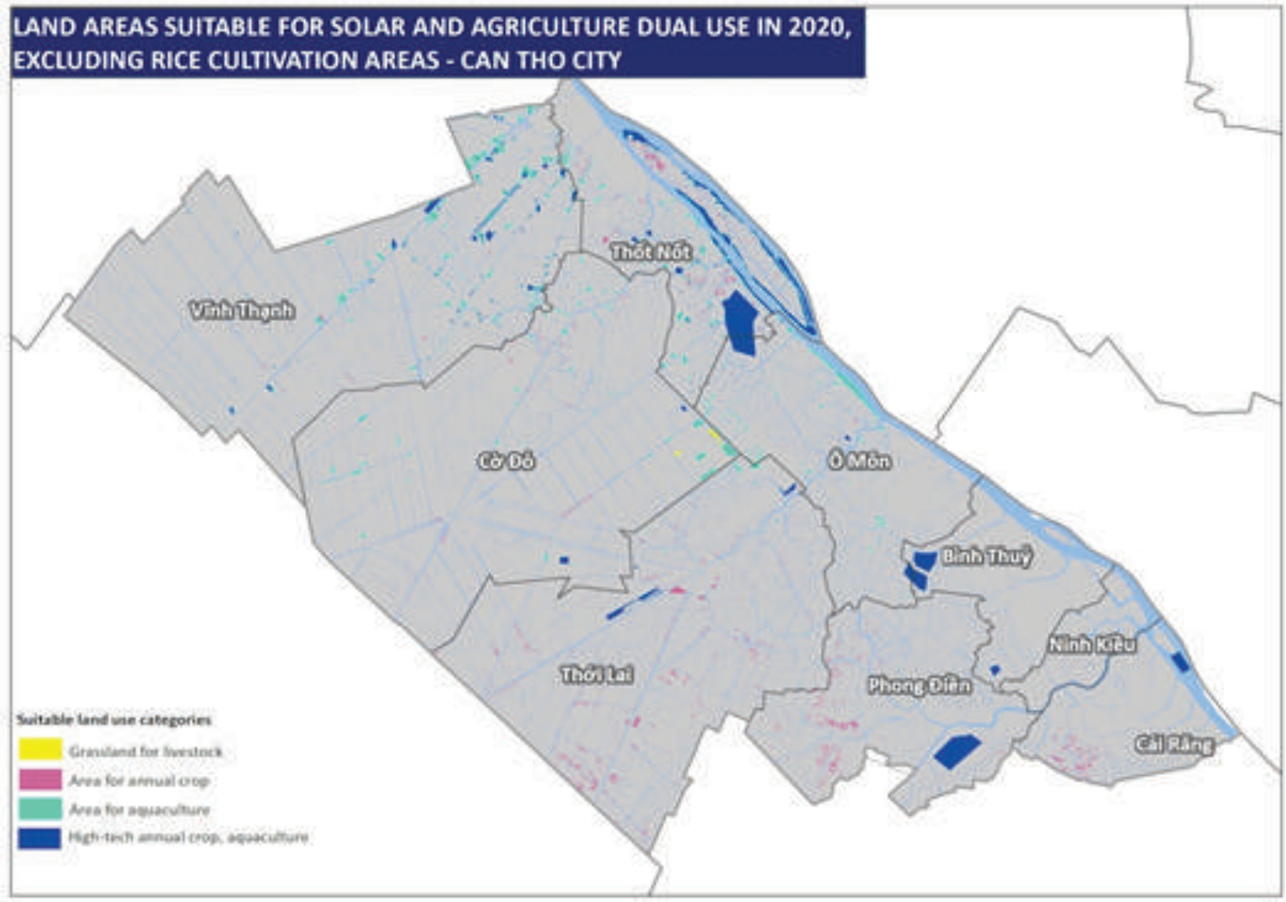



**Figure 10: Map of Land Areas Suitable for Solar Dual-Use (Excl. Rice)**

## DETERMINATION OF OUTPUT PARAMETERS FOR SOLAR DUAL-USE SYSTEMS IN CAN THO

After identifying the land area of generally suitable crops and aquaculture products for solar dual-use in Can Tho, the specific solar output of dual-use applications needs to be determined.

Firstly, the solar resources can be defined for Can Tho based on available solar irradiation data. Figure 9 shows the map of Global Horizontal Irradiation (GHI) zones in Can Tho, ranging from **4.64 to 4.7 kWh/m²/day**. The overall variance of irradiation is rather small which can be explained with the relatively small land area of Can Tho in general.

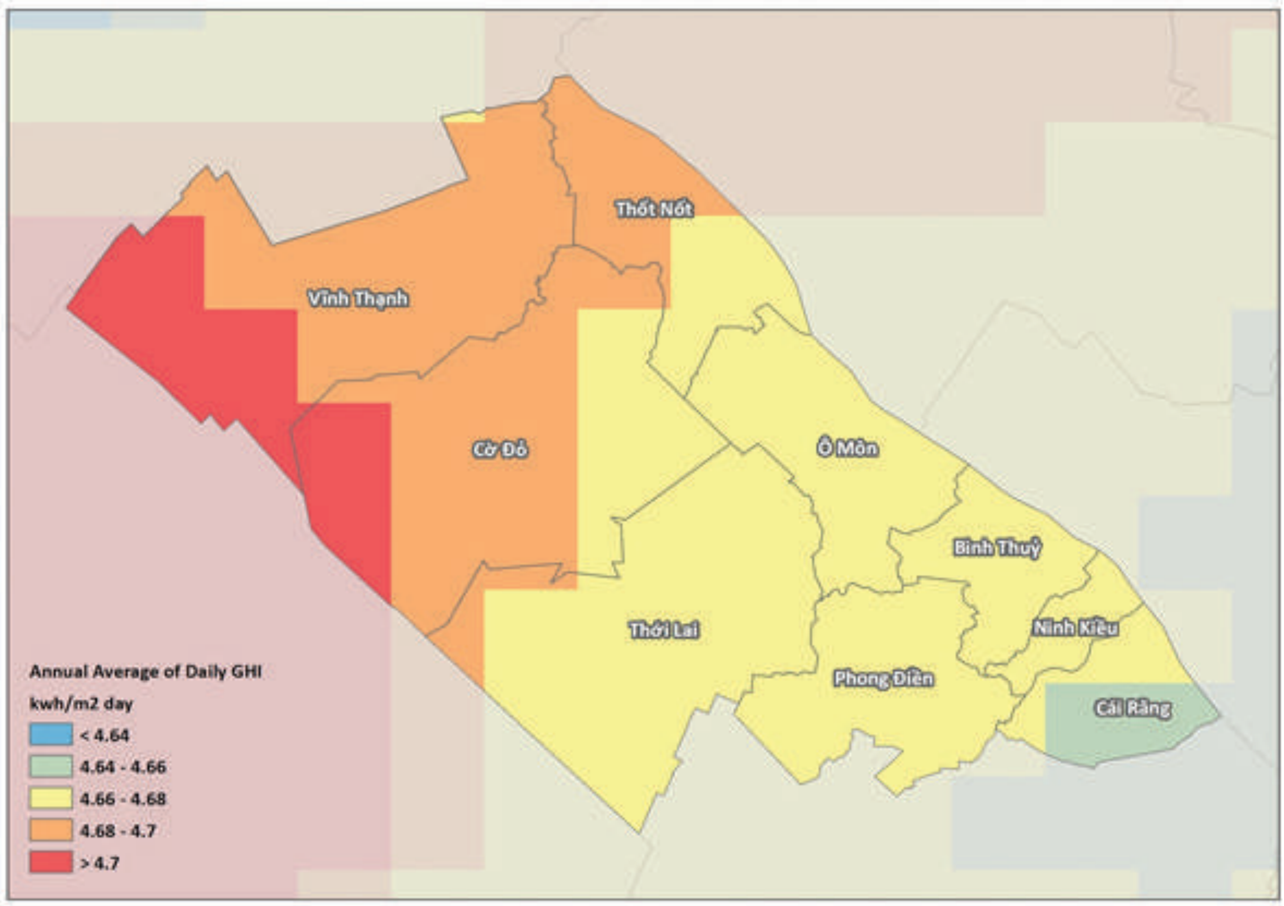



**Figure 11: Solar Radiation Map of Can Tho (Average Daily GHI in kWh/m2)**

Secondly, the **density of solar PV capacity per ha** will be defined. For the calculation of solar electricity outputs this study will follow a simplified approach and define a high scenario with more PV capacity per land area and thus, more shading, and a low scenario with lower PV density and thus, less shading. Derived from the international best practice projects presented in previous sections, the parameters will be **0.5 MWp/ha for the high scenario** and **0.33 MWp/ha for the low scenario.**

For the later discussion of overall benefits and social-economic effects it can be noted that for the high scenario a loss in agricultural yield can be expected that cannot be assessed in detail for each of the different crops within the scope of this study. However, the international experience shows that these losses on the agricultural yield would be overcompensated by additional revenues from the electricity sales and power savings.

Finally, the **specific solar electricity yield** for dual-use applications in Can Tho is expected to be **1,400 kWh per kWp installed capacity.** This assumption has been validated with the internationally acknowledged NREL tool RE Data Explorer. [105]

[105] See www.re-explorer.org

| | High Scenario | Low Scenario |
|---|---|---|
| PV Density | 0.5 MWp/ha | 0.33 MWp/ha |
| Specific Solar Yield | 1,400 kWh/kWp | |

**Table 11: Key Output Parameter for Solar Dual-Use Applications in Can Tho**

## SOLAR DUAL-USE POTENTIAL ASSESSMENT FOR CAN THO

With all key parameters determined, the solar dual-use potential for Can Tho can be calculated. This potential is thus a **technical potential**. That means the potential amount of power capacity (in MWp) or the amount of solar PV electricity (in MWh) that could be generated with solar PV dual-use systems that cover the identified land area with suitable crop cultivation. Since this land area has already been marked and identified for agricultural use, there is no need to further consider exclusion areas for the calculation such as roads, areas with too steep slopes to build the PV system, etc.

With the above considerations on rice cultivation on the one hand and different assumptions on PV density on the other hand four scenarios will be developed and calculated. Land-use data from the agricultural planning in Can Tho is available for 2015 and for 2020 (short-term plan). Since the potential estimation should look into the future and project opportunities for Can Tho for the upcoming years, the scenarios will be calculated for the 2020 perspective.

| Scenarios (land-use) | Scenarios on Power Density | |
|---|---|---|
| | Low (0.33MWp/ha) | High (0.5MWp/ha) |
| Without rice | 1 | 2 |
| Including rice | 3 | 4 |

**Table 12: Scenarios for Solar Dual-Use Potential in Can Tho**

The following maps show the result of the GIS-based potential calculation for the four different scenarios (displayed in solar PV capacity in MWp).

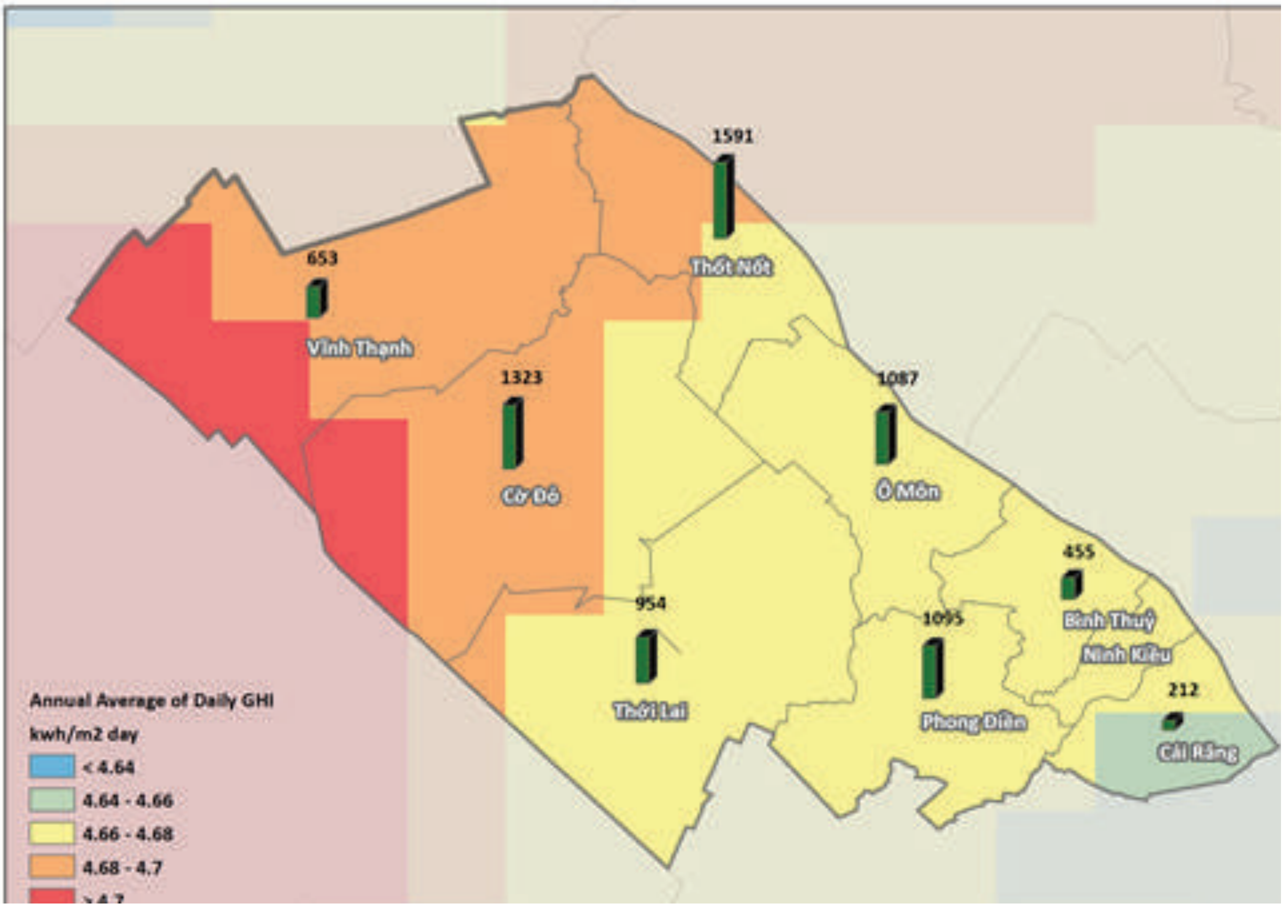



**Figure 11: Solar Dual-Use Potential for Can Tho - Scenario 1 (Low / Rice Excluded)**

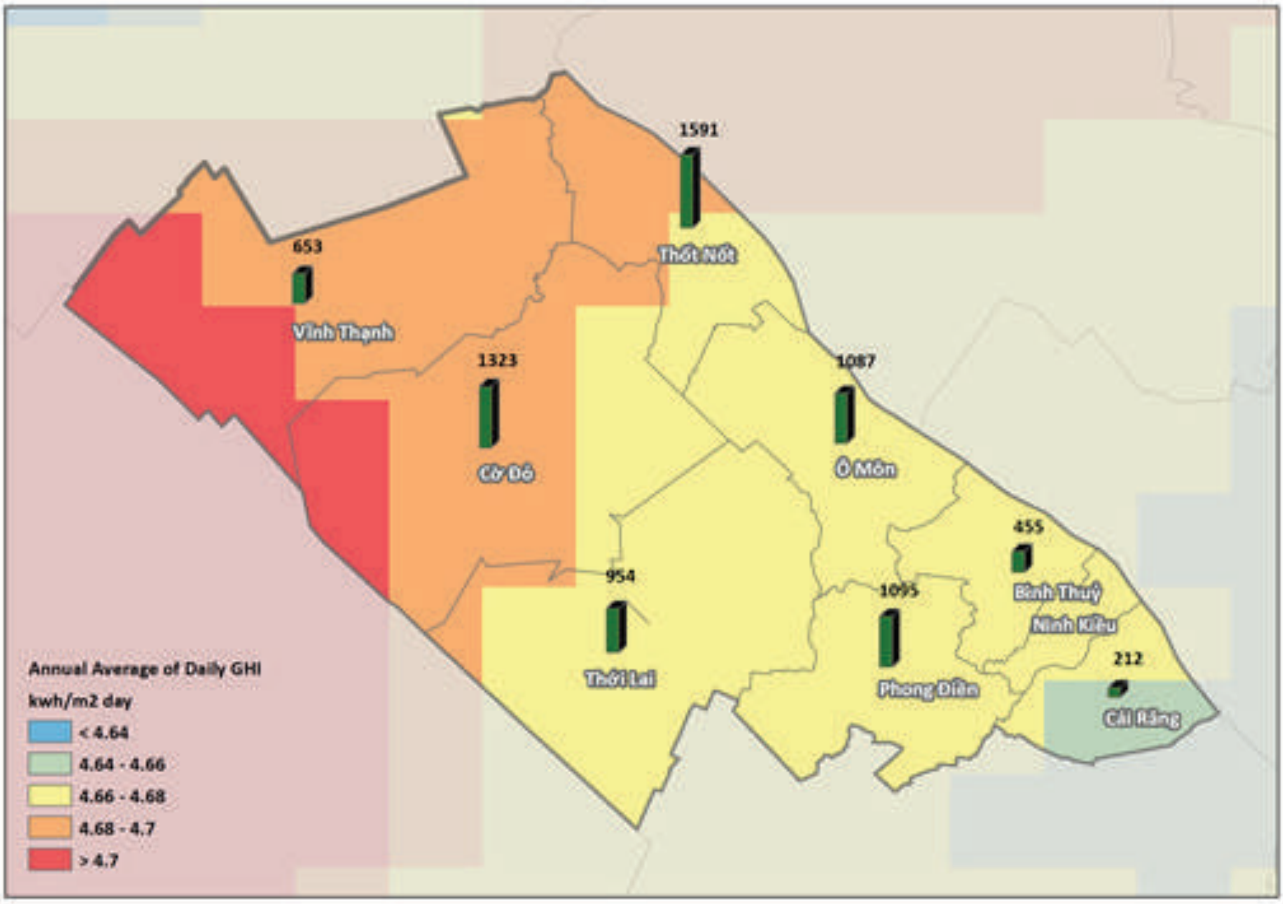



**Figure 12: Solar Dual-Use Potential for Can Tho - Scenario 2 (High / Rice Excluded)**

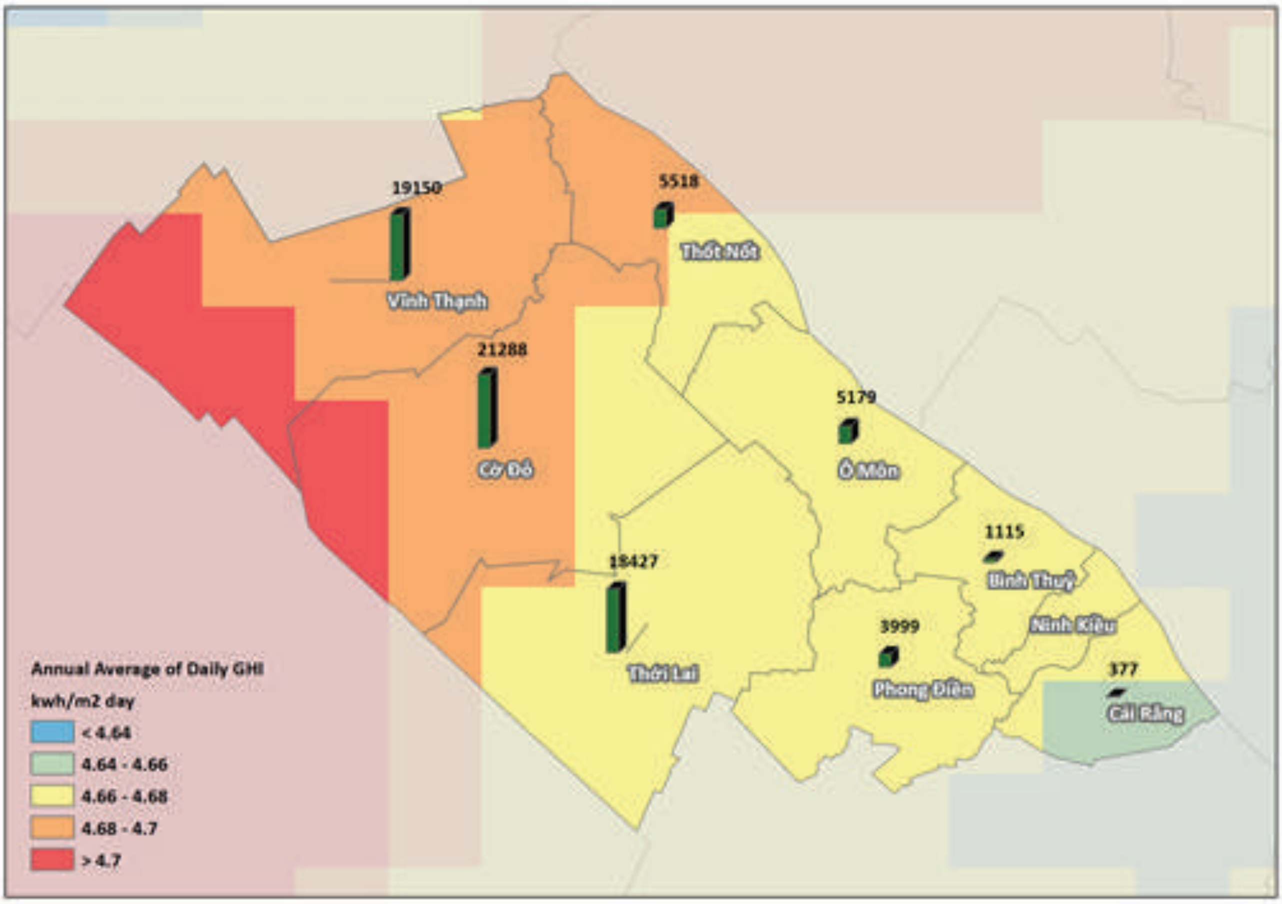



**Figure 13: Solar Dual-Use Potential for Can Tho - Scenario 3 (Low / Rice Included)**

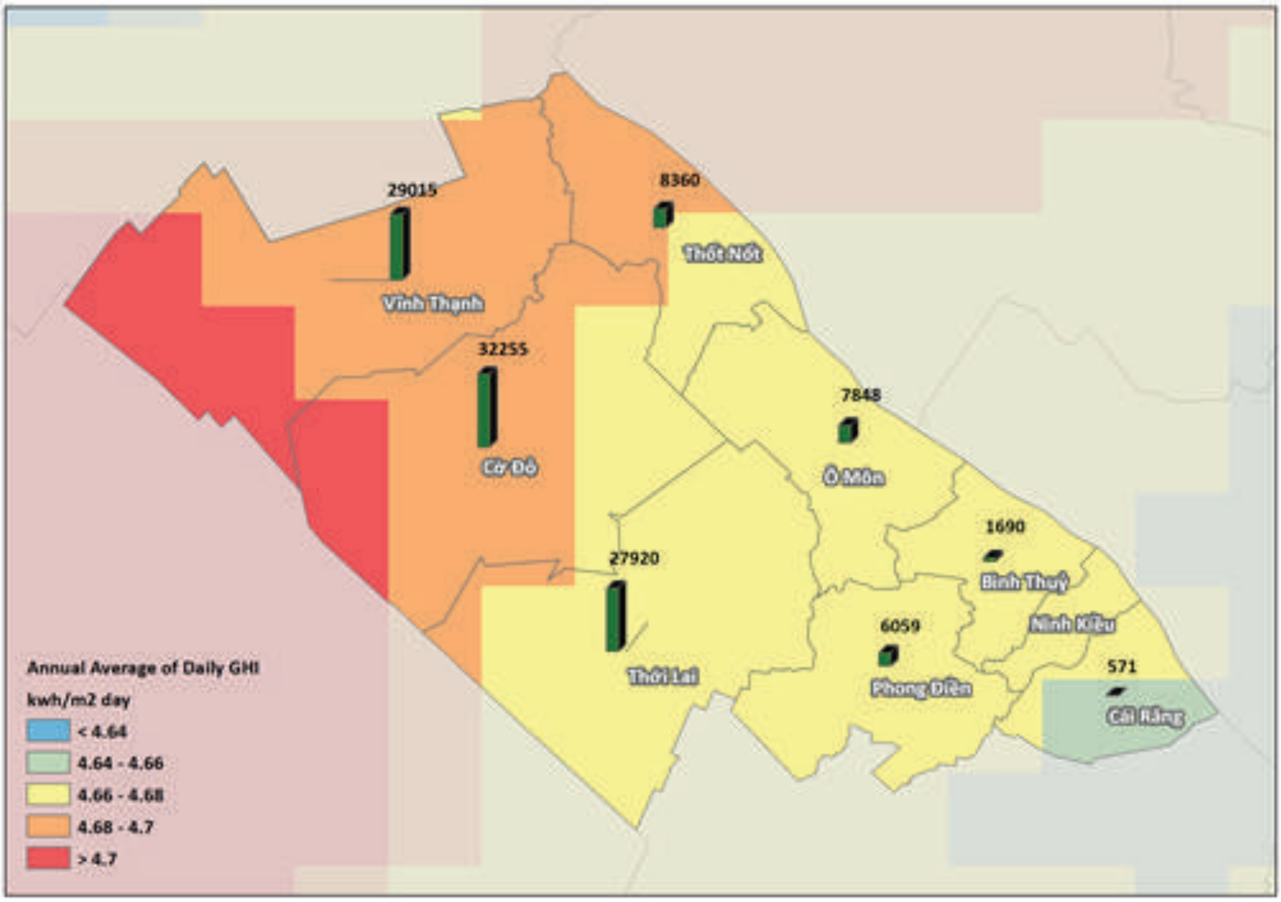



**Figure 14: Solar Dual-Use Potential for Can Tho - Scenario 4 (High / Rice Included)**

## OVERVIEW OF TECHNICAL POTENTIAL CALCULATION RESULTS FOR CAN THO

The following tables summarize the results of the technical potential calculation for all four scenarios for the land-use data for 2020. Table 13 is summarizing the results for capacity potential (in MWp). Table 14 is summarizing the results for solar electricity potential (in MWh).

| Scenarios (land-use) | Scenarios on Power Density | |
|---|---|---|
| | **Low** (0.33MWp/ha) | **High** (0.5MWp/ha) |
| Without rice | 7,363 | 11,157 |
| Including rice | 75,046 | 113,707 |
| In which from aquaculture | 1,093 | 1,657 |

**Table 13: Technical Potential for Solar Dual-Use in Can Tho (in Capacity, MWp)**

| Scenarios (land-use) | Scenarios on Power Density | |
|---|---|---|
| | **Low** (0.33MWp/ha) | **High** (0.5MWp/ha) |
| Without rice | 10,308,606 | 15,619,100 |
| Including rice | 105,064,806 | 159,189,100 |
| In which from aquaculture | 1,530,606 | 2,319,100 |

**Table 14: Technical Potential for Solar Dual-Use in Can Tho (in Electricity, MWh)**

The results indicate a **vast potential for solar PV in dual-use / agrivoltaic application for Can Tho** that exceeds the electricity demand of the city and surrounding districts by far. To put this in perspective - Can Tho's **electricity demand in 2017 was 2,211,200 MWh** (2.2 billion kWh). The full use of the dual-use potential of the non-rice agricultural and aquacultural areas in Can Tho alone would already have the **potential to generate more than 4-times the electricity demand** of the city.

However, this technical potential is **unlikely to be developed to its full scope** and also **not in the foreseeable future.** Therefore, the idea of a **"realistic potential"** is introduced. This would be the more realistically realizable technical potential in a short and medium-term perspective, meaning within the next 5-8 years (including a first phase of pilot projects and detailed scientific monitoring and evaluation of different dual-use applications and crop tests for at least 2 years).

This "realistic" technical potential could also be seen as the **"low-hanging fruits"** of this new technology and application. Dual-use crops and applications that immediately present as very suitable (meaning that they do not show any losses in agricultural yield with additional shading or even benefit from the shading) could find investors/interested farmers more easily and faster.

With this in mind, a realistic technical potential would assume that **only 10% of the overall technical potential** would be realizable in the short- and medium-term.

## OVERVIEW OF “REALISTIC” POTENTIAL CALCULATION RESULTS FOR CAN THO

The following tables are summarizing the results of the realistic potential calculation for all four scenarios for the land-use data for 2020. Table 15 and 16 is summarizing the results for capacity potential (in MWp) and solar electricity potential (in MWh) respectively.

| Scenarios (land-use) | Scenarios on Power Density | |
|---|---|---|
| | **Low**<br>(0.33MWp/ha) | **High**<br>(0.5MWp/ha) |
| Without rice | **736** | **1,116** |
| Including rice | **7,505** | **11,371** |
| In which from aquaculture | 109 | 166 |

**Table 15: “Realistic” Technical Potential for Solar Dual-Use in Can Tho (in Capacity, MWp)**

| Scenarios (land-use) | Scenarios on Power Density | |
|---|---|---|
| | **Low**<br>(0.33MWp/ha) | **High**<br>(0.5MWp/ha) |
| Without rice | **1,030,860** | **1,561,910** |
| Including rice | **10,506,480** | **15,918,910** |
| In which from aquaculture | 152,600 | 232,400 |

**Table 16: “Realistic” Technical Potential for Solar Dual-Use in Can Tho (in Electricity, MWh)**

The results show that **without rice** cultivation areas **between 700 and 1,100 MWp** and **including rice 7,500 to 11,300 MWp of solar dual-use potential could be realisti**c. To put this into perspective - the target for solar PV development in Viet Nam in the current power development planning of the government (PDP VII revised as of 2016) is 800 MWp until 2020; 4,000 MWp until 2025 and 12,000 MWp until 2030.

## ASSESSMENT OF ECONOMIC FEASIBILITY: LEVELIZED COSTS OF SOLAR DUAL-USE ELECTRICITY

As a final step the economic implications and feasibility of solar dual-use for Can Tho shall be analyzed. Detailed data on financial project parameter such as investment costs, financing conditions and operation and maintenance costs are hardly available for the existing international pilot and best practice projects. Therefore, this study draws on a detailed study of the German pilot project close to Lake Constance (see project description further above). [106]

The study analyzed the detailed cost structure of the German pilot project including capital expenditures for the system installation (CAPEX) as well as operational costs (OPEX). In essence the German experience suggests that costs for the mounting system (in the German case the PV modules were fixed on a 5m elevated system) where 109% higher than comparable mounting system costs of a conventional ground-mounted PV system. Further cost reducing factors (e.g. no fencing required) and increasing factors (e.g. higher labor and planning costs) were identified. In total, the study concluded that the **overall CAPEX** were **around 30% higher** compared to a conventional PV system.

For operation and maintenance also cost increasing (e.g. higher cleaning costs and more complex maintenance) and cost-decreasing factors (e.g. no land fees, no weed control) can be identified. In total, and especially for early market or pilot projects a **slight increase of OPEX of 10%** can be estimated.

With these assumptions and further input data (see table 17), the LCOE of a solar dual-use project in Can Tho can be calculated.

The **levelized cost of energy (LCOE)** is a measure that allows comparison of different methods of electricity generation on a consistent basis. It is an economic assessment of the average total costs to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime. The LCOE can also be regarded as the average minimum price at which electricity must be sold in order to break even over the lifetime of the project. It includes the investment costs, O&M costs, potential fuel expenditures (not relevant for solar) calculated over the lifetime of the project with a defined discount rate.

[106] Trommsdorff (2016)

| LCOE Calculation Parameter | Assumption |
|---|---|
| **Project Lifetime** | 20 years |
| **Installed Capacity** | 1,000 kWp |
| **Specific Energy Yield** | 1,400 kWh/kWp |
| **Degradation of Power Output** | 0.5% per year |
| **PV Density** | 0.33 MWp/ha |
| **Specific Investment Costs** | 1,100 USD/kWp (+30%) |
| **Operation & Maintenance Costs** | 9.64 USD/kWp/y (+10%) |
| **Inverter Replacement at Year** | 11 |
| **Insurance** | 5 USD/kWp/y |
| **Discount Rate** | 8% per year |

**Table 17: Parameters for LCOE Calculation of Solar Dual-Use System**

Table 17 shows the main parameters used for the calculation of potential solar dual-use LCOE in Can Tho. Most importantly, the specific investment costs were based on current market price assumptions for medium and large-scale solar PV systems in Vietnam (base case assumption: **850 USD/kWp** for PV systems of >1 MWp) increased by the dual-use (elevated mounting system) factor of **+30%**. The **O&M costs** are based on data from a real case in Thailand increased by **+10%** for a base case dual-use scenario.

The **discount rate** in the LCOE calculation is often based on the **opportunity costs of capital** (what would be the return on the best available alternative investment?) or the cost of capital. The costs of domestic bank loans (interest rates) are currently around 9-10% at the moment for domestic bank loans. However, in the case of the new solar dual-use application it can be assumed, that at the beginning of the market development a) expectations for the return on investment or the opportunity costs would be lower compared to fully commercial investments and b) some kind of public support, soft loans or other instruments risk-reduction would apply. Thus, a slightly lower discount rate of 8% could be applied.

The results of the LCOE calculation are shown in the table 18. The calculation is carried out in three scenarios, assuming that there will be a range of technical applications and thus, a variety of system costs in an early market stage. In a low cost scenario, investment costs might only be 20% above conventional systems, in a high cost scenario even more than the assumed base case (40%). The same applies to O&M costs that could differ.

[107] This investment cost assumption is based on a recent market analysis of an international consultant team in the context of a MoIT/EU/GIZ consultation project on the revision of the solar FIT (PM Decision 11/2011). The consultant team estimated the investment costs of ground-mounted solar PV systems in Viet Nam for the fourth quarter of 2018 in a range of 718-790 USD/kWp. With a conservative approach, the assumption of 850 USD/kWp is chosen in this study here as a base for the calculation of dual-use (plus an additional 30% for the higher costs for the elevated mounting structure) See E3Analytics/IET, Study on the revision of the Feed-in-Tariff for Solar PV n Viet Nam. Presentation at the MoIT/EU/GIZ consultation workshop on Solar FIT Revision on 28.11.2018 in Hanoi.

| | Low Cost | Base Case | High Cost |
|---|---|---|---|
| **Costs** | +20% CAPEX / +0% OPEX | +30% CAPEX / +10% OPEX | +40% CAPEX / +20% OPEX |
| **LCOE** | 8.40 USct/kWh | 9.07 USct/kWh | 9.81 USct/kWh |

**Table 18: LCOE Scenarios for Solar Dual-Use Systems in Can Tho**

If this calculation is based on current cost parameters in the solar market (mainly costs of the key components PV modules and inverters), a **projection to the near future** can expect **substantial cost reductions**. These cost reductions will mainly be driven by the expected further decline in PV module costs. The International Renewable Energy Agency, IRENA, recently expected a further reduction of the global average solar LCOE of -40% by 2020.[108] Even if this would only partially materialize, it would have substantial impacts on the costs of solar dual-use applications in Viet Nam.

Further system cost reductions can be expected from **technological learning effects** over the first 5-8 years of market development (thus, efficiency gains in the development, construction and operation & maintenance of solar dual-use systems). With this in mind, a cautious projection of future LCOE for solar dual-use applications in Viet Nam could be made as following. Again, all these assumptions are made for larger solar dual-use systems of at least 1 MWp solar capacity.

| | Base Case (2018) | Projected 2020-2025 (-20% Costs) | Projected 2020-2025 (-30% Costs) |
|---|---|---|---|
| **LCOE** | 9.07 USct/kWh | 7.26 USct/kWh | 6.35 USct/kWh |

**Table 19: LCOE Scenarios for Solar Dual-Use Systems in Can Tho – Future Projection**

[108] IRENA (2018)

# **CONCLUSIONS - SOLAR DUAL-USE POTENTIAL FOR CAN THO AND VIET NAM**

The above potential calculations for solar dual-use applications in Can Tho have shown remarkable results. There is technical potential of solar dual-use for Can Tho that far exceeds the demand of the city. Even when reduced to a "realistic" short-term potential, solar dual-use applied in Can Tho could cover substantial shares of the electricity demand of the city and its districts. The main results of the potential calculation can be summarized as follows:

**01**

**Suitability** for solar dual-use (agrivoltaic) applications could be **identified for nine agricultural and aquaculture products** (rice, corn/maize, soybean, sesame, vegetables, cassava/starch roots, livestock, fish, shrimp).

**02**

Based on these crops an overall **"realistic" technical potential** (thus realizable within the next 5-8 years) could be calculated. Excluding rice production this potential is in the range of 7**00 to 1,100 MWp** equaling an **electricity potential of 1 to 1.5 TWh per year**. This solar electricity generation would be able to cover 46% to 70% of Can Tho's annual electricity demand.

**03**

Including dual-use application on rice production areas this "realistic" potential would increase to **7,500 to 11,300 MWp or 10.5 to 16 TWh per year.** This amount of clean electricity could potentially cover **475% to 700% of the city's electricity demand** and could thus contribute to the demand of the wider Mekong Delta region and further neighboring provinces.

**04**

Regarding the **costs of solar power from dual-use** applications, a cautious assessment was made based on assumptions derived from the limited available international data. According to this assessment, the solar dual-use **LCOE are estimated at 9.07 USct/kWh** in a base case perspective with **a range between 8.40 USct/kWh** (low cost case) **and 9.81 USct/kWh** (high cost case) and therefore **within the range of the current FiT** in Viet Nam (9.35 USct/kWh) and about **1.5 USct/kWh above the current avoided cost tariff** for Southern Viet Nam (7.48 USct/kWh).

Detailed implications of the **effects of solar dual-use applications on the agricultural production** in Can Tho could not be assessed within the scope of this study. However, the international experience and best practice indicates that the combined solar energy generation and food production on the same area of land significantly increases the overall productivity of the land-use.

Thus, it can be assumed that farmers and the city itself would be able to realize **multiple socio-economic benefits**:

01

Farmers would mainly benefit from **energy cost savings** (solar self-consumption), **additional revenues** from solar power sales to the grid or other offtakers, **improved marketing opportunities** and **competitiveness** (sustainable production/supply chain), potentially **improved agricultural practices** and finally, a **reduction of land-use conflicts** in form of investor pressure on their land.

02

The city and people of Can Tho (and with a wider view the Mekong region also) would mainly benefit from a **reduction of land-use conflicts, additional income of local farmers** with potentially **higher investments** and **tax revenues**, a **reduction of (peak) energy demand** and further benefits from decentralized power generation (less demand for transmission grid extension), a **reduction of hazardous local emissions** from conventional thermal power plants (such as coal), and the development of a more competitive **sustainable agricultural sector in general** (for domestic and export markets).

03

Furthermore, with the solar dual-use application Can Tho could contribute to the **reduction of CO2-emissions by up to 8-13 million tons** per year (in the "realistic" scenario including rice production areas).[109]

If the **potential calculation were to be transferred to Viet Nam** in total, the potential of solar dual use for the developed of clean and renewable energy production goes far beyond the current planning for conventional renewable energies. If only **applied to a few suitable crops** and production areas such as **corn/maize, cassava, sweet potato and aquaculture**, the solar dual-use potential could already substantially contribute to the national electricity demand:

---

[109] The assumption here is that each solar kilowatt-hour replaces one kilowatt-hour of the current electricity generation mix in Viet Nam. Based on the latest available CO2 load of the Vietnamese electricity mix, this saves 0.8154 tons of CO2 per MWh (see MoNRE 2015).

01

These four crops/production sectors combined occupy a **land area of 3.8 million ha**.[110] If the 'low scenario' of Can Tho applied (with low shading) and with an even more conservative assumption that **only 1% of this potential would actually be realized**, this would result in a **12.5 GW solar dual-use potential**. This capacity could generate roughly **16,000 GWh** (with an averaged solar yield for all Vietnamese regions). This would **cover 8% of the overall electricity demand** in Viet Nam in 2017 (IoE 2018).

02

The same calculation for a **scenario only on rice** cultivation areas (7.7 million ha for Viet Nam in 2017) and again assuming that only 1% of the technical potential would actually be realized, a solar electricity potential of **32,000 GWh** would appear to equal more than **15% of today's electricity demand.** Combining all these agricultural areas together, this could generate enough electricity to cover **25% of current electricity demand** in Viet Nam and this **without substantial losses in agricultural production.**

However, a critical reflection has to be made regarding **available grid capacities** in Can Tho and the whole country. It seems feasible to integrate the 700 to 1,000 MWp of distributed solar dual-use capacity potential in the low scenario over a number of years of development. But any substantial deployment of larger amounts of solar power capacities would have to cautiously consider available grid capacity and the development and expansion of the power grid in the future.

A second critical reflection needs to be made regarding the **financing needs and capacities** in the local farming sector. A detailed analysis of the financial situation of farmers or the agricultural sector in Can Tho in general was not within the scope of this study. However, from the discussions with stakeholders in Can Tho during the development of this study it seems to be necessary to develop specific **financing concepts** that would aim at **mobilizing additional public** and **private sector investments** for the dual-use development. The average income situation of farmers does not seem to allow for larger investments in solar dual-use technology. There certainly are some potential of farmers or farming cooperatives that would be able to invest own funds into solar dual-use systems. But on average, additional funding seems necessary.

[110] Data for 2017, see www.gso.gov.vn

One perspective on this would be to consider third party investment models such as **Energy Service Company (ESCO)** models or **Direct Power Purchase Agreements (DPPA)** as a solution. In these models, an additional investor (a solar company, a clean tech investor, a specialized ESCO provider or a larger player from the food and beverage sector that aims at greening its supply chain) would come into the project and bring in at least a larger part of the necessary investment capital. This third party investor would then refinance the investment with a share of the additional revenues from the solar energy generation or from cost savings realized in the agricultural/aquacultural production. For this to happen, the regulatory framework needs to be further developed.[111]

# OUTLOOK - TOWARDS A DEVELOPMENT STRATEGY FOR SOLAR DUAL-USE IN VIET NAM

This study has highlighted the general feasibility and the related socio-economic benefits of a new approach in the development of renewable energy and agriculture – the combined production of clean energy and food on the same land area applying solar dual-use applications.

International experience shows that with the dramatically reduced costs for the solar PV technology and the growing number of agrivoltaic best practice projects and development of the dual-use application, this approach is a viable option for Viet Nam to avoid or reduce land-use conflicts related to the increased influx of solar energy investments and the pressure on land owners that comes with it.

[111] The framework for ESCO models is currently under discussion within the process of implementation oft he 3rd Viet Nam National Energy Efficiency Programme (VNEEP3). Regarding DPPA there is an ongoing process to develop a DPPA pilot scheme in cooperation of MoIT/ERAV and USAID.

To summarize, the following potential steps and activities could be included in a roadmap to develop solar dual-use in Can Tho, the Mekong Delta or Viet Nam in general:

First and foremost, it seems that a **Vietnamese solar dual-use pilot project** would need to be developed to test the assumptions made in this study and to verify the suitability of selected and potential crops in the local agro-ecological context. Such a pilot project would need close scientific monitoring especially from the agricultural perspective. The inclusion of local agricultural universities or research institutes as well as international experts and technology partners would be key for a successful pilot project. Furthermore, domestic and/or international funding would have to be mobilized.

To institutionalize the process of developing solar dual-use on the provincial or regional level, a **working group** or **steering committee** including **key stakeholders** from interested provinces, public authorities and agencies, farmer associations, research institutions etc. could be a first step to develop a strategy and action plan. Such an institution could also carry out **advocacy work** with the central government regarding necessary adjustments of the (national) regulatory framework, as well as **awareness raising among farmers** and other relevant stakeholders.

Part of a further analysis should be the **identification of potential further barriers** in the regulatory framework, in particular in land-use regulations that govern the change of land-use. This study could not identify any major obstacles but raises some open questions regarding the possibility to change the land-use of a certain area to 'dual-use'. The example of Japan demonstrates that there might be the need for an active regulation or permission to allow energy generation on agricultural land.

On the regulatory side, the **national regulation for solar energy** and the related FiT (in particular PM Decision 11/2017 and related MoIT Circular 16/2017) need to be opened for solar dual-use applications. This includes basically two aspects, the eligibility of dual-use applications for the support measures and secondly, the financial support necessary to trigger market development and pilot projects in the first place. **Existing barriers regarding land-use requirements** (the 1.2ha/MW quota) need to be **removed** for ground-mounted solar dual-use and solar dual-use applications. Furthermore, solar dual-use on covered shrimp ponds for example should explicitly be allowed under a rooftop definition ("building structure"). Secondly, it should be considered to **grant solar dual-use systems a FiT premium to motivate early mover investors**. This would be justified by the additional socio-economic benefits of solar dual-use.

Regarding the wider strategic planning and policy instruments of the Government, solar dual-use applications should be recognized and considered in the new Power Development Plan VIII, the Viet Nam Green Growth Strategy as well as in strategic sectoral or national targets for climate change (such as the NDC).

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# ANNEX I
# SCENARIOS FOR SOLAR DUAL-USE POTENTIAL IN CAN THO

Scenario 1 – Low PV Density (0.33kWp/ha) Excluding Rice

## 1. Calculation of capacity potential

| | Potential by district in 2015 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Crops** | | | | | | | | | | |
| - Rice | - | - | - | - | - | - | - | - | - | |
| - Corn | 3 | 13 | 31 | 1 | 12 | 7 | 63 | 139 | 80 | |
| - Soybean | 1 | 2 | 2 | - | 0 | 1 | 2 | - | 0 | |
| - Sesame | - | 865 | - | - | 1,171 | 196 | 359 | 20 | 71 | |
| - Vegetables | 12 | 125 | 277 | 112 | 145 | 107 | 677 | 916 | 487 | |
| - Plants for stark root (e.g., potato, cassava...) | - | 5 | - | - | 2 | - | 1 | - | - | |
| **Aquaculture** | - | - | - | - | - | - | - | - | - | |
| - Fish in ponds | 2 | 90 | 76 | 36 | 137 | 76 | 142 | 155 | 125 | |
| - Shrimp | - | 1 | 10 | - | - | 8 | - | - | 1 | |
| **Grassland for livestock** | - | - | - | - | - | - | - | - | - | |
| **Sum** | **17** | **1,102** | **394** | **149** | **1,468** | **395** | **1,243** | **1,231** | **764** | **6,763** |

Total potential (MWh)

| | Potential by district in 2020 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Crops** | | | | | | | | | | |
| - Rice | - | - | - | - | - | - | - | - | - | |
| - Corn | - | 33 | 66 | - | 50 | 33 | 165 | 165 | 149 | |
| - Soybean | - | 66 | 33 | - | 66 | 83 | 66 | - | 17 | |
| - Sesame | - | 660 | - | - | 990 | 99 | 165 | - | 66 | |
| - Vegetables | - | 198 | 182 | 182 | 330 | 264 | 809 | 759 | 578 | |
| - Plants for stark root (e.g., potato, cassava...) | - | - | - | - | - | - | - | - | - | |
| **Aquaculture** | - | - | - | - | - | - | - | - | - | |
| - Fish in ponds | - | 130 | 161 | 30 | 155 | 161 | 109 | 169 | 142 | |
| - Shrimp | - | - | 13 | - | - | 13 | 3 | 2 | 3 | |
| **Grassland for livestock** | - | - | - | - | - | - | 6 | - | - | |
| **Sum** | **-** | **1,087** | **455** | **212** | **1,591** | **653** | **1,323.4** | **1,095** | **954** | **7,370** |

Total potential (MWh)

## 2. Calculation of energy potential

| | Potential by district in 2015 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Sum** | **24,486** | **1,542,618** | **552,090** | **208,362** | **2,054,976** | **552,552** | **1,740,816** | **1,722,798** | **1,069,992** | **9,468,690** |

Total potential (MWh)

| | Potential by district in 2020 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Sum** | **-** | **1,522,290** | **637,098** | **296,604** | **2,226,840** | **914,298** | **1,852,763** | **1,532,454** | **1,335,180** | **10,317,527** |

Total potential (MWh)

Scenario 2 – High PV Density (0.5kWp/ha) Excluding Rice

## 1. Calculation of capacity potential

| | Potential by district in 2015 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Crops** | | | | | | | | | | |
| - Rice | - | - | - | - | - | - | - | - | - | |
| - Corn | 4 | 20 | 47 | 2 | 19 | 11 | 95 | 210 | 121 | |
| - Soybean | 1 | 3 | 3 | - | 1 | 2 | 4 | - | 1 | |
| - Sesame | - | 1,311 | - | - | 1,774 | 297 | 544 | 31 | 108 | |
| - Vegetables | 18 | 190 | 420 | 170 | 220 | 162 | 1,026 | 1,388 | 738 | |
| - Plants for stark root (e.g., potato, cassava...) | - | 8 | - | - | 4 | - | 2 | - | - | |
| **Aquaculture** | - | - | - | - | - | - | - | - | - | |
| - Fish in ponds | 4 | 137 | 115 | 54 | 208 | 115 | 215 | 236 | 190 | |
| - Shrimp | - | 1 | 15 | - | - | 13 | - | - | 2 | |
| **Grassland for livestock** | - | - | - | - | - | - | - | - | - | |
| **Sum** | **27** | **1,670** | **598** | **226** | **2,224** | **598** | **1,884** | **1,865** | **1,158** | **10,248** |

Total potential (MWh)

| | Potential by district in 2020 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Crops** | | | | | | | | | | |
| - Rice | - | - | - | - | - | - | - | - | - | |
| - Corn | - | 50 | 100 | - | 75 | 50 | 250 | 250 | 225 | |
| - Soybean | - | 100 | 50 | - | 100 | 125 | 100 | - | 25 | |
| - Sesame | - | 1,000 | - | - | 1,500 | 150 | 250 | - | 100 | |
| - Vegetables | - | 300 | 275 | 275 | 500 | 400 | 1,225 | 1,150 | 875 | |
| - Plants for stark root (e.g., potato, cassava...) | - | - | - | - | - | - | - | - | - | |
| **Aquaculture** | - | - | - | - | - | - | - | - | - | |
| - Fish in ponds | - | 198 | 245 | 46 | 235 | 245 | 166 | 256 | 215 | |
| - Shrimp | - | - | 20 | - | - | 20 | 5 | 3 | 5 | |
| **Grassland for livestock** | - | - | - | - | - | - | 10 | - | - | |
| **Sum** | **-** | **1,648** | **690** | **321** | **2,410** | **990** | **2,005** | **1,659** | **1,445** | **11,166** |

Total potential (MWh)

## 2. Calculation of energy potential

| | Potential by district in 2015 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Sum** | **37,100** | **2,337,300** | **836,500** | **315,700** | **3,113,600** | **837,200** | **2,637,600** | **2,610,300** | **1,621,200** | **14,346,500** |

Total potential (MWh)

| | Potential by district in 2020 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Sum** | **-** | **2,306,500** | **965,300** | **449,400** | **3,374,000** | **1,385,300** | **2,807,217** | **2,321,900** | **2,023,000** | **15,632,617** |

Total potential (MWh)

Scenario 3 – Low PV Density (0.33kWp/ha) Including Rice

## 1. Calculation of capacity potential

| | Potential by district in 2015 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Crops** | | | | | | | | | | |
| - Rice | 35 | 5,091 | 1,108 | 213 | 4,633 | 22,234 | 23,025 | 3,348 | 18,836 | |
| - Corn | 3 | 13 | 31 | 1 | 12 | 7 | 63 | 139 | 80 | |
| - Soybean | 1 | 2 | 2 | - | 0 | 1 | 2 | - | 0 | |
| - Sesame | - | 865 | - | - | 1,171 | 196 | 359 | 20 | 71 | |
| - Vegetables | 12 | 125 | 277 | 112 | 145 | 107 | 677 | 916 | 487 | |
| - Plants for stark root (e.g., potato, cassava...) | - | 5 | - | - | 2 | - | 1 | - | - | |
| **Aquaculture** | - | - | - | - | - | - | - | - | - | |
| - Fish in ponds | 2 | 90 | 76 | 36 | 137 | 76 | 142 | 155 | 125 | |
| - Shrimp | - | 1 | 10 | - | - | 8 | - | - | 1 | |
| **Grassland for livestock** | - | - | - | - | - | - | - | - | - | |
| **Sum** | **52** | **6,193** | **1,503** | **361** | **6,100** | **22,629** | **24,269** | **4,579** | **19,601** | **85,287** |

Total potential (MWh)

| | Potential by district in 2020 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Crops** | | | | | | | | | | |
| - Rice | - | 4,092 | 660 | 165 | 3,927 | 18,497 | 19,965 | 2,904 | 17,474 | |
| - Corn | - | 33 | 66 | - | 50 | 33 | 165 | 165 | 149 | |
| - Soybean | - | 66 | 33 | - | 66 | 83 | 66 | - | 17 | |
| - Sesame | - | 660 | - | - | 990 | 99 | 165 | - | 66 | |
| - Vegetables | - | 198 | 182 | 182 | 330 | 264 | 809 | 759 | 578 | |
| - Plants for stark root (e.g., potato, cassava...) | - | - | - | - | - | - | - | - | - | |
| **Aquaculture** | - | - | - | - | - | - | - | - | - | |
| - Fish in ponds | - | 130 | 161 | 30 | 155 | 161 | 109 | 169 | 142 | |
| - Shrimp | - | - | 13 | - | - | 13 | 3 | 2 | 3 | |
| **Grassland for livestock** | - | - | - | - | - | - | 6 | - | - | |
| **Sum** | **-** | **5,179** | **1,115** | **377** | **5,518** | **19,150** | **21,288** | **3,999** | **18,427** | **75,053** |

Total potential (MWh)

## 2. Calculation of energy potential

| | Potential by district in 2015 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Sum** | **73,458** | **8,670,354** | **2,103,948** | **505,890** | **8,540,532** | **31,680,264** | **33,975,942** | **6,410,250** | **27,440,952** | **119,401,590** |

Total potential (MWh)

| | Potential by district in 2020 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Sum** | **-** | **7,251,090** | **1,561,098** | **527,604** | **7,724,640** | **26,809,398** | **29,803,763** | **5,598,054** | **25,798,080** | **105,073,727** |

Total potential (MWh)

Scenario 4 – High PV Density (0.5kWp/ha) Including Rice

## 1. Calculation of capacity potential

| | Potential by district in 2015 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Crops** | | | | | | | | | | |
| - Rice | 53 | 7,714 | 1,680 | 322 | 7,019 | 33,688 | 34,887 | 5,073 | 28,540 | |
| - Corn | 4 | 20 | 47 | 2 | 19 | 11 | 95 | 210 | 121 | |
| - Soybean | 1 | 3 | 3 | - | 1 | 2 | 4 | - | 1 | |
| - Sesame | - | 1,311 | - | - | 1,774 | 297 | 544 | 31 | 108 | |
| - Vegetables | 18 | 190 | 420 | 170 | 220 | 162 | 1,026 | 1,388 | 738 | |
| - Plants for stark root (e.g., potato, cassava...) | - | 8 | - | - | 4 | - | 2 | - | - | |
| **Aquaculture** | - | - | - | - | - | - | - | - | - | |
| - Fish in ponds | 4 | 137 | 115 | 54 | 208 | 115 | 215 | 236 | 190 | |
| - Shrimp | - | 1 | 15 | - | - | 13 | - | - | 2 | |
| **Grassland for livestock** | - | - | - | - | - | - | - | - | - | |
| **Sum** | **80** | **9,384** | **2,277** | **548** | **9,243** | **34,286** | **36,771** | **6,938** | **29,698** | **129,223** |

Total potential (MWh)

| | Potential by district in 2020 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Crops** | | | | | | | | | | |
| - Rice | - | 6,200 | 1,000 | 250 | 5,950 | 28,025 | 30,250 | 4,400 | 26,475 | |
| - Corn | - | 50 | 100 | - | 75 | 50 | 250 | 250 | 225 | |
| - Soybean | - | 100 | 50 | - | 100 | 125 | 100 | - | 25 | |
| - Sesame | - | 1,000 | - | - | 1,500 | 150 | 250 | - | 100 | |
| - Vegetables | - | 300 | 275 | 275 | 500 | 400 | 1,225 | 1,150 | 875 | |
| - Plants for stark root (e.g., potato, cassava...) | - | - | - | - | - | - | - | - | - | |
| **Aquaculture** | - | - | - | - | - | - | - | - | - | |
| - Fish in ponds | - | 198 | 245 | 46 | 235 | 245 | 166 | 256 | 215 | |
| - Shrimp | - | - | 20 | - | - | 20 | 5 | 3 | 5 | |
| **Grassland for livestock** | - | - | - | - | - | - | 10 | - | - | |
| **Sum** | **-** | **7,848** | **1,690** | **571** | **8,360** | **29,015** | **32,255** | **6,059** | **27,920** | **113,716** |

Total potential (MWh)

## 2. Calculation of energy potential

| | Potential by district in 2015 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Sum** | **111,300** | **13,136,900** | **3,187,800** | **766,500** | **12,940,200** | **48,000,400** | **51,478,700** | **9,712,500** | **41,577,200** | **180,911,500** |

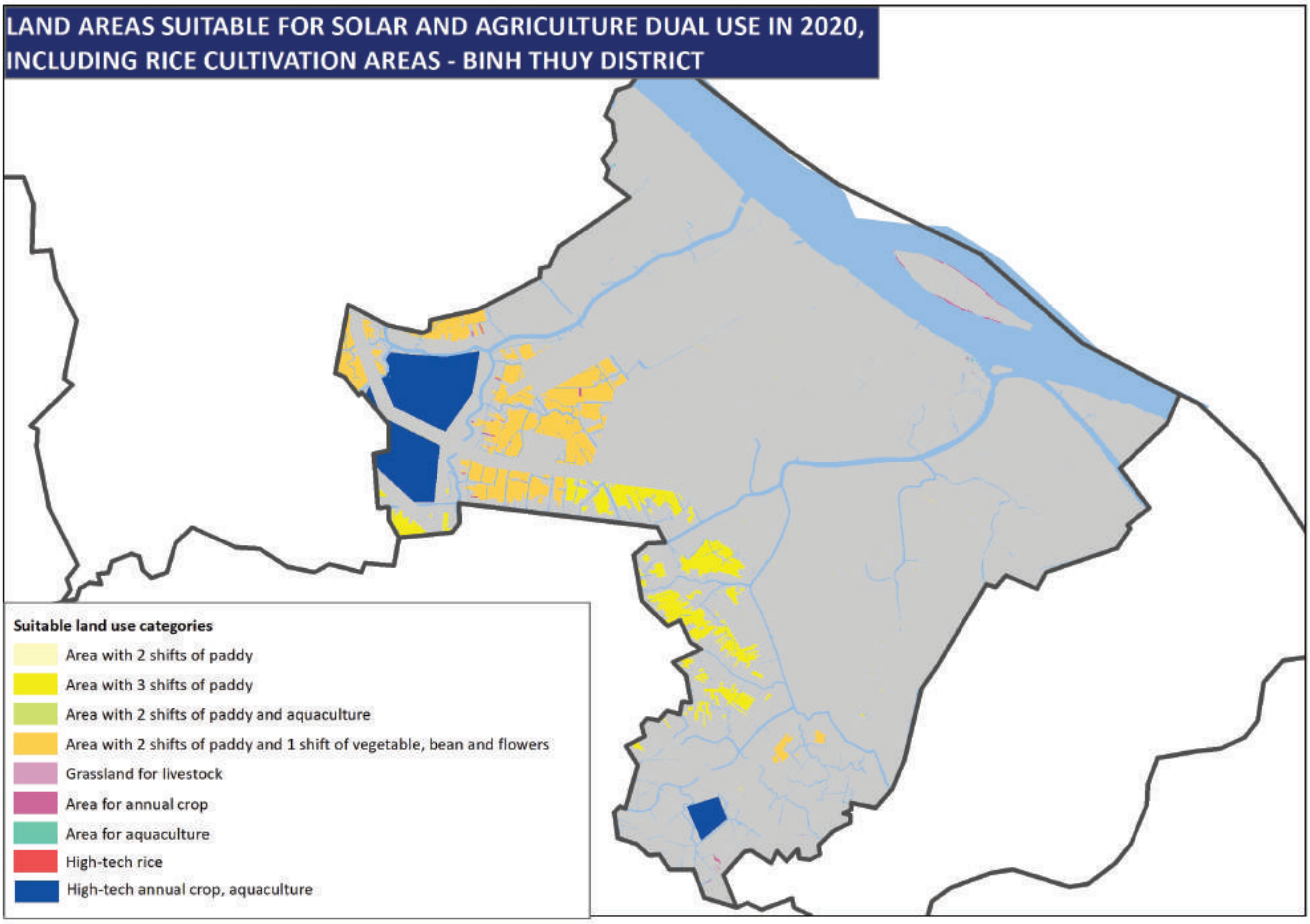
Total potential (MWh)

| | Potential by district in 2020 (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ninh Kieu | O Mon | Binh Thuy | Cai Rang | Thot Not | Vinh Thanh | Co Do | Phong Dien | Thoi Lai | |
| **Sum** | **-** | **10,986,500** | **2,365,300** | **799,400** | **11,704,000** | **40,620,300** | **45,157,217** | **8,481,900** | **39,088,000** | **159,202,617** |

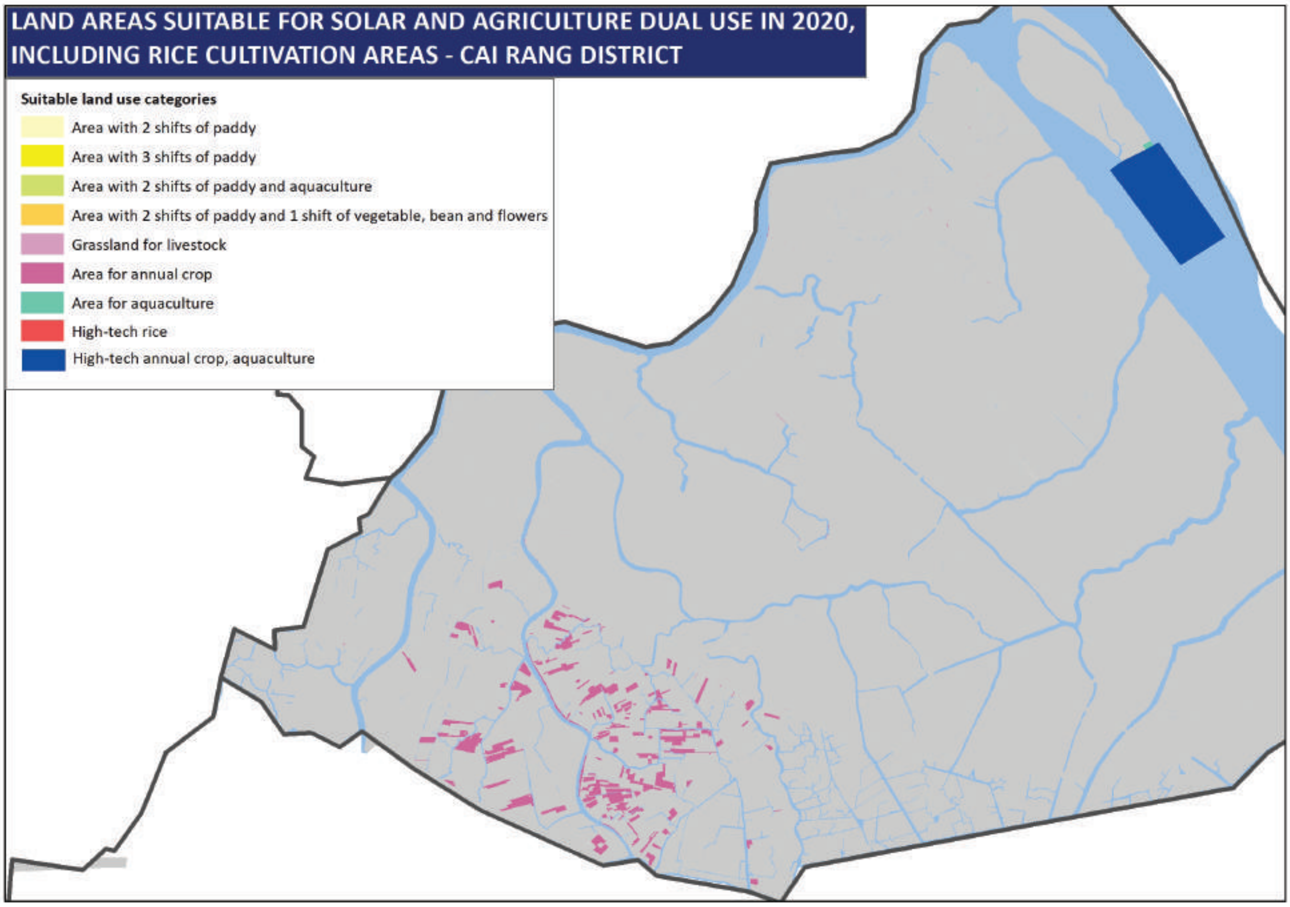
Total potential (MWh)

# ANNEX II
# SUITABLE DUAL-USE LAND AREAS PER DISTRICT IN CAN THO

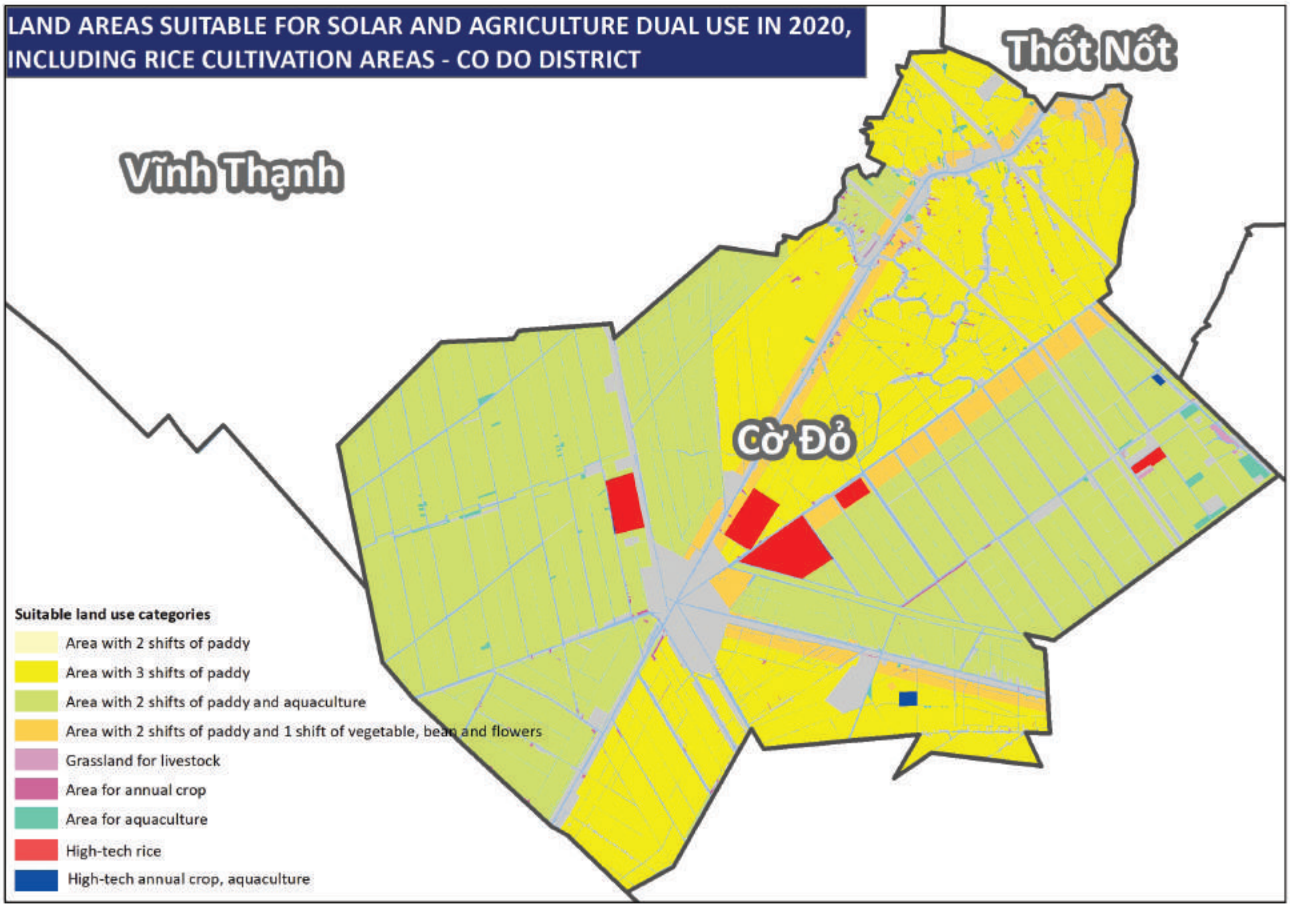
Binh Thuy District:



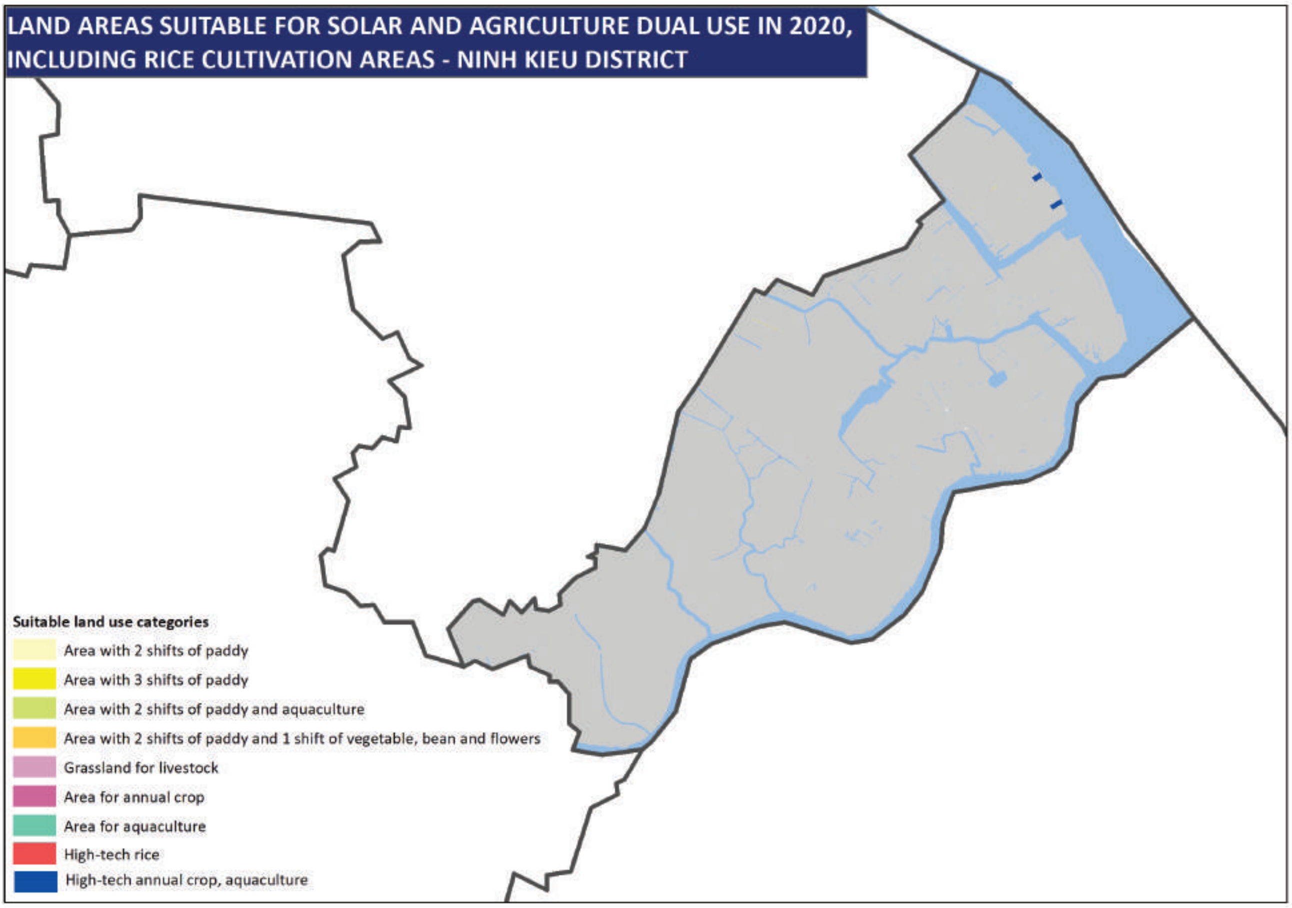
Cai Rang District:



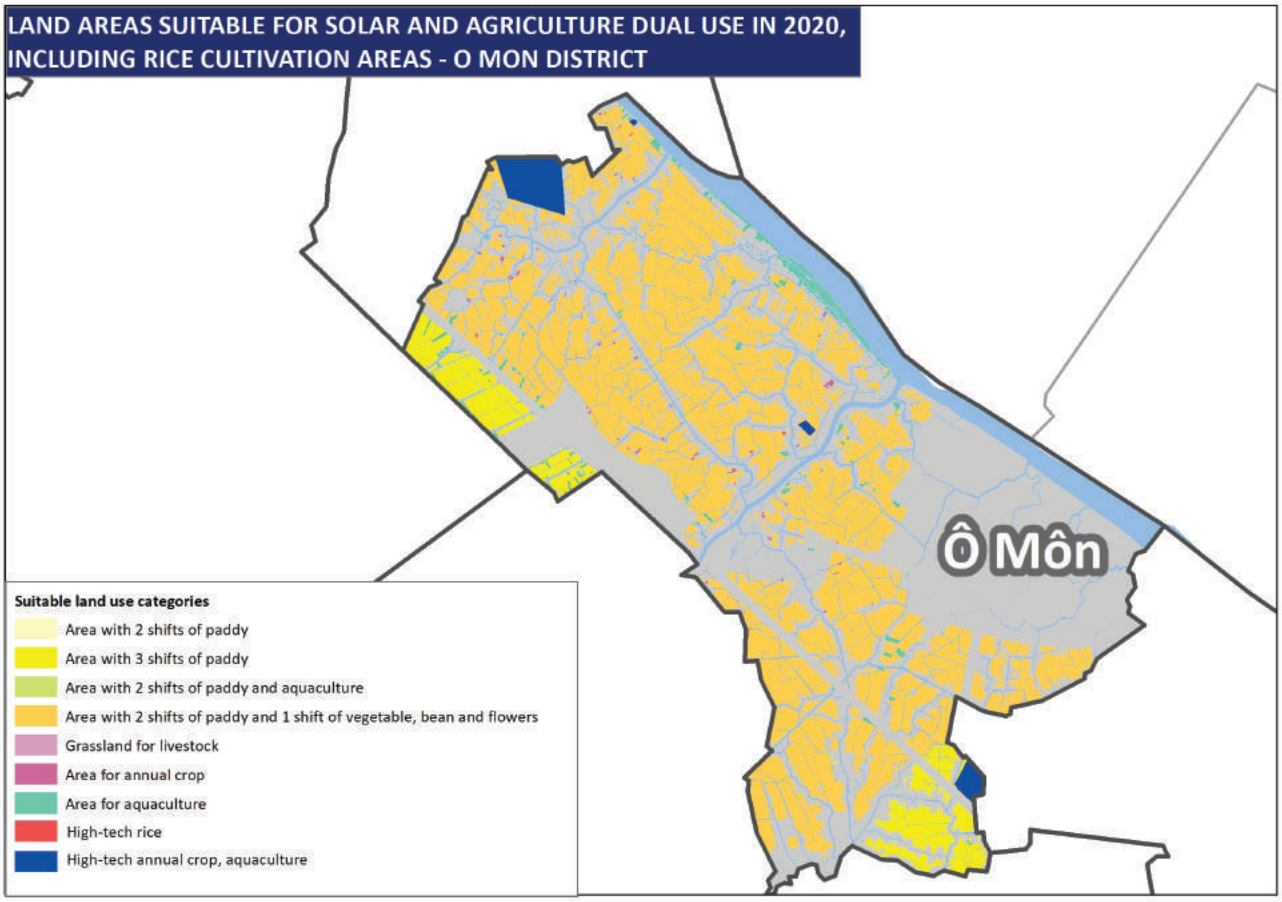

Co Do District:



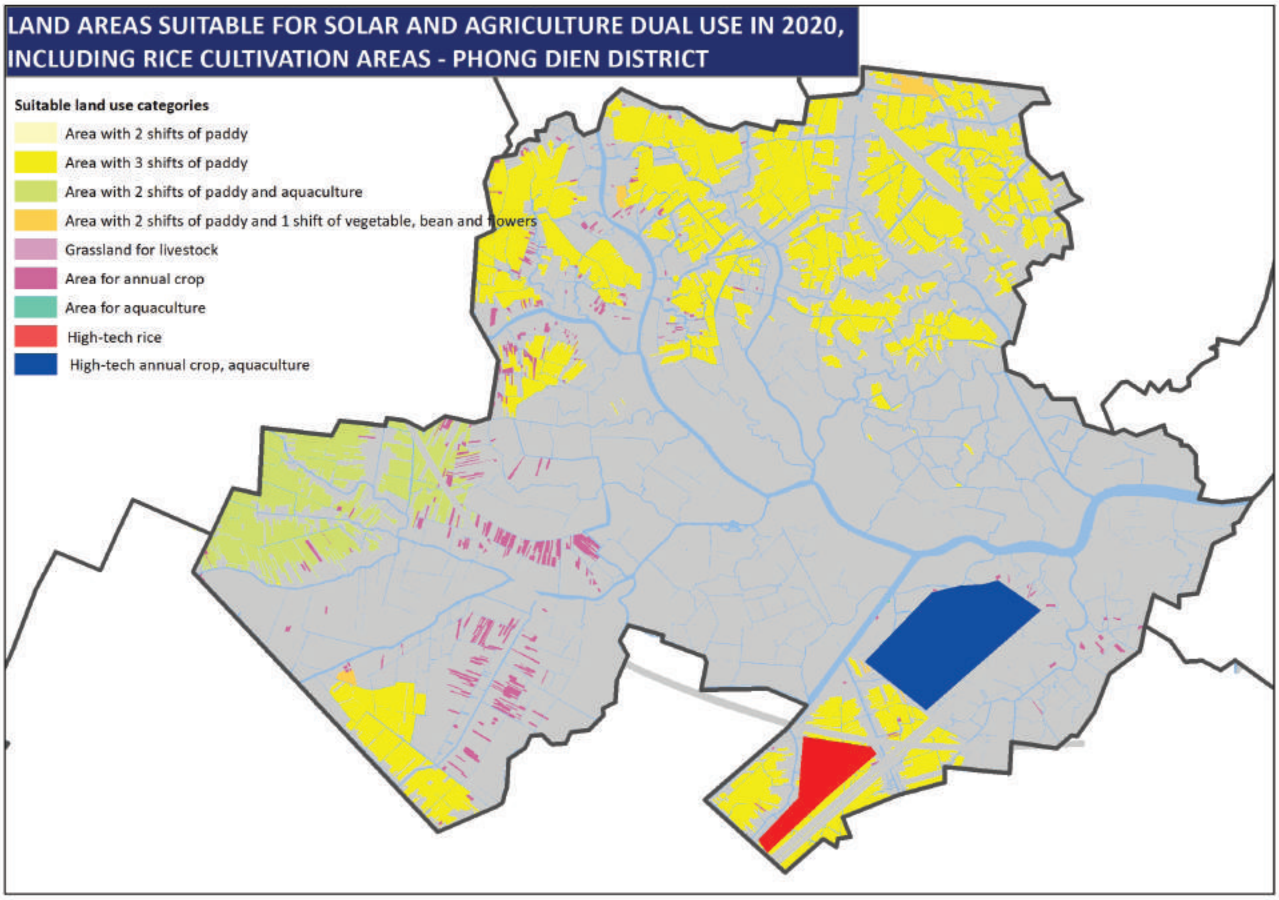
Ninh Kieu District:



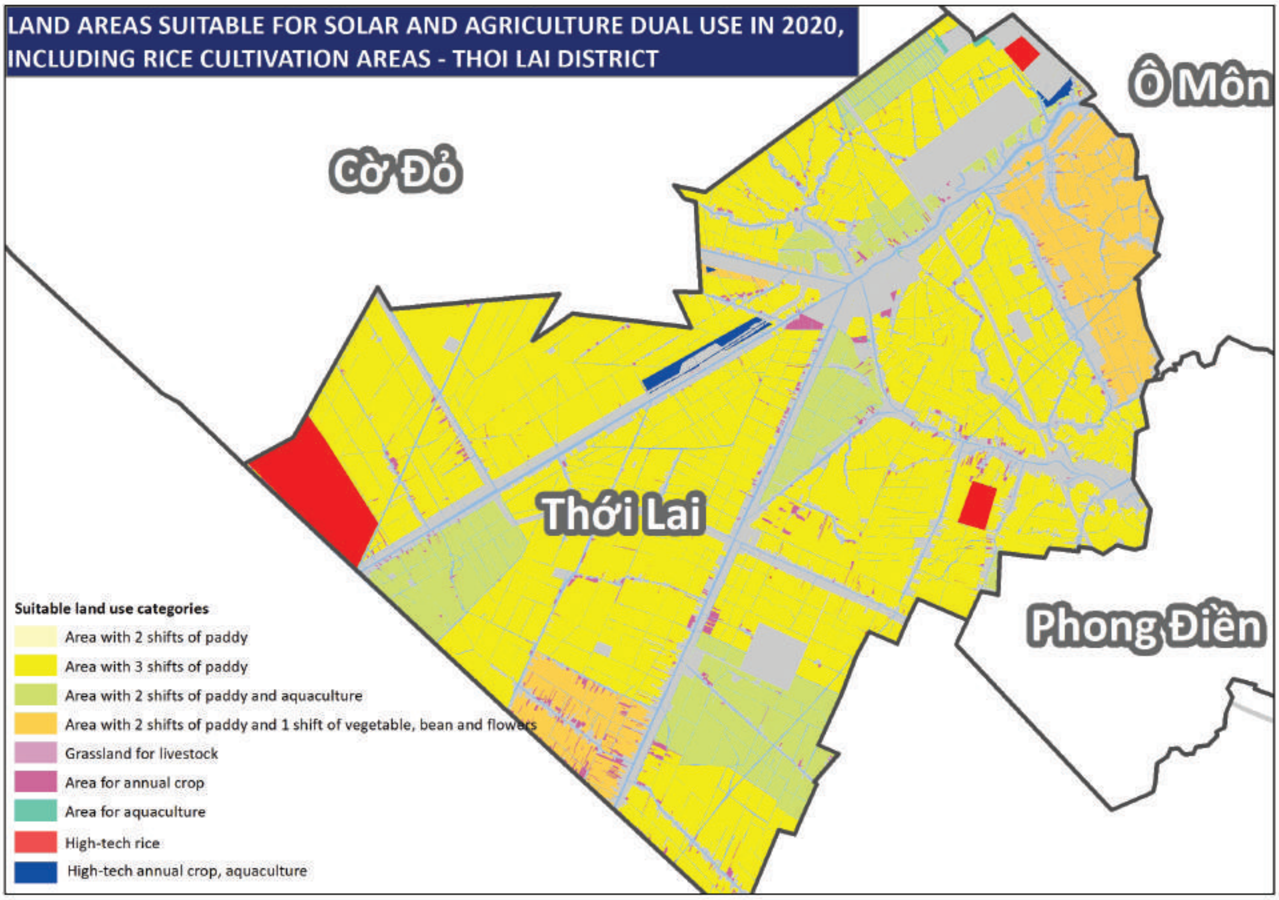

O Mon District:



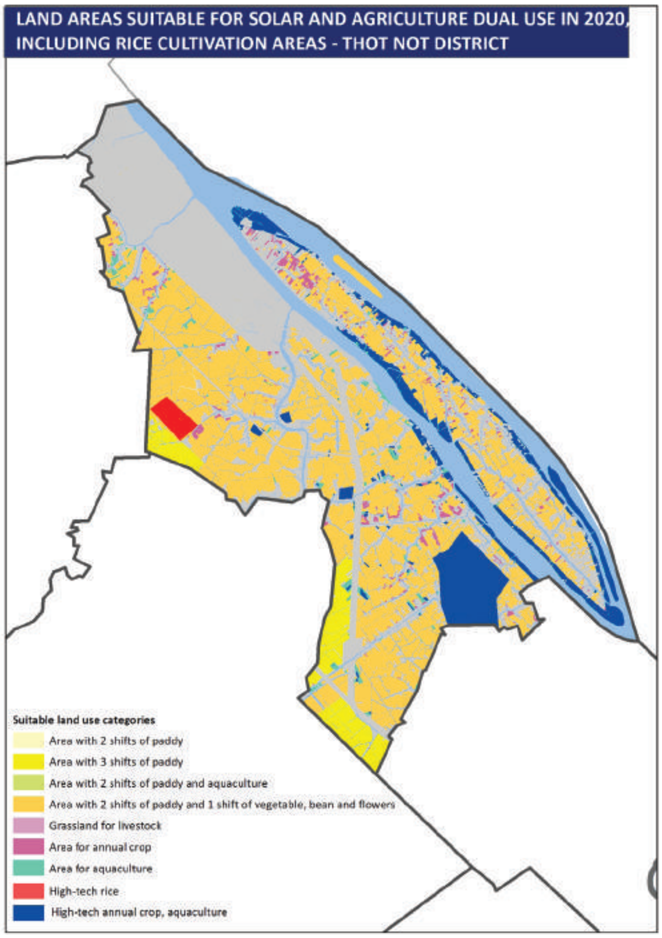
Phong Dien District:



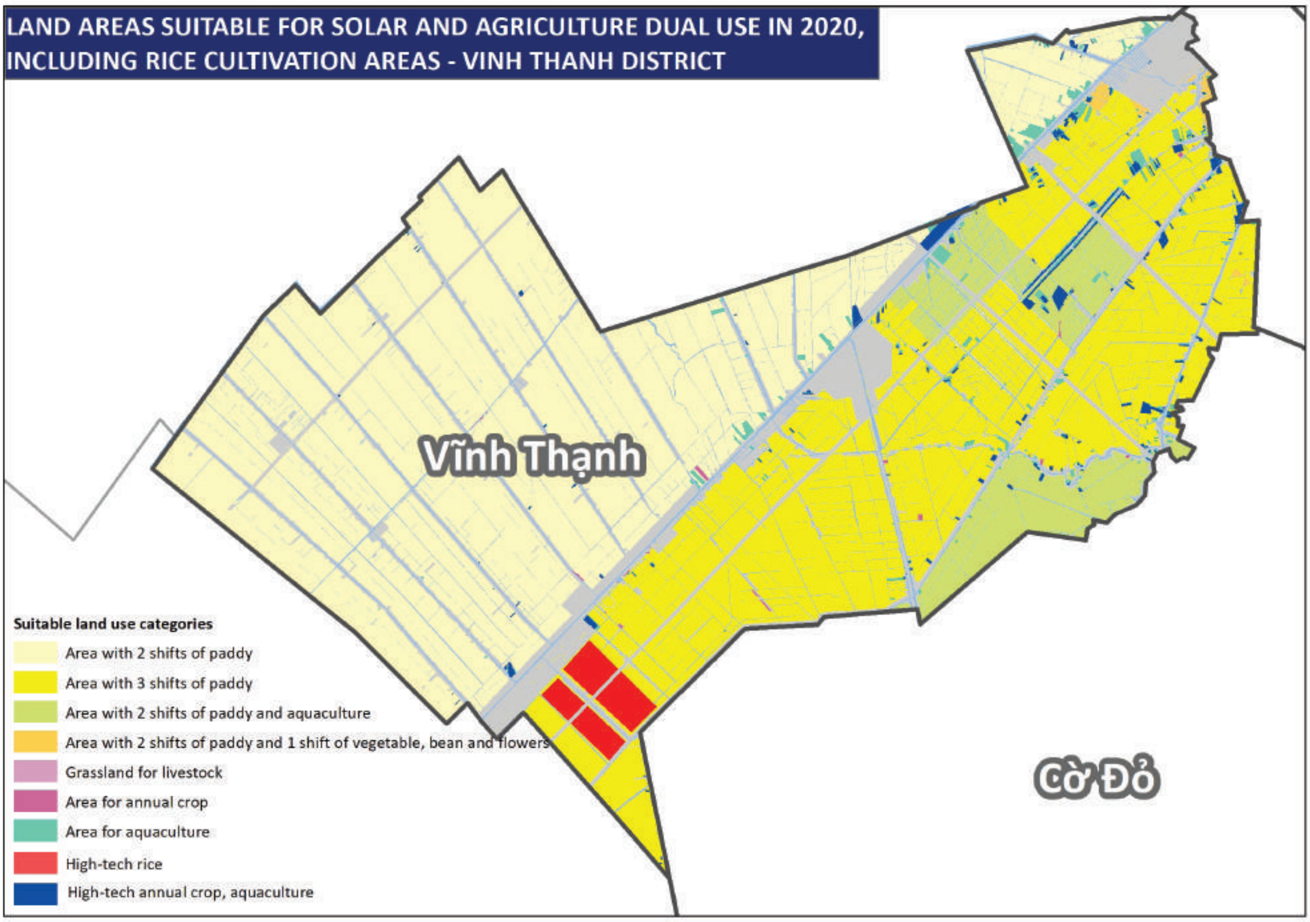

Thoi Lai District:



Thot Not District:




Vinh Thanh District:



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