Food and Agriculture Organization of the United Nations

ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT

WORKING PAPER

96

ENERGY

RENEWABLE ENERGY INTERVENTIONS IN THE WHEAT LANDSCAPE IN UZBEKISTAN

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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FOREWORD

The agriculture sector plays an important role in the economy of Uzbekistan. In 2020, agriculture provided employment for approximately 25 percent of the working population and constituted around 28 percent of the country's GDP. The aim of the country's agriculture policy is to increase resource efficiency and yields and added value of the final products. This is to be achieved through improvements along the agrifood value chains.

Energy and agriculture are closely interlinked, as agriculture relies on energy inputs for the production, processing, storage and transportation of agrifood products. Despite its abundant fossil fuel resources, Uzbekistan's energy sector faces challenges that affect productive sectors, including agriculture. For example, agricultural production is hindered by the extensive use of outdated equipment and frequent power outages that negatively affect irrigation schedules, as well as the storage and processing of agricultural products. These challenges are especially prominent in remote rural areas, where smallholders are also facing difficulties accessing the market. Deployment of renewable energy technologies can help overcome some of these challenges. The integration of renewable energy sources can provide energy access and reliable supply along the agrifood chains. The potential benefits include improved irrigation and processing efficiency, expansion of cold storage facilities and consequently added value to final produce.

This report was prepared by the Energy Team of the Office of Climate Change, Biodiversity and Environment, as a study that informs the Project Preparation Grant (PPG) application for the Global Environment Facility (GEF) under the Food System, Land Use, and Restoration (FOLUR) Impact Programme. The report's main objective is to evaluate the potential integration of renewable energy sources in the agrifood value chains of three regions of Uzbekistan: the Republic of Karakalpakstan, Khorezm and Kashkadarya. The aim of the interventions is to increase the efficiency of operations and provide benefits for smallholder farmers, while minimizing greenhouse gas emissions (GHG) from the agriculture sector. First, the potential to generate sustainable energy from solar, wind and biomass resources in the three regions was assessed, and subsequently the techno-economic analysis of the possible interventions conducted. The study shows that renewable energy interventions along the wheat, alfalfa, dairy and horticulture value chains can have significant positive impacts, improving the efficiency of the chains and adding value to the final produce. The renewable energy technologies and types of interventions that can be used along the chains are described, and the required investments estimated. In addition, for each intervention the potential for GHG emission reductions has been evaluated.

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ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
AEP	annual energy production
BEFS	bioenergy and food security
CCI-LC	Climate Change Initiative Land Cover
CHP	cogeneration of heat and power
DHI	diffuse horizontal irradiation
DHR	dehydrated
DNI	direct normal irradiation
DTU	Technical University of Denmark
EA	Euroasia
EBRD	European Bank for Reconstruction and Development
ESMAP	Energy Sector Management Assistance Program
FOLUR	Food Systems, Land Use and Restoration Impact Program
FSPV	floating solar photovoltaics
GA	global average
GDP	gross domestic product
GEB	global environmental benefits
GEF	Global Environment Facility
GHG	greenhouse gas
GHI	global horizontal irradiation
GIS	Geographic Information Systems
GWA	Global Wind Atlas
HAR	high adoption rate
HPP	hydropower plant
IFC	International Finance Corporation

IFI	international financial institution
INDC	intended nationally determined contributions
LAR	low adoption rate
LHV	lower heating value
Mtoe	million tonnes of oil equivalent
O&M	operation and maintenance
OA	Other Asia
PV	photovoltaic
PVOUT	PV output (technical potential of solar PV system)
RCR	residue to crop ratio
RES	renewable energy sources
RMP	realistic methane potential
SPP	solar photovoltaic power plant
TPP	thermal power plant
V	Volt
WDPA	World Database on Protected Areas
WPP	wind power plant

EXECUTIVE SUMMARY

Energy, agriculture and climate change are closely interlinked, and by targeting growth and renewable energy interventions in the agriculture sector, poverty reduction and climate change can be mitigated. Indeed, energy is used at all stages of the value chain, from production of food on farm to storage and processing, as well as during consumption. The global agriculture sector relies heavily on fossil fuels to meet food demand, and energy consumption in the global agriculture sector is furthermore expected to increase as the global population rises. This represents a challenge, and also an opportunity. The challenge lies in how to ensure that the response to energy demand from the agriculture sector does not further exacerbate climate change. At the same time, the use of renewable energy to satisfy the demands of the agriculture sector represents an opportunity. Many countries across the world have developed targets to reduce reliance on fossil fuels and increase renewable energy use, while others are currently developing such targets. Increasing the use of renewable energy in the agriculture sector can modernize agri-food chains, increase local entrepreneurships, reduce poverty as well as positively impact the local environment and climate at large.

Uzbekistan has announced policies that target poverty reduction, renewable energy, and the agriculture sector. The country aims to achieve a 50 percent reduction in poverty levels by 2026, and subsequently to reach upper-middle-income status by 2030. Agriculture is an important economic sector for Uzbekistan, and because it employs 26 percent of the total working population, it could be an essential part of the process.

Uzbekistan has universal access to energy and vast fossil fuel resources supported by a well-extended energy distribution network, but the outdated and inefficient infrastructure slows the process down. Thermal power plants operate at relatively low conversion efficiency, while technical losses in transmission and distribution networks are estimated at 2.7 percent and 12.5 percent, respectively. The natural gas distribution network has also suffered losses due to low pressure. Moreover, power assets in the country are not placed strategically, in fact, approximately 70 percent of the electricity production occurs in the north, while 90 percent of the gas production is in the south. [1] This means that as a result, energy has to be transmitted over long distances which further increases transmission and distribution losses.

Irrigation is key to ensuring productivity in the agriculture sector, and it is the major consumer of electricity used to power water pumps and move water. In Uzbekistan, for example, irrigation systems rely on outdated and inefficient pumps that consume 20 percent of the country's electricity. Furthermore, most of the country is connected to the water lines and electricity grids power outages in rural areas, especially during the cold season. [2] Power outages are the cause of dysfunctional water pumps, directly impacting the farmers ability to plan and execute irrigation schedules that are key to maintaining crop yields.

In response to these challenges, the Government of Uzbekistan adopted the Concept Note for Ensuring Electricity Supply in Uzbekistan in 2020-2030. [3] Their objective is

[1] **Ministry of Energy of the Republic of Uzbekistan (MoE of Uzbekistan)**. 2020. Concept Note for ensuring electricity supply in Uzbekistan in 2020-2030. , 43(1): 7728.
[2] **ADB.** 2019. *Uzbekistan 2019 - 2023: Supporting economic transformation*. Asian Development Bank.
[3] **Ministry of Energy of the Republic of Uzbekistan (MoE of Uzbekistan)**. 2020. Concept Note for ensuring electricity supply in Uzbekistan in 2020-2030. , 43(1): 7728.

to ensure a sustainable electricity supply to all consumers and to diversify electricity production sources with particular emphasis on renewable energy sources, in addition to establishing a renewable energy market. Access to reliable and dependable sources of energy can benefit the agriculture sector by improving irrigation infrastructure, increasing cold storage of fresh produce, and expanding processing thereby adding value to primary produce.

This report is part of the technical analysis that informs the GEF's (Global Environment Facility) project preparation grant application (PPG) under the GEF's Food Systems, Land Use and Restoration (FOLUR) Impact Programme. Overall, the PPG aims to transform the management of wheat-dominated landscapes in Uzbekistan by promoting inclusive, sustainable agricultural value chains that address underlying drivers of landscape degradation and enhance global environmental benefits (GEBs). One of the components of the envisaged PPG is to observe the role that renewable energy can play in improving the wheat landscape in the country. This report formulates a background assessment with the aim to identify renewable energy interventions that can potentially benefit Uzbekistan's wheat landscape. More specifically, it focuses on three regions of Uzbekistan: Republic of Karakalpakstan, Kashkadarya and Khorezm. These three regions were selected based on consultations, and also because they have been identified as regions with areas that have the largest and most severe land degradation.

The overall scope of the report is two-fold: first, to understand the overall potential to produce energy from the solar, wind and biomass available in the three study regions. Second, it identifies specific renewable energy interventions that potentially could have a positive impact on the wheat landscape in the country; in addition, it evaluates their capacity to scale up. While wheat production dominates the regions, the landscape approach helps to identify other existing agri-food chains, together with the wheat chain. Through consultations with the national experts, the wheat, alfalfa, dairy and horticulture chains were identified as the target chains where renewable energy interventions can have significant positive impacts.

The first part of the report provides an overview of the potential for solar, wind and bioenergy; the analysis of wind and solar potential for electricity generation is based on publicly available data. It is estimated that sustainably-sited wind power plants could supply 49 percent capacity of the projected national electricity demand in 2030. Solar power is much stronger, with the potential to cover 148 percent of the projected demand. A third source for renewable energy, biomass, is also a feasible option, with the advantage of turning the agricultural waste product cotton stalks into a useful resource.

The second part of the report identifies the main renewable energy technologies that can be used across the targeted value chains to increase the efficiency of operations while minimizing greenhouse gas (GHG) emissions. Each sector details options that offer the best potential for short-term deployment and long-term benefits. The interventions selected are solar photovoltaic (PV) based, given that they were found to be commercially available and easily deployable when compared to other interventions, and generally less expensive. Furthermore, the identified solar interventions can be tailored to perform a range of tasks by adding or removing PV panels, thanks to their modular nature.

Under the wheat value chain, the use of solar PV-powered irrigation pumps and mills bring several benefits. Solar PV water pumps can increase irrigation and reduce the burden on ageing infrastructures, and solar PV mills can reduce GHG emissions and allow for wheat to be processed in close proximity to the crop fields.

Alfalfa is a perennial legume known for its high nutritional value and as a major source of feed for livestock, which is in short supply in Uzbekistan. Transport is costly due to its bulkiness; however, dehydrating and pelletizing alfalfa can reduce transport costs; moreover, pellets contain nutrients that can create a value-added product.

Horticulture is a growing sector in Uzbekistan that provides jobs in rural areas, in addition to significant employment for women. The analysis suggests that one of the major bottlenecks in increasing market linkage and reducing losses is the lack of cold storage in the regions, as horticulture products are susceptible to biological decay when not stored in optimal conditions. The lack of cold storage is also problematic for milk, which must be cooled as soon as it is extracted, and also requires long-term storage. The assessment investigated the possibility of using solar-powered cold storages that could be deployed across the regions to increase cold storage capacity, while minimizing GHG emissions.

In sum, the aim of this report is to provide evidence on which renewable energy technologies can potentially add value and reduce losses along the selected value chains in three regions in Uzbekistan. In addition, it provides an estimate of the total investment required to deploy these technologies and demonstrates how reduction of GHG emissions can be achieved.

CHAPTER

1

INTRODUCTION

This report is part of the technical analysis and assessment work that was carried out to support GEF's project preparation grant application (PPG) under GEF's Food Systems, Land Use and Restoration Impact Program (FOLUR) impact programme. The project specifically focuses on three regions in Uzbekistan, namely the Republic of Karakalpakstan, Kashkadarya and Khorezm, and also the wheat value chain.

The scope of this report is to assess the opportunities for climate change mitigation through renewable energy interventions in the wheat value chain. In addition, some other key value chains in the country, with a focus on the specific regions of interest, were also analysed. The report first assesses the solar and wind energy potential at national level, and then addresses the potential at regional level. Biomass resource availability was also analysed but at an initial level of assessment. First, the report aims to assess the overall potential to produce renewable energy from the solar, wind and biomass resources available in the three study regions. Second, it identifies specific renewable energy interventions that can potentially have a positive impact on the wheat landscape in the country, while also evaluating their capacity to scale up. In addition to the wheat value chain, the alfalfa, dairy and horticulture chains were identified as target chains where renewable energy interventions can potentially add value and reduce losses. Furthermore, the report provides an estimate of the total investment required to deploy these technologies and demonstrates how reduction of GHG emissions can be achieved.

Agriculture is an important economic sector for Uzbekistan, as it employs around 26 percent of the total working population. Irrigation is vital to ensuring productivity in agricultural production, and the majority of electricity within the sector is consumed to power water pumps and move water. Irrigation systems typically rely on outdated and inefficient pumps that consume 20 percent of the country's electricity. Furthermore, power outages negatively affect the operation of agricultural processes, causing disruptions in the use of water pumps, thus directly impacting the farmers ability to plan and execute irrigation schedules that are key to maintaining crop yields (ADB, 2019).

Uzbekistan is energy-independent, with significant oil and natural gas resources. Approximately 85 percent of the population has access to clean cooking fuels and all residents have access to electricity (IRENA, 2020a). The country's energy sector is dominated by fossil fuels, with natural gas contributing 85 percent, crude oil 9 percent and coal 5 percent to the primary energy supply. The role of renewable energy sources is still limited to hydropower and a negligible share of biomass and wastes, which jointly account for around 1 percent to the total primary supply (IEA, 2021a). Regarding electricity production, the overall installed capacity on the national level is around 14 GW (IRENA, 2020a). Thermal power plants account for more than 85 percent of the total installed capacity, with hydropower plants assuming an overall capacity of 1.9 GW. Natural gas is the primary source of electricity generation, representing 83 percent of the overall production in 2019, followed by hydropower at 10 percent. Coal and oil contribute 6 percent and 1 percent of the total electricity production in the country respectively (MoE of Uzbekistan, 2020).

Despite the country's vast fossil fuel resources and universal access to energy, there are several challenges hindering the energy sector. Outdated and inefficient infrastructures are the source of the low conversion efficiencies of thermal power plants. At the same time, the transmission and distribution losses are estimated at 2.7 percent and 12.5 percent, respectively. Losses have furthermore been sustained due to low pressure in the natural gas distribution network (Ministry of Energy, 2020).

In order to combat these challenges and support the development of the renewable energy sector, the Government of Uzbekistan adopted the Concept Note for Ensuring Electricity Supply in Uzbekistan in 2020-2030. The aim is to diversify the country's energy mix by promoting the use of renewable energy sources. Access to reliable and dependable sources of energy can also benefit the agriculture sector by improving irrigation infrastructure, increasing cold storage of fresh produce, and expanding processing thereby adding value to primary produce (Ministry of Energy, 2020). Additionally, the country has set several targets to increase the share of renewables in the energy mix. By 2030 it is envisioned to achieve a newly installed capacity of 3.8 MW for hydropower plants, 5 MW of solar power plants and 3 MW of wind power plants (MoE of Uzbekistan, 2020). Lastly, Uzbekistan ratified the Paris Agreement and adopted a national commitment to reduce GHG emissions per unit of gross domestic product (GDP) by 10 percent by 2030 from the level of 2010 (Government of Uzbekistan, 2018). The development of renewable energy projects can play an important role in achieving this goal.

The report uses the methodologies of the Energy Smart Food (ESF) programme of FAO. The Energy Smart Food (ESF) programme of FAO and the related approaches and methodological tools, support countries assess energy needs and options that integrate agriculture needs and food security. For the specific case of bioenergy, the Bioenergy and Food Security (BEFS) Approach of FAO assists countries in developing a sustainable bioenergy sector that integrates food security and agriculture needs into its development. More specifically, the sustainable bioenergy assessment component assists countries in defining viable bioenergy pathways and how they can assist in meeting sustainable energy targets. This report builds on a number of the components of the ESF technical elements.

The development of a sustainable renewable energy sector in the country requires robust analysis to identify the availability of resources and the potential for their utilization. This report focuses on solar, wind and biomass-based energy in terms of renewable energy options. Chapter 2 provided an overview of the country context, its economy, the agriculture sector and broad policy environment. Additionally, it gives a detailed overview of the country's energy sector and the related policies, the challenges and targets that have been set for renewable energy. Chapter 3 provides an overall assessment of the potential of solar energy, wind energy and selected biomass resources focusing on the three regions of interest. This section aims to define renewable energy potential in the regions of interest. Chapters 4 to 7 assess renewable energy interventions for the wheat value chain and specific agriculture value chains of interest in the regions, namely alfalfa, horticulture and dairy value chains in the regions. The focus of the analysis is to identify the suitable renewable energy technologies for the value chains of focus, and estimate the initial values for investment and cost requirements, as well as potential GHG emission savings. Chapter 8 provides conclusions based on the results of the assessment.

[4] For further information on the BEFS Approach, please see: www.fao.org/energy/bioenergy on the Bioenergy programme of FAO and www.fao.org/energy/bioenergy/bioenergy-and-food-security/en/.

CHAPTER 2

LOCATION AND THE ENVIRONMENT

2.1 UZBEKISTAN

Uzbekistan is a Central Asian country bordering five different countries: Kazakhstan in the north and west, Tajikistan and Kyrgyzstan in the east, and Afghanistan and Turkmenistan in the south (**Figure 1**). With no direct connection of the coastline to its border or to its neighbours' borders, Uzbekistan is one of the only two, double landlocked countries in the world. Since the fall of the Soviet Union, Uzbekistan has become an independent country administratively divided into 12 provinces, together with the autonomous Republic of Karakalpakstan. Uzbekistan covers a diverse area of 447 400 km^2 extending from the Tian Shan and Pamir mountains in the east to the Aral Sea in the west. Lowlands, mainly deserts and plains, comprise around 80 percent of Uzbekistan's area.

The total Uzbekistan population is 33 905 200 (2020) with an average population density of 77 inhabitants per km^2, whereby the population and settlement density gravitate towards the eastern half of the country (UZSTAT, 2021b, 2021c). **Figure 2** shows the average population density and main infrastructure corridors in Uzbekistan.

Uzbekistan mainly lies between two major rivers, the Amu Darya to the southwest and the Syr Darya to the northeast, however they only partly form its borders. Rivers are primarily used for irrigation, with numerous water canals and water resources unevenly distributed across the country that are mostly scarce (USAID, 2018). The climate is continental with arid areas that cover over 60 percent of the country. Average rainfall ranges from higher values in the mountainous regions in the eastern and southern areas to lower values in the western parts of the country.

FIGURE 1.

ADMINISTRATIVE MAP OF UZBEKISTAN

Source: WorldAtlas. 2021. Maps of Uzbekistan. In: *World Atlas*. [Cited 30 July 2021]. www.worldatlas.com/maps/uzbekistan

The country's temperature varies significantly, throughout the day as well as annually, with high temperatures in the summer months and low ones in winter. Climate and agriculture strongly affect drainage and water availability, due to river water rapidly escaping through evaporation and filtration or extraction for irrigation systems. Therefore, because of the rapid population growth and continuing pressure on the environment, the ecological status of the country has declined (Djumaboev *et al.*, 2017).

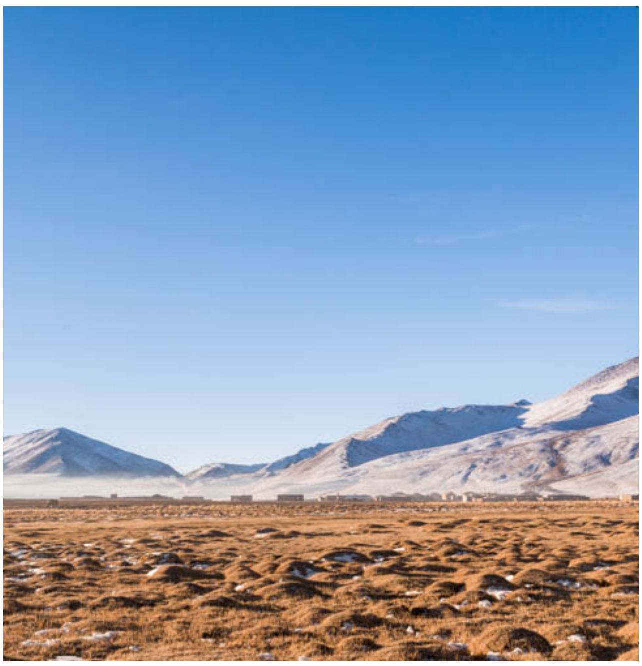
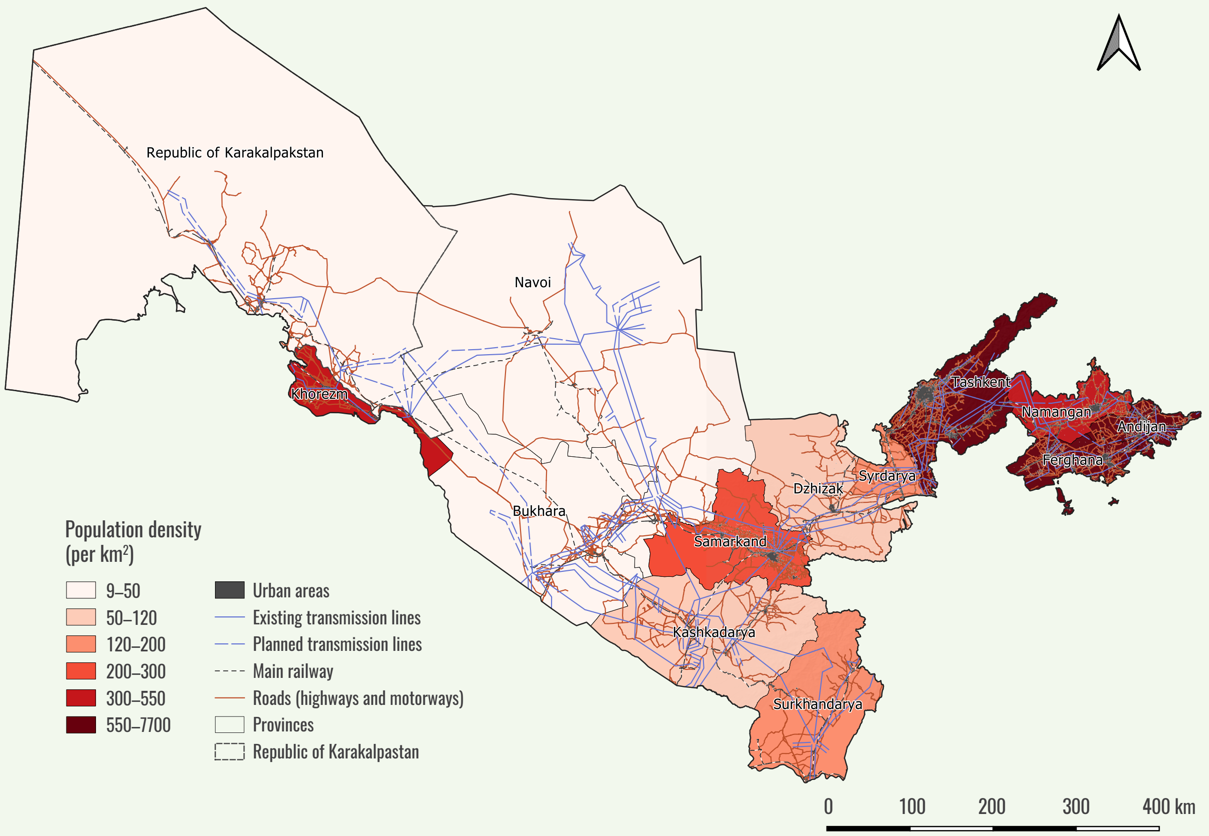


FIGURE 2.

MAP OF UZBEKISTAN: POPULATION DENSITY AND INFRASTRUCTURE



Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors*

2.2 THE REPUBLIC OF KARAKALPAKSTAN, KHOREZM PROVINCE AND KASHKADARYA PROVINCE

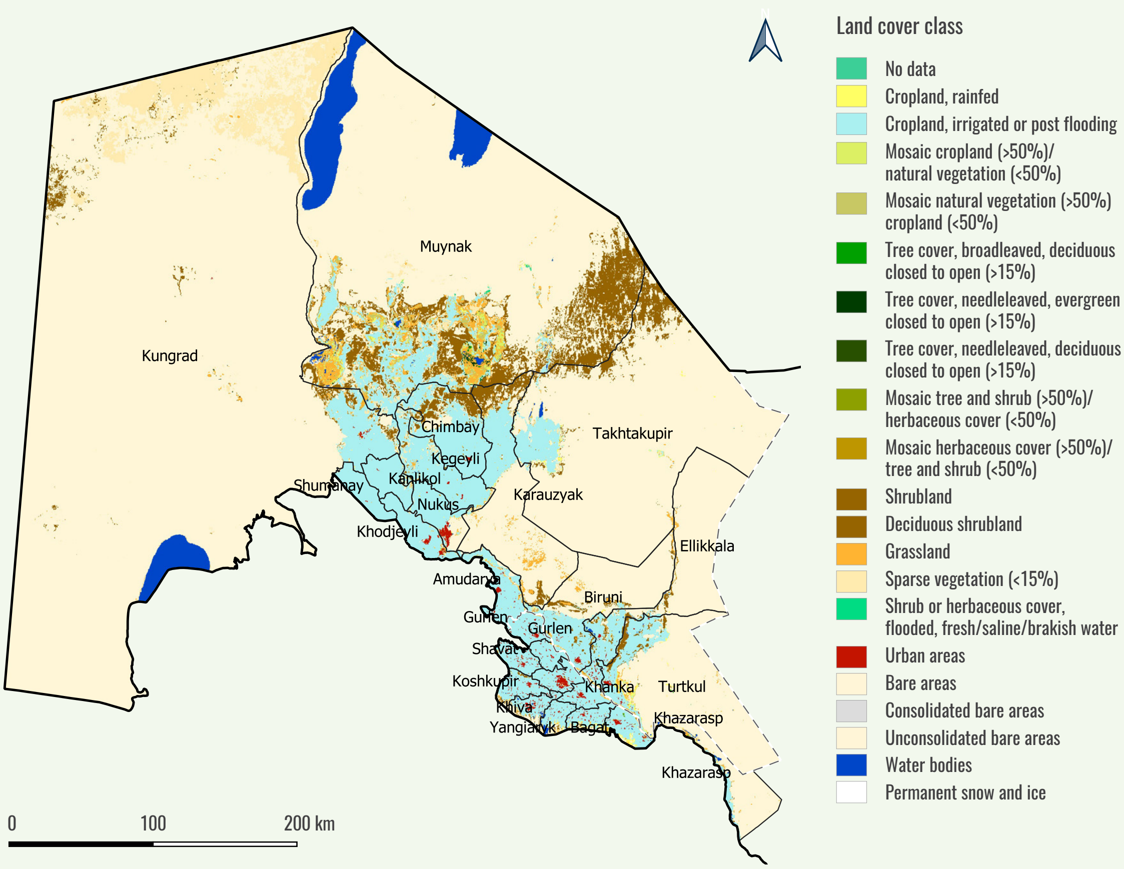
The Republic of Karakalpakstan covers an area of 166 590 km^2 and occupies 37.1 percent of Uzbekistan's territory with a population of 1.89 million (as of 2020), which accounts for only 5.6 percent of the country's total population (UZSTAT, 2021c). Its borders are composed of Kazakhstan in the east and north, the Navoi region in the west, Bukhara and Khorezm regions in the southeast, and Turkmenistan in the south. Dry lowlands in the western-most part of the country make up the topography of Karakalpakstan. In the northwest, the Turan Plain rises up to 90 metres above sea level and surrounds the Aral Sea. This terrain evolved into part of the southern desert area of Kyzylkum, and in the far west the desert becomes the Ustyur Plateau. Southeast of the Aral Sea, a series of small hills break the flatness and the low elevation of the Kyzylkum desert. Karaklapakstan is mainly a sparsely populated area with ongoing emigration trends as a result of the Aral Sea environmental crisis, while a relatively young population contributes to the high population growth rate (FAO, 2012; UZSTAT, 2020, 2021c).

The province of Khorezm is divided into 10 administrative districts, bordering the Republic of Karakalpakstan in the north, Bukhara Region in the east, and Turkmenistan in the south. Khorezm stretches along the left bank of the Amu Darya river, between the Kyzylkum and Karakum deserts, covering an area of 6 050 km². The topography is flat with elevation values ranging between 112 m and 138 m above sea level. The total population amounts to 1.86 million (2020), of which one third lives in rural areas, with an above-average population density of 308.5 inhabitants/km² (UZSTAT, 2021b, 2021c).

The Republic of Karakalpakstan and Khorezm Province as well as the western part of the country share desert and steppe climates. Rainfall mostly occurs in the late fall through early spring, and rainfall values are extremely low in the summer months. Temperatures in the plains reach over 40 °C in the summer months and below -35 °C during winter, averaging between -5 °C and 26 °C. Average January temperatures range from -5 °C to -8 °C while temperatures in July average from 26 °C to 28 °C, with an annual average precipitation of 100 mm per year. The average January temperature in Khorezm is 12 °C, which by July reaches about 30 °C with an average annual precipitation of 78 mm–79 mm (IPA, 2021). The vegetation and land cover of the two regions are shaped by the climate conditions, precipitation and irrigation infrastructure, as can be seen in **Figure 3**.

FIGURE 3.

THE REPUBLIC OF KARAKALPAKSTAN AND KHOREZM PROVINCE: ADMINISTRATIVE DIVISION AND LAND COVER MAP

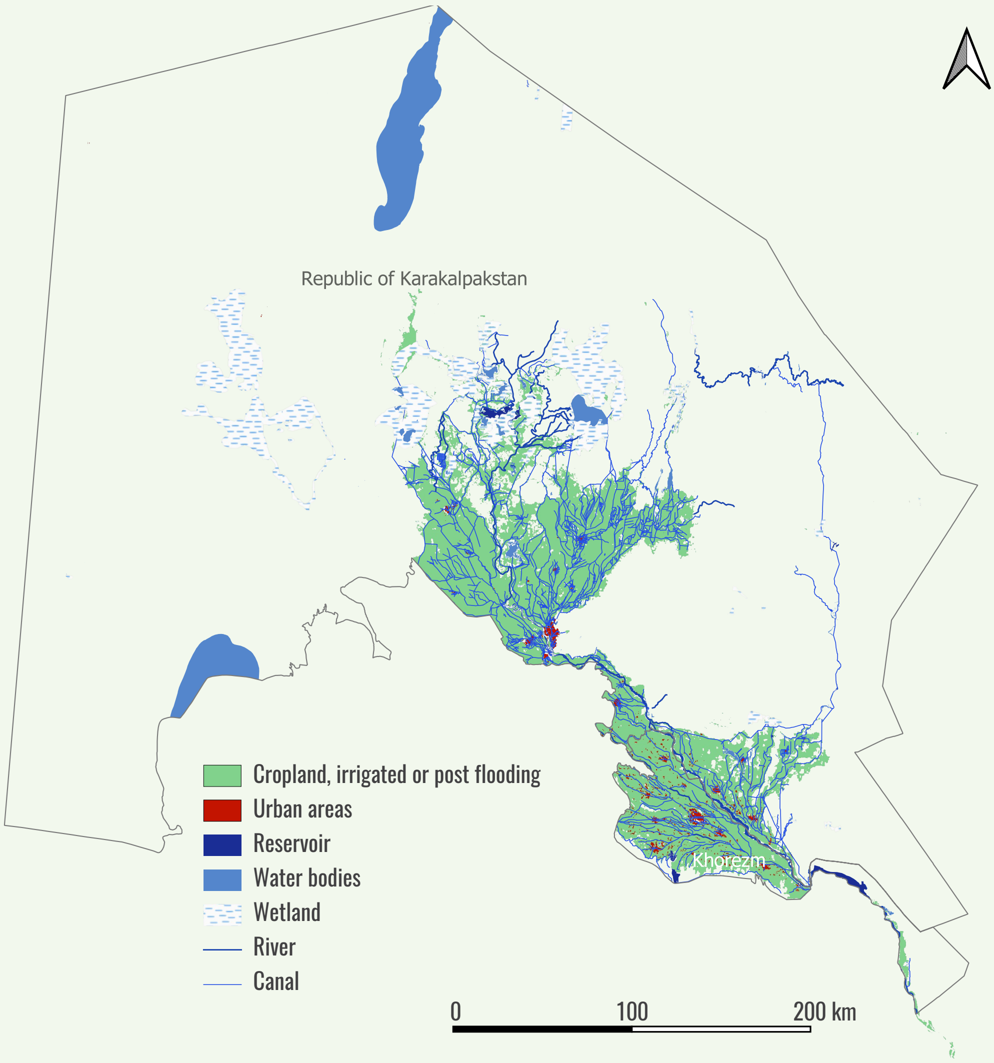


Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors*

As regards the Republic of Karakalpakstan and Khorezm, the Amu Darya serves as a main waterway and transit river. Many water reservoirs and irrigation channels are used for agriculture purposes. Currently, the Amu Darya reaches the district of Muynak where it expands into a wide lagoon. However, the lower Amu Darya discharge fluctuates considerably throughout the year and can reach critically low values (SCEEP, 2019). **Figure 4** shows natural water bodies and irrigation network in the two regions.

FIGURE 4.

THE REPUBLIC OF KARAKALPAKSTAN AND KHOREZM PROVINCE: WATER RESOURCES AND IRRIGATED AGRICULTURAL LAND

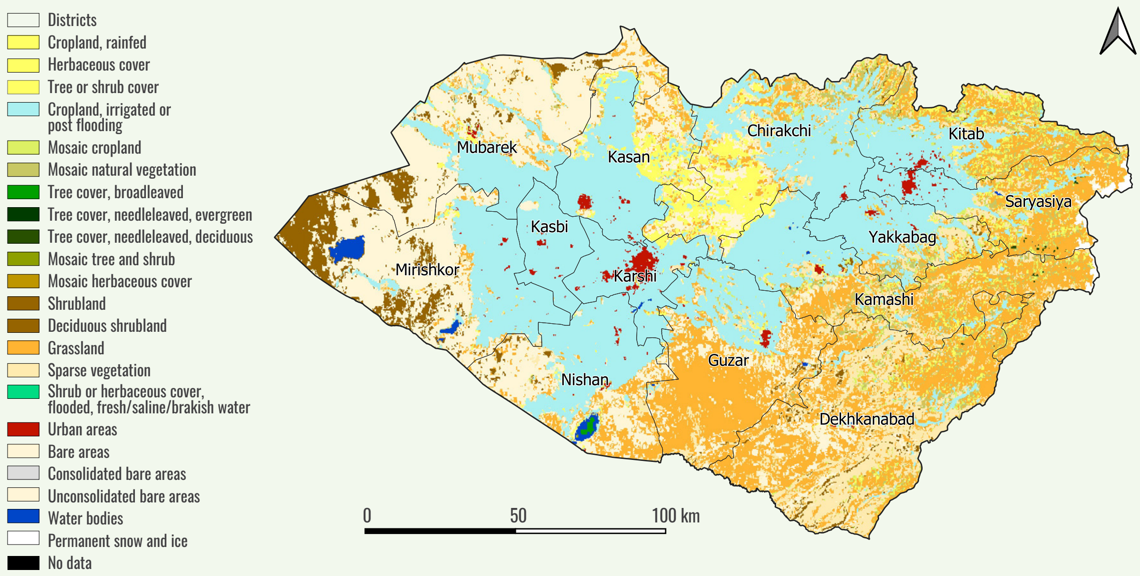


Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors*

Kashkadarya Province is located in the southern part of Uzbekistan bordering the Bukhara region in the west, the Navoi region in the northwest, the Samarkand region in the north, Tajikistan in the northeast Surkhandarya region in the east, and finally Turkmenistan in the south. The province is located in the Kashkadarya river basin and covers an area of 28 570 km^2. The topographical profile changes from the eastern and central lowlands to western foothills and high elevation points of the Pamir Alay mountains. Kashkadarya is the third most populated province in Uzbekistan with a population of 3.28 million inhabitants (2020), of which 57 percent are rural (UZSTAT, 2021c). Population density is above the national average and amounts to 114.8 inhabitants per km^2 (UZSTAT, 2021b). The climate of the Kashkadarya Province is dry continental with precipitation mainly occurring during the winter season. High mountain ranges on the southern, eastern and north-eastern border prevent the penetration of cold air masses making the winters fairly warm, while maximum summer temperatures can exceed 40 °C. The Kashkadarya river serves as a main waterway in the province and is widely used for irrigation purposes. Irrigation canals and water reservoirs form important oases for irrigated agriculture (SCEEP, 2019). **Figure 5** shows the administrative division and land cover map of Kashkadarya, and **Figure 6** depicts water bodies and agricultural irrigated land in the region.

FIGURE 5.

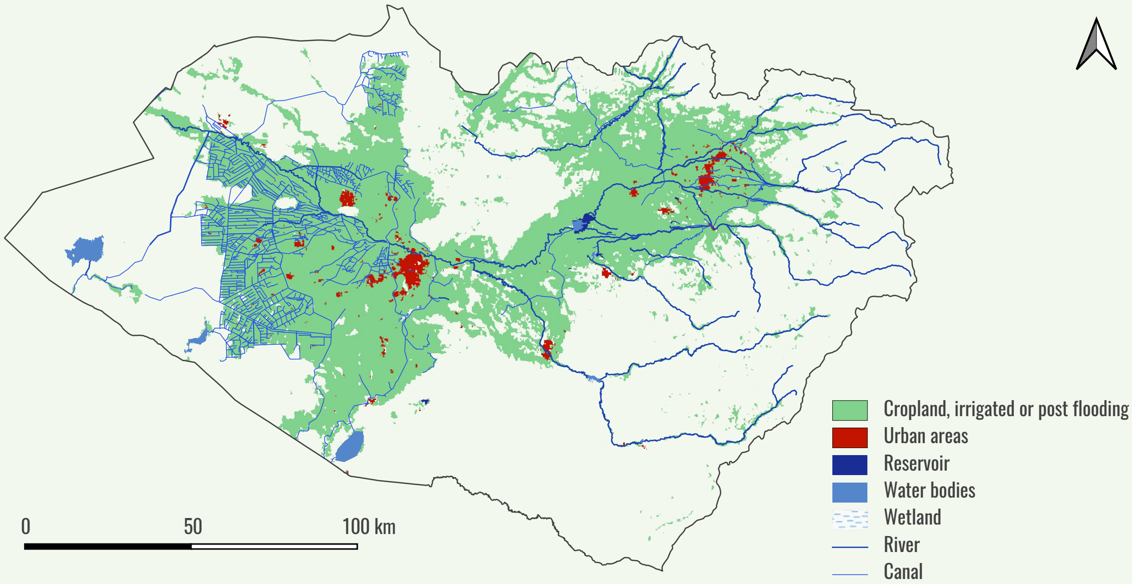
KASHKADARYA PROVINCE: ADMINISTRATIVE DIVISION AND LAND COVER MAP



Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors*

FIGURE 6.

KASHKADARYA PROVINCE: WATER RESOURCES AND IRRIGATED AGRICULTURAL LAND



Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors*

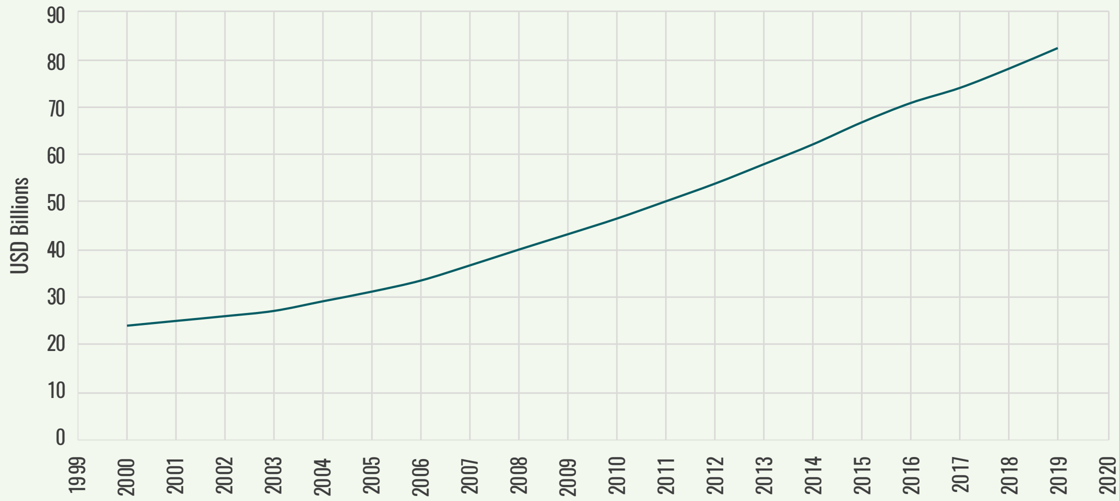
2.3 ECONOMY AND DEVELOPMENT

Uzbekistan is a lower-middle-income country and is a major exporter of natural gas and cotton.

The country has seen consistent gross domestic product (GDP) growth for the last two decades (**Figure 7**). In 2017 the country opened up the economy by liberalizing the foreign exchange market and reducing import tariffs as well as taxes for business in the country (ADB, 2019; World Bank Group, 2019).

FIGURE 7.

UZBEKISTAN GDP AT CONSTANT 2010 USD FROM 2000 TO 2019



Source: World Bank. 2021. World Development Indicators | DataBank. In: *World Bank*. [Cited 14 July 2021]. https://databank.worldbank.org/reports.aspx?source=world-development-indicators

After the collapse of the Soviet Union, Uzbekistan embarked on an economic model that was characterized by strong state control of resources. In 2016 the country initiated a drastic economic transition that focussed on improving the business environment, initiating tax reforms, diversifying agricultural production and liberalization of prices (ADB, 2019). As a result of the policies, the country saw an increase in both investment and consumption, in addition to an increase in real GDP growth from 4.5 percent in 2017 to 5.1 percent in 2018; furthermore, it saw 5.3 percent year-on-year in the first quarter of 2019 (World Bank Group, 2019).Estimates from the National Statistical Commission indicate that in the year 2020 the industrial sector and the service sector contributed equally to the GDP (36 percent), while agriculture constituted the remaining 28 percent of the GDP.

2.4 ENERGY CONTEXT AND RELEVANT POLICY ELEMENTS

2.4.1 Current energy supply and demand

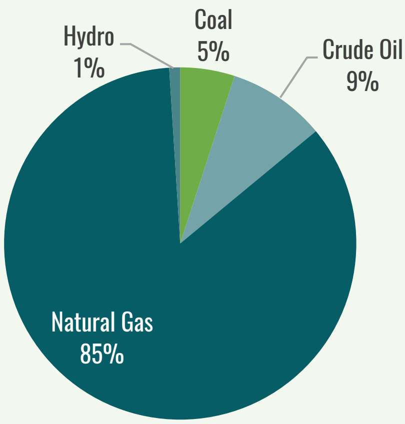
Uzbekistan is an energy-independent country rich in oil, natural gas and uranium, where electricity is accessible to all residents and 85 percent of the population has access to clean cooking options (IRENA, 2020a). Fossil fuels dominate the primary energy supply, with natural gas contributing 85 percent, crude oil 9 percent and coal 5 percent. As detailed in **Figure 8**, renewable energy supply is limited to hydropower and an almost negligible share of biomass and wastes, which jointly contribute around 1 percent to the total primary supply (IEA, 2021a).

With natural gas reserves of 2.2 trillion cubic meters, Uzbekistan has the 14th largest reserve of natural gas in the world. The annual extraction rate is increasing over the past several years, reaching more than 60 billion cubic meters (bcm) in 2019. The major part of the production is used domestically, while the remainder is exported to neighbouring countries. Since the 2000s, between 10 bcm and 15 bcm of natural gas is exported to Russia, China, Kazakhstan and other Central Asian countries. On the other hand, approximately 30 percent of the required crude oil for the refineries of the country is being imported. The refining output can cover the market demand and also be used for exports in small quantities (IEA, 2020a).

The overall power generation capacity in the country is around 14 GW (IRENA, 2020a). Electricity is produced by 11 thermal powerplants (TPPs) and 42 hydropower plants (HPPs). The overall installed capacity of TPPs is approximately 12 GW and the annual power generation is around 56.4 TWh. The main fuel used by TPPs is natural gas, while the share of electricity generated from coal is expected to increase from the current 6 percent to nearly 10 percent by 2030. The aggregated installed capacity of HPPs is 1.9 GW, out of which 1.68 GW are large scale HPPs. In 2019, the electricity generated in HPP totalled 6.8 TWh. As shown in **Figure 9**, natural gas is the primary source of electricity generation, accounting for 83 percent of the overall production in 2019, followed by hydropower representing 10 percent. Coal and oil contribute 6 percent and 1 percent of the total electricity production in the country respectively (MoE of Uzbekistan, 2020).

FIGURE 8.

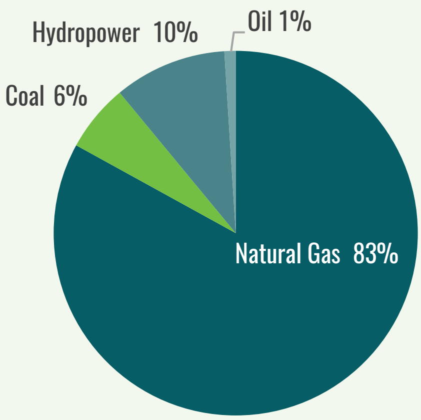
PRIMARY ENERGY SUPPLY IN 2018



Source: IEA. 2020a. Uzbekistan Energy Profile. In: *International Energy Agency.* [Cited 26 March 2021]. https://www.iea.org/reports/uzbekistan-energy-profile

FIGURE 9.

ELECTRICITY PRODUCTION BY SOURCE IN 2019

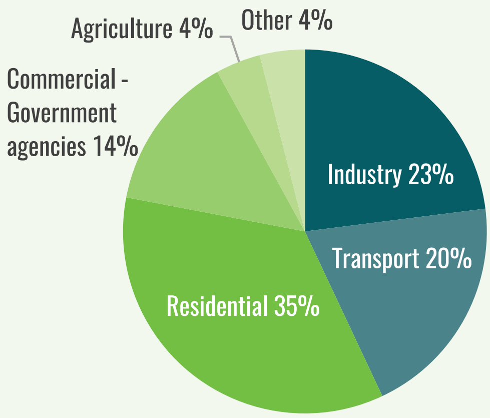


Source: Ministry of Energy of the Republic of Uzbekistan (MoE of Uzbekistan). 2020. Concept Note for ensuring electricity supply in Uzbekistan in 2020-2030., 43(1): 7728.

In terms of energy consumption, according to the Pilot Fuel and Energy Balance for 2019 published by the Ministry of Energy of the Republic of Uzbekistan, as much as 35 percent of energy was consumed in the residential sector, while the industry and transport sectors followed with 23 percent and 20 percent respectively, as presented in **Figure 10**. As shown in **Figure 11**, in the case of electricity consumption in 2019, industry was the leading consumer, accounting for 31 percent of the total demand, while the shares of agriculture and residential sectors in the total final electricity consumption were 28 percent and 26 percent, respectively (MoE of Uzbekistan, 2021).

FIGURE 10.

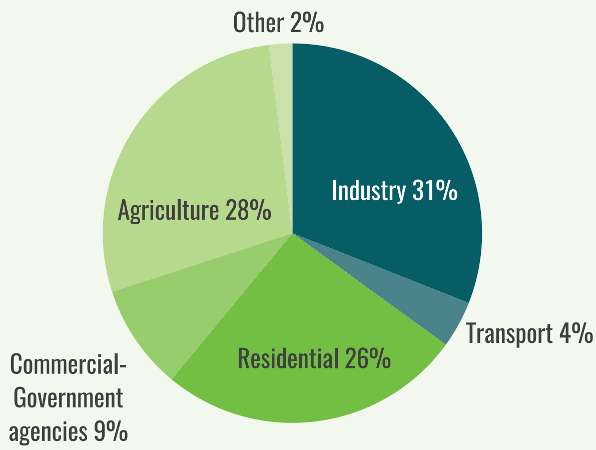
ENERGY CONSUMPTION BY SECTOR IN 2019



Source: Ministry of Energy of the Republic of Uzbekistan (MoE of Uzbekistan). 2021. Pilot fuel and energy balance of the Republic of Uzbekistan for 2019.

FIGURE 11.

ELECTRICITY CONSUMPTION BY SECTOR IN 2019



Source: Ministry of Energy of the Republic of Uzbekistan (MoE of Uzbekistan). 2021. Pilot fuel and energy balance of the Republic of Uzbekistan for 2019.

2.4.2 Challenges

While Uzbekistan has vast resources of fossil fuels and a well extended energy distribution network, the dated and inefficient energy production and distribution infrastructure create challenges. Namely, a substantial part of the power sector assets has been in use for over 30 years, with no major upgrades implemented since its commissioning. The thermal power plants operate at a conversion efficiency of 25 to 35 percent, which is relatively low compared to modern power plants with a combined cycle process that can achieve a conversion efficiency of over 60 percent. Technical losses in the electricity transmission and distribution networks are around 2.7 percent and 12.5 percent, respectively. The natural gas distribution network also suffers from operating issues due to low pressure, which results in losses. Overall, the low level of automation of the power sector assets reduces the capacity to prevent and eliminate technical issues in a timely manner (IEA, 2020a). Moreover, power assets in the country are not placed strategically, with approximately 70 percent of electricity production occurring in the north and 90 percent of gas production in the south (MoE of Uzbekistan, 2020).

Within the agriculture sector, the irrigation systems rely on dated and inefficient irrigation pumps that consume 20 percent of the country's electricity. Moreover, while almost the entire country is technically connected to the water lines and electricity grids, the out-of-date distribution network is the cause for unreliable electricity and water connection in the rural areas. Power outages are common in rural areas, especially during the cold season (ADB, 2019).

One of the reasons for the inadequate investments in maintaining and renewing energy infrastructure may be because of the limited returns from electricity sales due to low electricity tariffs – namely, the tariffs for households and businesses in September 2020 were 0.028 USD/kWh and 0.043 USD/kWh, respectively (GlobalPetrolPrices, 2021). Overall, there are ten different tariff groups, depending on the consumer type and the purpose of electricity use. Socially and financially vulnerable groups are provided support by way of discounts and compensation payments for the rising electricity prices. The socially and financially vulnerable groups are eligible for discounts, which are balanced by the compensation payments from other consumers. The tariffs are determined by the Interdepartmental Tariff Commission and should maintain a profitability of electricity production within the range of 10 to 20 percent (Cabinet of Ministers, 2019). However, the current tariffs are substantially lower than the global averages of 0.139 USD/kWh for households and 0.126 USD/kWh for businesses. This has led to regular increases in prices in recent years in the country.

In response to these challenges, the Government of Uzbekistan adopted the Concept Note for ensuring electricity supply in Uzbekistan in 2020-2030 in May 2020 (MoE of Uzbekistan, 2020). This document defines the objectives, goals and priorities for short- to medium-term development of the country's power sector. The key objectives are to ensure self-sufficiency in electricity generation through increased, modernized and diversified generation capacities; to reduce losses and increase the energy efficiency along the supply chain (production, transmission, distribution and consumption) through modernisation of the existing and construction of new transmission and distribution infrastructure; furthermore, to enhance governance and regulatory framework that will support increased transparency of state-owned utilities, strengthen trans-boundary trade and cooperation and enable the development of competitive wholesale and retail markets. As part of these objectives, special emphasis is placed on the utilisation of renewable energy sources and establishment of renewable energy (RE) market.

2.4.3 Renewable energy policy and outlook by 2030

In 2018, Uzbekistan ratified the Paris Agreement and adopted a national commitment to reduce GHG emissions per unit of GDP by 10 percent by 2030 from the level of 2010 (Government of Uzbekistan, 2018). The achievement of the Intended Nationally Determined Contributions (INDCs) is foreseen through the implementation of climate change mitigation measures aiming at energy efficiency improvements and deployment of renewable energy sources (UNFCCC, 2017).

Regarding the use of renewable energy sources, the Law on the Use of Renewable Energy Sources (RES) of 16 April 2019, together with the Law on Public-Private Partnership of 26 April 2019, create a regulatory and legal basis for accelerating the implementation of renewable energy projects. The law on RES nominates the Ministry of Energy as an authorized state body responsible for implementation of national RES policy, while local governmental bodies participate in the development and implementation of the state and territorial RES programmes. The law also prescribes the rights and responsibilities of the producers of renewable energy as well as RES installations, RES support measures and benefits, features of the use of RES in production of electricity, thermal energy and biogas, state register and tariffs for RES electricity, access to information and rights of citizens and civil society organisations.

To create a favourable investment environment and good conditions for RES producers, a set of state support measures, benefits and preferences have been defined by the law:

- exemption from all type of taxes for the duration of five years for the manufacturers of renewable energy installations;
- exemption from property and land tax for ten years for locations that are utilized for renewable energy generation, with a minimum rated capacity of 0.1 MW;
- exemption from property and land taxes for three years for individuals using renewable energy on residential premises, with disconnection for the existing energy network;
- a guaranteed connection to a single electric power system of RES;
- the right for enterprises owning territorial electric networks to purchase electric energy from energy producers from RES, subject to agreement with a single purchaser of electricity and local governmental bodies;
- possibility of tax and customs benefits for importing renewable energy sources, the use of which significantly increases the efficiency of using renewable energy sources.

It is also worth mentioning that the law prescribes that tariffs for RES electricity must be determined based on competitive bidding. Furthermore, when setting the electricity tariffs for end-consumers, all expenses for the purchase of electricity from all sources of production, including RES, are to be considered.

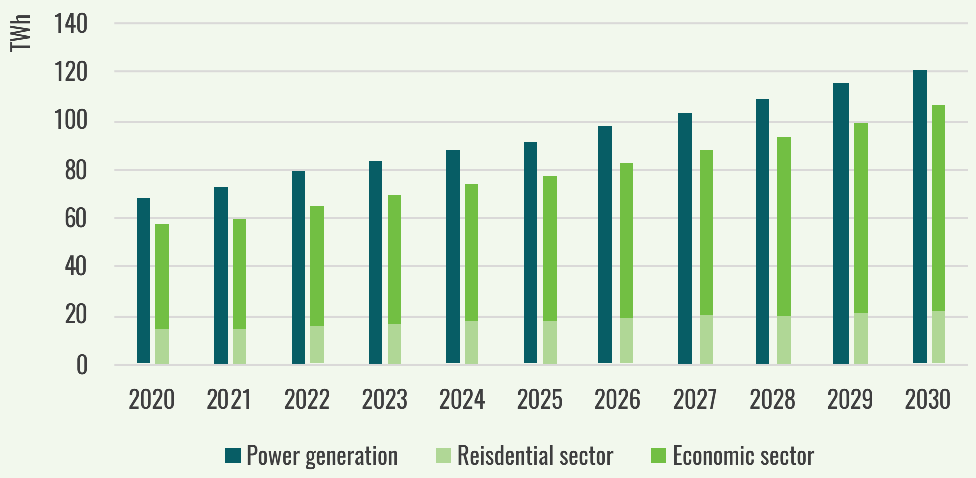
The other regulatory acts relevant for deployment of RES are:

- resolution of the President No.3012 "On program of measures of further development of renewable energy, increase energy effectiveness for the economic and social sectors for 2017-2021" of 26 May 2017;
- resolution of the President No. 3981 "On measures for accelerated development and providing financial sustainability of electric energy industry" of 23 October 2018;
- resolution of the President No. 610 "On approving Regulation for connecting to the unified electric energy system of business operators, producing electric energy, including renewable energy resources" of 22 July 2019;
- decree of the President No. 5646 "On fundamental measures to improve the system of administration over fuel energy industry" of 1 February 2019;
- the Concept Note for ensuring electricity supply in Uzbekistan in 2020 to 2030 as of 4 May 2020.

In order to diversify the electricity generation sources and to ensure the increase in the share of RES in the energy mix, the target of the latter concept sets is for a newly installed capacity of RES by 2030. These include 3.8 MW of hydropower plants, 5 MW of solar energy installations and 3 MW of wind power plants (MoE of Uzbekistan, 2020), which is somewhat higher than that the goal of 1.7 GW set by the Presidential Decree No. PP-4477 (2019). Regarding the targeted share of RES in electricity mix, the Decree of the President of the Republic of Uzbekistan dated 08.22. PP-4422 sets a targeted level of at least 25 percent by 2030. By 2030, it is expected that the nationwide power production will rise to 120.8 TWh, with the residential sector having a share of 21.9 TWh, which is nearly double the demand in 2018. Additionally, the energy demand of the economic sectors will significantly increase up to 85 TWh. The electricity generation and demand, and the RES generation capacities trajectories for the period from 2019 to 2030 are depicted in **Figure 12** and **Figure 13** (MoE of Uzbekistan, 2020).

FIGURE 12.

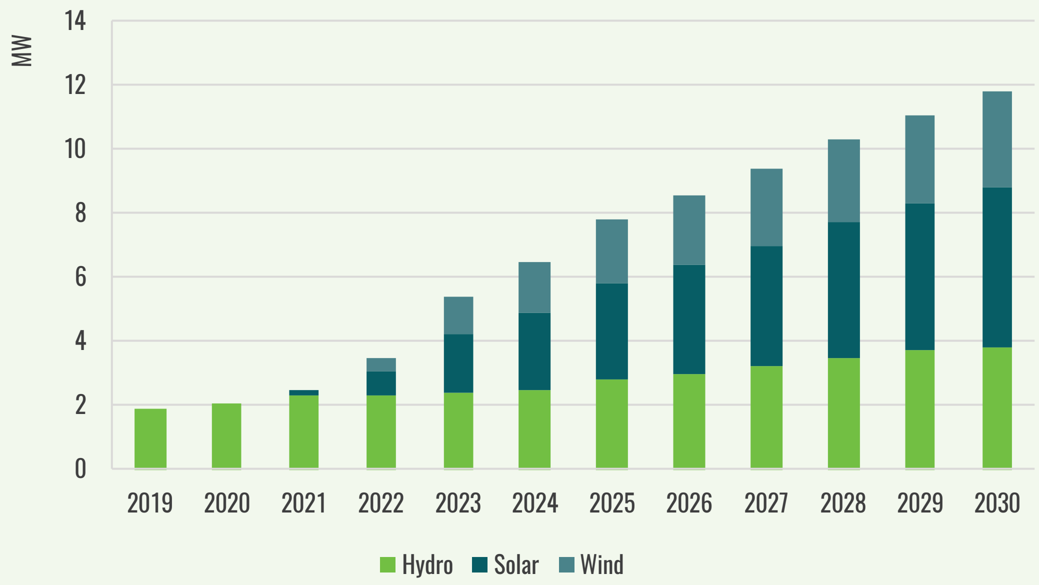
ELECTRICAL POWER GENERATION AND DEMAND OUTLOOK BY 2030



Source: Ministry of Energy of the Republic of Uzbekistan (MoE of Uzbekistan). 2020. Concept Note for ensuring electricity supply in Uzbekistan in 2020-2030. , 43(1): 7728.

FIGURE 13.

INSTALLED CAPACITY FOR RENEWABLES OUTLOOK BY 2030



Source: Ministry of Energy of the Republic of Uzbekistan (MoE of Uzbekistan). 2020. Concept Note for ensuring electricity supply in Uzbekistan in 2020-2030. , 43(1): 7728.

2.4.4 Renewable energy potentials and initiated projects

According to IEA (2019), the country's total (gross) RES potential, excluding bioenergy, is estimated at 117 984 Mtoe, while the technical potential at 179.3 Mtoe. As shown in **Table 1**, solar energy has the largest technical potential of about 177 Mtoe followed by hydro and wind. The solar energy technical potential is almost four times the country's primary energy consumption.

TABLE 1.

RENEWABLE ENERGY POTENTIAL IN UZBEKISTAN

RENEWABLE ENERGY SOURCE	GROSS POTENTIAL (Mtoe)	TECHNICAL POTENTIAL (Mtoe)
HYDROPOWER	9.2	2
WIND POWER	2.2	0.4
SOLAR POWER	50 973	177
GEOTHERMAL ENERGY	67 000	0.3
TOTAL ALTERNATIVE ENERGY SOURCES	117 984	179.3

Source: IEA. 2019. Energy profile Uzbekistan - Report extract Sustainable development. In: *International Energy Agency*. [Cited 19 April 2022]. https://www.iea.org/reports/uzbekistan-energy-profile/sustainable-development#abstract

Although the current electricity production from RES is limited to the hydropower plants managed by the JSC Uzbekhydroenergo, a state-owned hydropower producer, after adoption of the RES regulatory framework and targets and the announced government's plans to increase the RES capacities via public-private partnerships, a number of solar and wind energy projects have been initiated. Many of them are supported by the international financial institutions (IFIs), namely International Finance Corporation (IFC) of the World Bank, European Bank for Reconstruction and Development (EBRD) and the Asian Development Bank (ADB), however other projects have been initiated by private investors who are supported by commercial banks. A list of the initiated programmes and projects and their characteristics are summarized in **Table 2**. The information presented was gathered through an internet search of publicly available information and media coverage.

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TABLE 2.

INITIATED RENEWABLE ENERGY PROJECTS IN UZBEKISTAN

PROJECT NAME	PROJECT STATUS	PLANNED CAPACITY	ESTIMATED TOTAL INVESTMENT	LOCATION ALLOCATED LAND AREA	REFERENCE
MASDAR WIND PROJECT	AGREEMENT SIGNED; OPERATION BY 2024	500 MW	USD 825 MILLION	ZARAFSHON DISTRICT, NAVOI REGION.	EVWIND, 2020; WINDPOWERMONTHLY, 2020; XINHUANET, 2020
KARAKALPAKSTAN WIND PROJECT	TENDER FOR PROPOSALS (70 COMPANIES SUBMITTED)	100 MW		QORAO'ZAK DISTRICT, THE REPUBLIC OF KARAKALPAKSTAN.	PETROVA, 2020; REW, 2020
LIAONING LIDE WIND PROJECT	WIND SPEED MEASUREMENTS STARTED	1 500 MW, (IN 3 PHASES, 1ST PHASE 200 MW).	USD 1.8 BILLION (USD 240 MILLION IN DIRECT FOREIGN INVESTMENT).	GIJDUVAN DISTRICT, BUKHARA REGION 6 000 ha.	KUN, 2019; ORASAM, 2019
ETKO CO ENERJI A.S. WIND PROJECT	PLANNING PHASE	600 MW		BAYSUN DISTRICT, SURKHANDARYA REGION.	GEFCA, 2020
SCALING SOLAR 1	COMMISSIONING PLANNED FOR 2021	100 MW	USD 41 MILLION	NAVOI REGION 270 ha.	WORLD BANK GROUP, 2020
SCALING SOLAR 2	TENDER ISSUED IN FEBRUARY 2020	400 MW IN TWO SPP.		SAMARKAND AND JIZZAKH REGION.	BHAMBHANI, 2020; MOE OF UZBEKISTAN, 2020
SCALING SOLAR 3	PLANNING PHASE	500 MW IN THREE SPPs		BUKHARA, NAMANGAN AND KHOREZM.	KUN, 2020
SHERABAD SOLAR PROGRAMME	TENDER ISSUED FOR THE 1ST PHASE	500 MW (200 MW IN THE 1ST PHASE).		SHERABAD IN THE SURKHANDARYA REGION.	BELLINI, 2020; PUBLICOVER, 2020
NAMANGAN SOLAR PROJECT	APPROVED IN 2019 BY UZBEKISTAN'S MINISTRY OF INNOVATIVE DEVELOPMENT	40 MW		NAMANGAN REGION.	BELLINI, 2019; BHAMBHANI, 2019
SIRDARYA SOLAR PROJECT	COMMISSIONING PLANNED FOR 2023	110 MW		SIRDARYA REGION, 35 ha.	SHUMKOV, 2019
PROJECT FACTORY HYDROPOWER INITIATIVE	ONGOING	907.5 MW (23 PROJECTS).	USD 1.57 BILLION		NSENERGY, 2020
	COMMISSIONING PLANNED FOR 2022	24 MW (IN THREE PLANTS)	USD 60 MILLION	AKSU RIVER: TAMSHUSH, CHAPPASUY, RABAT	MOE OF UZBEKISTAN, 2020; NSENERGY, 2020
		440 MW (IN THREE PLANTS)		MULLALAK, UPPER-PSKEMM, KHOJIKENT	

Source: Authors' own elaboration.

CHAPTER

3

OVERVIEW OF THE RENEWABLE ENERGY RESOURCE POTENTIAL

This section gives an overview of the wind, solar and the biomass energy potential in the three provinces of Uzbekistan: the Republic of Karakalpakstan, Khorezm and Kashkadarya. The analysis of wind and solar potential for electricity generation is based on the publicly available data on wind speed and solar irradiation in Uzbekistan. The biomass assessment of agricultural residues was conducted based on the national agricultural statistics and technical consultation with the national experts active in the field of crop production, soil and livestock production.

3.1 WIND ENERGY POTENTIAL ASSESSMENT

Wind energy, along with solar energy, is the most rapidly growing renewable energy source in the last decade. In 2020 the total installed capacity reached 744 GW, which is equivalent to seven percent of the world's electricity demand. Despite the COVID-19 pandemic, 93 GW of new wind turbines were installed in 2020, around 50 percent more than in 2019 and more than ever installed in one year (WWEA, 2021). If the decrease in installation and operating costs continues, it is estimated that the total installed capacity will increase more than three-fold by 2030, and progressively reach around 6 000 GW by 2050. These expectations regard both onshore and offshore wind farms (IRENA, 2020b).

3.1.1 Approach and methodology

The wind energy potential of a specific area is directly related to the wind speed and temporal distribution (continuity) of the wind. The kinetic energy of wind is utilized to provide mechanical power to a wind turbine, which in turn transforms it to electrical power via a generator. The amount of power that can be produced is dependent on wind speed and technical characteristics of the wind turbine (height, electric capacity of turbine and the length of its blades). The wind speed is affected by different factors, such as the orography of the region, season of the year and the altitude. In addition to the climatic and orographic characteristics, environmental and land-use (anthropogenic) aspects of an area play a crucial role in the utilisation of wind energy, for example, the establishment of wind power plants (WPP). Since WPPs require a relatively large area per installed MW and their operation can impose negative impacts on the environment, land-use aspects are a key parameter for the sustainable siting of WPPs. Finally, the realisation of a wind project will depend on the financial feasibility of the project. The parameters affecting the financial feasibility include wind power density (W/m^2), the topography of the terrain (e.g. slope), distance to the electricity grid, and the capacity of the electricity system (grid) to integrate intermittent electricity production.

Within the scope of this report, the assessment of wind energy potential in Uzbekistan, with a specific focus on the Republic of Karakalpakstan and Khorezm and Kashkadarya Provinces was conducted in several steps.

I. TECHNICAL WIND ENERGY POTENTIAL

▶ a. analysis of mean annual wind speed and power density at a height of 100 m

The data on mean annual wind speed and wind density were derived from Global Wind Atlas 3.0 (GWA), a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP).

This tool offers wind resource mapping at several different heights above the sea level, while also allowing users to assess the variability of wind resource by year, month and hour. The GWA uses a downscaling process, starting with large-scale wind climate data and finishing with microscale wind climate data. Due to the meso- and micro-scale modelling, some uncertainty can be introduced into the calculations.

▶ b. wind speed probability distribution

To make a detailed assessment on the performance of a wind energy system, the wind speed probability distribution function is required. The two-parameter Weibull distribution function can be used to represent the wind speed distribution, considering the scale and shape factors. Moreover, to determine wind speeds at a certain height, the logarithmic velocity profile is utilized, taking into account the roughness length z_0 of the location.

The wind speed probability distribution and the shape and scale factors for the Weibull distribution three regions was based on annual measurements of hourly wind speeds at a height of 10 m at five different locations ¬ three in the Republic of Karakalpakstan, one in Khorezm and one in Kashkadarya (Bahrami *et al.*, 2019).

▶ c. selection of the optimal wind turbine

Seven different wind turbines were analysed to determine the prospects of wind energy utilization in the considered regions: Vestas V105/3450, EnoEnergy 126/3.5, Lagerwey LW72/2000, GE 3.2/130, Multibird M500, Nordex N131/3600 Delta and Aerodyn SCD 8/168. The annual energy production and the capacity factor were the two main parameters that were considered to determine which combination of location and wind turbine yields the optimal result.

Based on the selection of the optimal wind turbine the chosen wind turbine was GE 3.2/130, as it displayed the highest capacity factor among the analysed wind turbines, and was therefore the most effective solution.

A detailed description of the methodology used in this step of the analysis is given in Appendix A.

II. SUSTAINABLE TECHNICAL WPP POTENTIAL

▶ a. identification of WPP exclusion zones

As indicated in section 2.1.1, the establishment and operation of WPP may impose negative environmental impacts, which include biodiversity (e.g. bird and bat populations, fragmentation of habitats) and people (visual impacts, noise, land occupation). Therefore, to minimize potential negative effects and ensure sustainable siting of WPPs, potentially vulnerable areas should be avoided at the onset of wind energy planning.

In this desk-based study, the exclusion areas were defined based on the ESA Climate Change Initiative Land Cover (CCI-LC) data for Uzbekistan (ESA, 2017). The spatial resolution of CCI-LC raster maps is 300 m, and they include 22 land cover classes. The following land cover classes were included in the exclusion zones:

- cropland, irrigated or post-flooding;
- mosaic cropland (>50 percent) / natural vegetation (tree, shrub, herbaceous cover) (<50 percent);
- tree cover, broadleaved, deciduous, closed to open (>15 percent);
- tree cover, needleleaved, evergreen, closed to open (>15 percent);
- tree cover, needleleaved, deciduous, closed to open (>15 percent);
- mosaic tree and shrub (>50 percent) / herbaceous cover (<50 percent);
- urban areas;
- water bodies.

In addition to these land cover classes, nature protected areas were also included in the exclusion zones. The spatial data of nature protected areas in Uzbekistan was derived from the World Database on Protected Areas (WDPA) (IUCN, 2021).

▶ b. distance to the existing and planned transmission lines

The distance of the WPP site to the electricity grid has a direct effect on the investment costs of the WPP. The greater the distance, the higher the costs. Therefore, the areas closer to the electricity grid where a WPP can connect would be preferable for a WPP siting.

The preferable areas for the establishment of WPPs were identified based on the routes of the existing and planned electricity transmission network (high voltage transmission lines) in the Republic of Karakalpakstan, and Khorezm and Kashkadarya Provinces. The analysis is based on the spatial data collected through the Modernization and Upgrade of Transmission Substations Project for Uzbekistan and available in the World Bank's online data catalogue (World Bank Group, 2017). It should be noted that the data (vectoral shapefiles) were derived from digitalized a PDF map, which provides rough locations of the power network. Thus, the information is not sufficient for applications requiring high spatial accuracy, but it is sufficient for the analysis presented in this report (resolution of raster maps used for calculating the area of suitable WPP zones was 300 m).

Distances up to 10 km and 20 km from the existing and planned transmission lines were considered as preferable within the analysed regions.

▶ c. suitable WPP zones

The zones suitable for establishing a WPP were determined as the areas out of exclusion zones and within a 20 km distance from the existing and planned transmission lines. It is assumed that up to 70 percent of the suitable area could be used for the establishment of a WPP.

For the suitable WPP zones, the annual mean wind speeds are grouped in intervals of 1 m/s (e.g. 7-8 m/s), after which the overall area that displays such wind speeds was calculated and expressed in hectares. This information was used as input data for evaluating the potential installed capacity and annual electricity generation.

This step included Geographic Information Systems (GIS) analysis, which was conducted using software application QGIS 3.16.1 – Hannover.

III. POTENTIAL ELECTRICITY PRODUCTION

The area occupied per MW of a constructed WPP depends on the orography and topography of the WPP site, wind directions, wind turbine hub height and blades' length and respective WPP design, etc. Based on the information about the land requirements for the existing onshore WPPs globally (Denholm *et al.*, 2009), it is estimated that 34.5 ha of land per 1 MW of installed capacity is required for a WPP. Taking this into account, it was possible to determine how many wind turbines could be installed within the suitable WPP zones in each province and thus find the potential installed capacity.

The annual energy production potential was then determined based on the annual mean wind speeds considering the 1 m/s intervals. Considering the power curve of the GE 3.2/130 turbine, the annual energy production for the respective area was calculated. The overall wind energy production potential within each province was estimated by summing up each annual energy production (AEP) calculated for areas within different wind speed intervals.

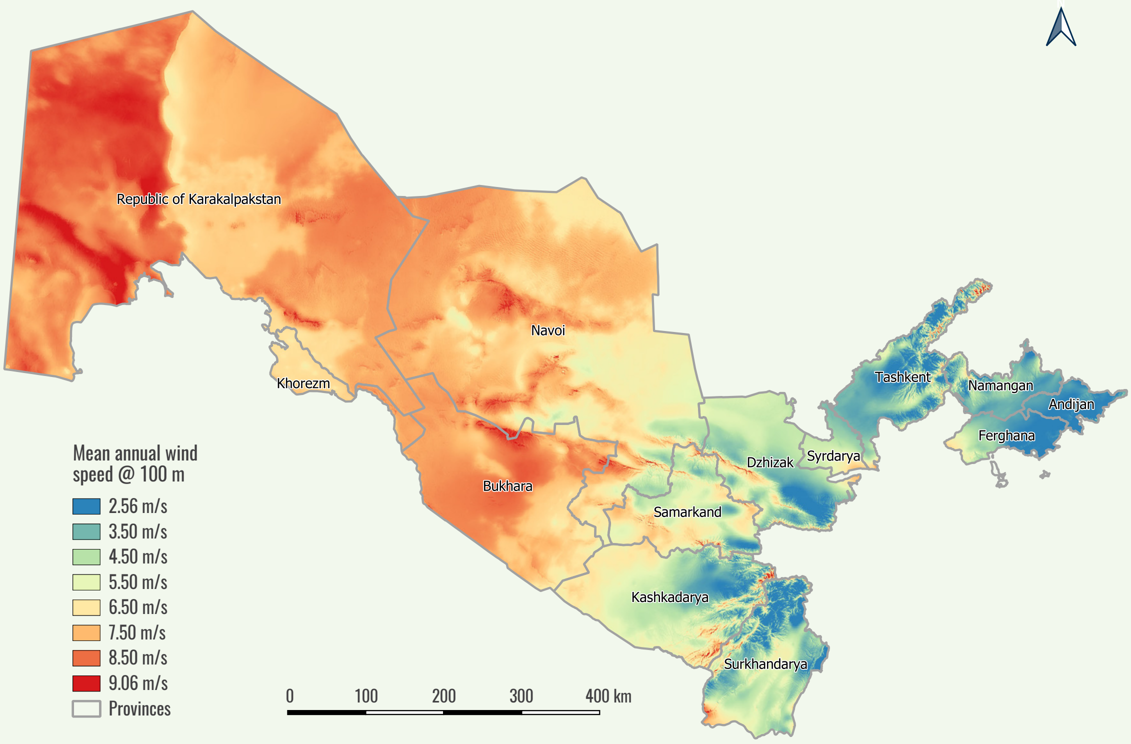
3.1.2 Wind energy potential

3.1.2.1 Uzbekistan

An overview of the annual mean wind speed and power density at a height of 100 m for Uzbekistan is given in **Figure 14** and **Figure 15**, respectively. As described by the legend of **Figure 14** areas marked with blue colours indicate lower mean wind speeds, with the magnitude ranging from 2.5 m/s to 3.5 m/s. On the contrary, the shades of orange colour display annual mean wind speeds 7 m/s to 8.5 m/s, thus having a higher potential for wind energy generation. The red coloured areas have the highest wind speeds, above 8.5 m/s. Similarly, in **Figure 15** areas with a low wind power density of 30 W/m^2 to 100 W/m^2 are marked with shades of blue, while red areas display a power density in the range from 600 W/m^2 to 700 W/m^2. Clearly, there is a direct correlation between wind speed and power density, as areas of higher potential (orange-red) are connected with larger values for these two parameters.

FIGURE 14.

MEAN ANNUAL WIND SPEED AT 100 m

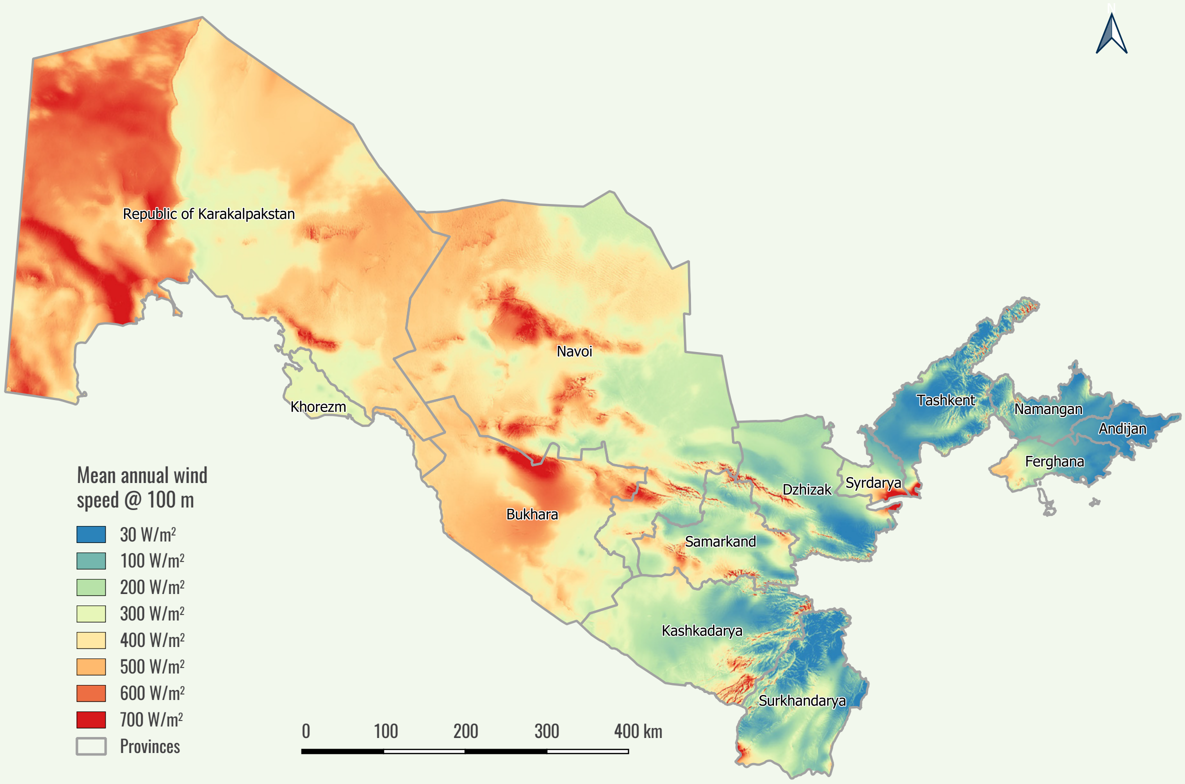


Source: Adapted from Global Wind Atlas. 2022. Global Wind Atlas - Wind profile Uzbekistan. In: *Global Wind Atlas*. [Cited 19 April 2022]. https://globalwindatlas.info/area/Uzbekistan

After determining the suitable sites for a wind energy installation in the three provinces, the potential and performance of the annual energy production were calculated. In all of the analyses, the chosen wind turbine resulted as GE 3.2/130, as it displayed the highest capacity factor and is therefore the most efficient solution.

FIGURE 15.

MEAN ANNUAL WIND POWER DENSITY AT 100 m



Source: Adapted from Global Wind Atlas. 2022. Global Wind Atlas – Wind profile Uzbekistan. In: *Global Wind Atlas.* [Cited 19 April 2022]. https://globalwindatlas.info/area/Uzbekistann

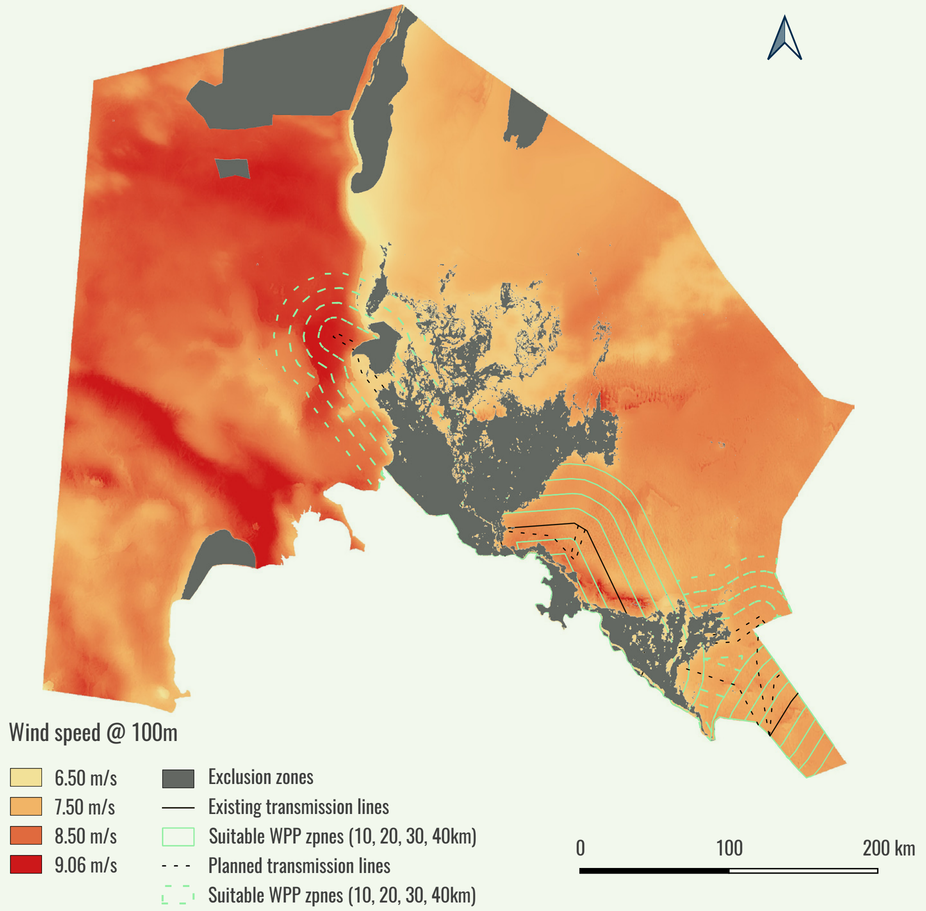
3.1.2.2 The Republic of Karakalpakstan

The Republic of Karakalpakstan shows the largest prospect of the three analysed provinces (as shown in **Figure 14** and **Figure 15**). For much of the area, wind speeds and power densities are approximately 7 m/s to 7.5 m/s and 300 W/m^2 to 500 W/m^2, respectively, while in the western part of the Republic, wind speeds can reach up to 9 m/s. The assessment of the total potential installed capacity of WPPs, the annual electricity production and related investment and operating costs are based on the area within the zones suitable for wind siting in the Republic of Karakalpakstan, as depicted in **Figure 16**.

As indicated in the legend, the grey areas are exclusion zones, while the suitable zones for WPP establishment are detailed with light green lines (full lines represent 10 km, 20 km, 30 km and 40 km buffer zones around the existing transmission lines, while dashed lines the equivalent buffer zones around the planned transmission lines).

FIGURE 16.

THE REPUBLIC OF KARAKALPAKSTAN: SUITABLE ZONES FOR THE ESTABLISHMENT OF WPPS



Source: Adapted from Global Wind Atlas. 2022. Global Wind Atlas - Wind profile Uzbekistan. In: *Global Wind Atlas*. [Cited 19 April 2022]. https://globalwindatlas.info/area/Uzbekistan

Table 3 shows the total area of suitable WPP zones expressed in hectares, grouped in intervals of mean wind speeds in each of the suitable zone groups and subgroups (buffer zones). The techno-economic analysis assumes that WPPs have been established on 70 percent of the total area within the suitable WPP zones.

Based on the wind speed and technical characteristics of optimal wind turbines the wind energy potential in the best performing areas of the WPP suitable zones was evaluated: suitable WPP areas within a 10 km distance along the transmission lines where wind speed is higher than 7.5 m/s. The number of wind turbines, thus the potential installed capacity, was calculated with the assumption that approximately 34.5 ha are required for 1 MW of installed capacity in a wind farm (Denholm *et al.*, 2009). The annual energy production for the respective areas was calculated based on the power curve of the GE 3.2/130 turbine (see Appendix A). The potential AEP of the province was calculated by tallying up the AEP for each wind speed interval. The results are presented in **Table 4**.

TABLE 3.

THE REPUBLIC OF KARAKALPAKSTAN: AREA AND MEAN ANNUAL WIND SPEED IN THE SUITABLE WPP ZONES

DISTANCE TO THE TRANSMISSION LINES	WIND SPEED (m/s)	EXISTING TRANSMISSION LINES		PLANNED TRANSMISSION LINES	
		AREA SUITABLE FOR WPP SITING (ha)	AREA SUITABLE FOR WPP SITING (70% OF TOTAL) (ha)	AREA SUITABLE FOR WPP SITING (ha)	AREA SUITABLE FOR WPP SITING (70% OF TOTAL) (ha)
<10 km	6–7	0	0	41 162	28 813
	7–8	9 649	6 754	187 927	131 549
	8–9	234 115	163 880	47 644	33 351
	>9	79 629	55 740	83 857	58 700
10–20 km	6–7	0	0	15 444	10 811
	7–8	13 286	9 300	163 585	114 510
	8–9	207 345	145 142	75 076	52 553
	>9	62 648	43 853	66 358	46 450

Source: Authors' own elaboration.

TABLE 4.

THE REPUBLIC OF KARAKALPAKSTAN: WIND ENERGY POTENTIAL IN THE BEST PERFORMING SITES WITHIN SUITABLE WPP ZONES

DISTANCE FROM THE TRANSMISSION LINES		WPP SITING AREA (ha)	NUMBER OF TURBINES	POTENTIAL INSTALLED CAPACITY (MW)	POTENTIAL ANNUAL ELECTRICITY PRODUCTION (GWh/year)
EXISTING TL	**<10 km**	226 374	2 050	6 561	30 912
PLANNED TL	**<10 km**	223 600	2 025	6 481	25 989
TOTAL		**449 974**	**4 075**	**13 042**	**56 901**

Source: Authors' own elaboration.

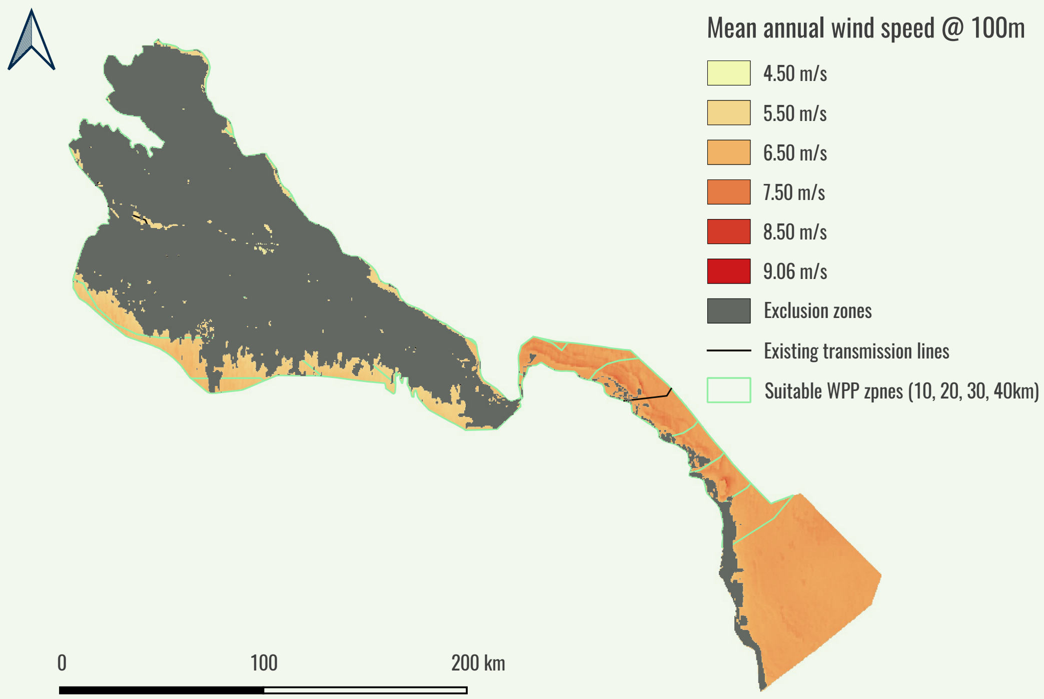
As presented in **Table 4**, more than 13 GW WPPs could be installed within the best performing areas for the establishment of WPPs in the Republic of Karakalpakstan, resulting in an annual electricity production of 56 901 GWh. In comparison, this would be sufficient to supply the total electricity consumption in Uzbekistan in 2019, which was around 54 174 GWh.

3.1.2.3 The Khorezm Province

In Khorezm, wind speeds and wind power densities are typically within a range between 6 m/s and 7.5 m/s, and 250 W/m^2 and 325 W/m^2 at 100 m, respectively, therefore stressing the potential of the region. As seen in **Figure 14** the annual mean wind speed displays uniformity throughout the whole province; the district of Khazarsp has the highest speeds. The techno-economic assessment of wind potential utilisation is based on the assumption that the WPPs are established within the zones suitable for wind siting in Khorezm, which are presented in **Figure 17**. The grey areas in the figure represent the exclusion zones, while the suitable zones for WPP establishment are detailed with light green lines around the existing and planned transmission lines (full lines represent 10 km, 20 km, 30 km and 40 km buffer zones around the existing transmission lines, while dashed lines the equivalent buffer zones around the planned transmission lines).

FIGURE 17.

THE KHOREZM PROVINCE: SUITABLE ZONES FOR THE ESTABLISHMENT OF WPPS



Source: Adapted from Global Wind Atlas. 2022. Global Wind Atlas - Wind profile Uzbekistan. In: *Global Wind Atlas*. [Cited 19 April 2022]. https://globalwindatlas.info/area/Uzbekistan

Table 5 shows the total area of suitable WPP zones expressed in hectares, grouped in intervals of mean wind speeds in each of the suitable zone groups and subgroups (buffer zones). The techno-economic analysis assumes that WPPs are established on 70 percent of the total area within the suitable WPP zones.

TABLE 5.

THE PROVINCE OF KHOREZM: AREA AND MEAN ANNUAL WIND SPEED IN THE SUITABLE WPP ZONES

DISTANCE TO THE TRANSMISSION LINES	WIND SPEED (m/s)	EXISTING TRANSMISSION LINES		PLANNED TRANSMISSION LINES	
		SUITABLE WPP ZONE (ha)	WPP SITING AREA (ha)	SUITABLE WPP ZONE (ha)	WPP SITING AREA (ha)
<10 km	6–7	11 394	7 976	0	0
	7–8	22 443	15 710	36	25
	8–9	4 533	3 173	0	0
10–20 km	6–7	9 007	6 305	0	0
	7–8	25 944	18 161	77	54
	8–9	3 610	2 527	0	0

Source: Authors ' own elaboration.

As in the case of the Republic of Karakalpakstan, it is assumed that 34.5 ha are required for 1 MW of installed capacity in a wind farm (Denholm *et al.*, 2009). Based on this estimate, the number of wind turbines that can be installed within 10 km along the transmission lines where the wind speed is higher than 7.5 m/s. The potential installed capacity of WPPs and the respective potential annual electricity production was then calculated based on the power curve of the GE 3.2/130 turbine. The results are presented in **Table 6**.

Due to relatively limited area suitable for the establishment of WPPs in the Khorezm Province compared to the Republic of Karakalpakstan, if the best performing sites were utilized and 547 MW of WPP installed, the annual electricity production of 1 857 GWh would surpass the total electricity consumed in that province in 2019, which was round 1 766 GWh.

TABLE 6.

THE PROVINCE OF KHOREZM: WIND ENERGY POTENTIAL IN THE BEST PERFORMING SITES WITHIN SUITABLE WPP ZONES

DISTANCE FROM THE TRANSMISSION LINES		WPP SITING AREA (ha)	NUMBER OF TURBINES	POTENTIAL INSTALLED CAPACITY (MW)	POTENTIAL ANNUAL ELECTRICITY PRODUCTION (GWh/year)
EXISTING TL	**<10 km**	18 883	171	547	1 857

Source: Authors 's own elaboration.

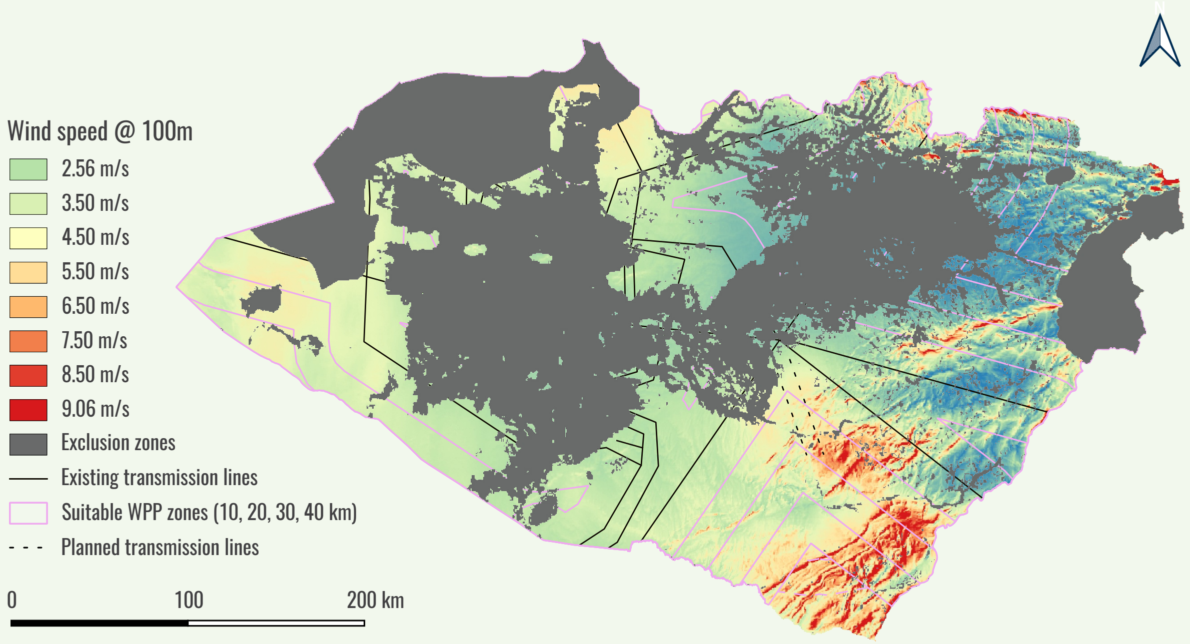
3.1.2.4 The Kashkadarya Province

The annual mean wind speeds and the wind energy density in the Kashkadarya Province are comparatively lower than those in the Republic of Karakalpakstan and Khorezm Province. Overall, the annual mean wind speeds are typically low, with the majority of the province showing values of approximately 3 m/s–4 m/s at a height of 100 m. Despite small areas that indicate slightly better conditions for wind energy utilization, the overall wind energy potential of Kashkadarya appears to be moderate (**Figure 14**). The zones suitable for WPP establishment in Kashkadarya are presented in **Figure 18**. The grey areas in the figure represent the exclusion zones, while the suitable zones for WPP establishment are depicted with light green lines around the existing and planned transmission lines (full lines represent 10 km, 20 km, 30 km and 40 km buffer zones around the existing transmission lines, while dashed lines the equivalent buffer zones around the planned transmission lines).

Table 7 shows the total area of suitable WPP zones, expressed in hectares, grouped in intervals of mean wind speeds in each of the suitable zone groups and subgroups (buffer zones). The potential installed capacity of WPPs, their energy production and required investment and operating costs were calculated assumes that WPPs are established on 70 percent of the total area within the suitable WPP zones.

FIGURE 18.

THE KASHKADARYA PROVINCE: SUITABLE ZONES FOR THE ESTABLISHMENT OF WPPS



Source: Adapted from Global Wind Atlas. 2022. Global Wind Atlas - Wind profile Uzbekistan. In: *Global Wind Atlas.* [Cited 19 April 2022]. https://globalwindatlas.info/area/Uzbekistan

The potential installed capacity in the best performing areas of the Kashkadarya Province and the respective annual electricity production were calculated in the same way as the other two analysed provinces. The best performing areas would be located on sites within a distance of 10 km from the transmission lines, where the wind speed is higher than 7.5 m/s (see **Table 8**).

Compared to the other two regions, the wind speeds across Kashkadarya are considerably lower, especially in the northern and north-western parts of the province, which reflects on the potential electricity production. As seen in **Table 8**, within the suitable WPP zones the area where the wind speed is higher than 7.5 m/s is sufficient for the installation of 117 MW of WPPs. The respective WPPs would have a potential for a production of 625 GWh annually. This is equivalent to 11 percent of the total electricity consumed in Kashkadarya in 2019.

TABLE 7.

THE PROVINCE OF KASHKADARYA: AREA AND MEAN ANNUAL WIND SPEED IN THE SUITABLE WPP ZONES

DISTANCE TO THE TRANSMISSION LINES	WIND SPEED (m/s)	EXISTING TRANSMISSION LINES	
		SUITABLE WPP ZONE (ha)	WPP SITING AREA (ha)
<10 KM	2.5–3	5 070	3 549
	3–4	71 242	49 870
	4–5	221 794	155 256
	5–6	310 611	217 428
	6–7	161 064	112 745
	7–8	6 650	4 655
	8–9	1 847	1 293
	>9	250	175
10–20 KM	2.5–3	2 056	1 439
	3–4	32 043	22 430
	4–5	55 177	38 624
	5–6	131 211	91 848
	6–7	91 083	63 758
	7–8	14 300	10 010
	8–9	2 207	1 545
	>9	290	203

Source: Authors' own elaboration.

TABLE 8.

THE KASHKADARYA PROVINCE: WIND ENERGY POTENTIAL IN THE SUITABLE WPP ZONES AND RELATED INSTALLATION AND OPERATING COSTS

DISTANCE FROM THE TRANSMISSION LINES		WPP SITING AREA (ha)	NUMBER OF TURBINES	POTENTIAL INSTALLED CAPACITY (MW)	POTENTIAL ANNUAL ELECTRICITY PRODUCTION (GWh/year)
EXISTING TL	**<10 km**	6 123	37	117	625

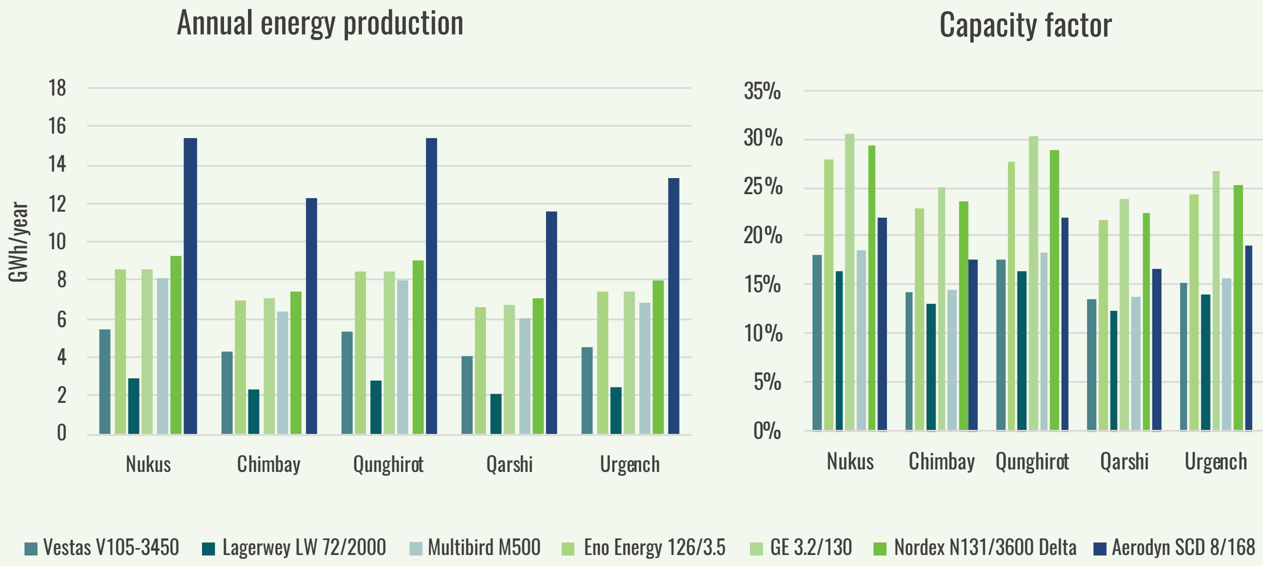
Source: Authors' own elaboration.

BOX 1: ASSESSMENT OF WIND ENERGY POTENTIAL FOR FIVE SELECTED LOCATIONS

The probability distribution function of wind speeds is a vital means for making a detailed assessment of the wind energy potential of a region. When experimental data is not available, the Weibull distribution (described in the Appendix A) can be utilized. Its two parameters, the shape and scale factors, are used to estimate the wind speed frequency distribution. **Figure 50** in the Appendix A displays an example of where Weibull parameters of interest obtained from the literature were used to illustrate the assessment of wind potential for five locations within the provinces. Chimbay, Qunghirot and Nukus are the locations in the Republic of Karakalpakstan, while Qarshi is in the Province of Kashkadarya and Urgench in Khorezm Province. Using the respective shape and scale factors for the five locations, it was possible to create the wind speed frequency distribution. For the assessment, seven different wind turbines were analysed to identify the optimal choice for the specific location. The annual energy production (AEP) was calculated by combining their respective power curve with the Weibull distribution in each location. The performance of each turbine was also assessed based on the capacity factor (CF), which expresses the power output of the system as a percentage of the maximum power capacity. The results of the assessment are presented **Figure 19**, where array losses and electrical conduction losses were taken as 10 percent and 5 percent, respectively, while also considering a 90 percent availability. Based on these findings, the optimal combination of location and wind turbine can be determined.

FIGURE 19.

ANNUAL ELECTRICITY PRODUCTION AND CAPACITY FACTOR IN THE FIVE SELECTED LOCATIONS.



Source: Authors' own elaboration

It is evident that the Aerodyn SCD 8/168 wind turbine has the highest output in all the locations. More precisely, Nukus and Qunghirot display the highest AEP with 15.43 GWh/year and 15.48 GWh/year, respectively. The least promising results appear in Qarshi, with an annual production of 11.62 GWh/year. Although Aerodyn SCD 8/168 has the highest outputs, its capacity factor is significantly lower compared to other turbines, indicating that its operation is not very effective and thus it is not the preferred choice. On all locations, Nordex N131/3600 Delta, Eno Energy 126/3.5 and GE 3.2/130 display by far the highest capacity factors, with the latter being the most efficient option. Using this turbine, Qarshi has the lowest AEP and capacity factor among the chosen sites, namely 6.65 GWh/year and 21.7 percent respectively. Again, Nukus and Qunghirot appear to be the most promising locations. In the case of Nukus, the AEP is 8.57 GWh/year and the capacity factor 30.6 percent, which is the highest value that can be observed. In Qunghirot the GE 3.2/130 wind turbine can generate 8.45 GWh/year, with a capacity factor of 30.2 percent, while in Urgench 7.47 GWh could be produced annually.

3.1.3 Investment requirements

The overall capital investment for WPP entails the cost of equipment, construction and connection to the grid, as well as the preparation of the project document, land acquisition and licencing. Finally, there are also costs related to WPP deployment. The investment costs differ from one country to another, depending on the site-specific conditions and requirements, e.g. logistics and limitations for transportation, locally applicable policies, land-use limitations, and labour costs.

Since there is no utility level WPPs operating in Uzbekistan, the information about the country specific investment requirements per capacity unit is limited. Therefore, in this study the estimated range of the investment requirements was determined by using the global weighted average specific investment costs in 2019, and furthermore for comparing the equivalent values obtained for Euroasia (EA) and Other Asia (OA), as defined in the RES costing report by IRENA (IRENA, 2020b). The global average (GA) capital investment cost in 2019 were 1 473 USD per kW installed capacity, in Euroasia it was 1 633 USD/kW while in the Other Asia region 2 358 USD/kW.

The maintenance and operation costs of WPP include the costs of maintaining the turbines (e.g. lubrification), repair and spare parts, insurance and administrative costs. The annual O&M costs can vary considerably, often depending on the availability of specialized services and components. According to the IRENA's report: Renewable Power Generation Costs in 2019 (IRENA, 2020b), the annual O&M costs in the WPP operating in 2019 varied between 0.006 USD and 0.2 USD per generated kWh.

In this study, the investment requirements and annual operating and maintenance costs were analysed for tree scenarios related to the national 2030 RES targets:

- scenario 1: establishment of total capacity of 3 000 MW and 1 700 MW on the national level;
- scenario 2: establishment of WPPs in each region at the capacity level that would be sufficient to supply the whole regional electricity demand in 2030;
- scenario 3: establishment of WPPs in each region at the capacity level that would be sufficient to supply the 25 percent of the regional electricity demand in 2030.

The regional electricity demand in 2030 was estimated based on the projected national consumption in 2030 (MoE of Uzbekistan, 2020), and the regional shares in electricity supplied in 2019 (UZSTAT, 2021a).

SCENARIO 1: ESTABLISHMENT OF WIND POWER PLANTS WITH A TOTAL INSTALLED CAPACITY OF 1.7 GW AND 3 GW

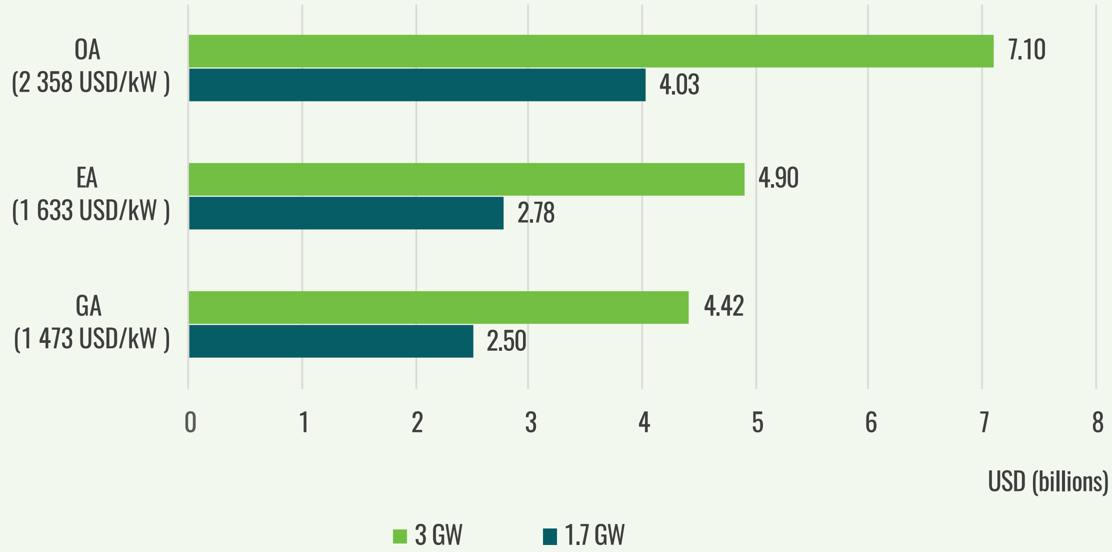
Assuming that the specific capital investment costs for WPP vary from 1 473 USD/kW (GA) to 2 358 USD/kW (OA), it is possible to determine the overall investment requirements to meet the national targets for 2030. Two separate WPP installed capacity targets have been mentioned, namely 1 700 MW and 3 000 MW. As seen in **Figure 20**, for an overall installed capacity of 1.7 GW, the investment requirements range from USD 2.5 billion to USD 4.03 billion. For the deployment of 3 GW of WPPs, the overall investments would range between USD 4.42 billion and USD 7.10 billion for the GA and the OA specific investment costs, respectively.

The regulatory framework for RES deployment in Uzbekistan is still under development and the wind power market development will coincide with its full implementation. Thus, it can be expected that the specific investment costs for WPPs would initially be closer to the higher estimated cost range and are subjected to decrease over time, as the strengthening of regulations along with capacity and market development can result in cost reductions.

With the estimated range of annual O&M costs between USD 0.006 and USD 0.02 per generated kWh, the yearly expenditure for the operation and maintenance of 1.7 GW WPPs would vary between USD 46.3 million and USD 154.4 million per year. Similarly, for an installed capacity of 3 GW, the annual O&M costs are in the range of USD 76.5 million to USD 254.8 million.

FIGURE 20.

ESTIMATED INVESTMENT REQUIREMENTS FOR THE DEPLOYMENT OF 1.7 GW AND 3 GW IN WPPs



Source: Authors' own elaboration.

SCENARIO 2: ESTABLISHMENT OF WPPs IN EACH REGION AT THE CAPACITY LEVEL THAT WOULD BE SUFFICIENT TO SUPPLY THE WHOLE REGIONAL ELECTRICITY DEMAND IN 2030

In this scenario, first the projected regional electricity demand in 2030 was calculated, next the required capacity of WPPs necessary to supply that demand was estimated. As seen in **Table 9**, the potential wind power capacity in the Republic of Karakalpakstan is far above the national targets for installed capacity of WPPs in 2030 and can fully cover the regional electricity demand in 2030.

TABLE 9.

REGIONAL WIND POWER POTENTIAL AND REGIONAL ELECTRICITY DEMAND IN 2030

REGION		AREA OF BEST PERFORMING SUITABLE WPP ZONES (ha)	POTENTIAL WIND POWER CAPACITY (MW)	ANNUAL ENERGY PRODUCTION (GWh/year)	REGIONAL ELECTRICITY DEMAND IN 2030 (GWh/year)	WIND POWER CAPACITY FOR 2030 DEMAND (MW)	WIND POWER CAPACITY FOR 25% OF 2030 DEMAND (MW)
KARAKALPAKSTAN	EXISTING TL	226 374	6 562	30 907	3 769	670	168
	PLANNED TL	223 600	6 481	25 989			
KHOREZM		18 883	547	1 857	3 936	1 159	290
KASHKADARYA		6 123	177	625	12 475	3 533	883
TOTAL		**474 980**	**13 767**	**59 378**	**20 180**	**5 362**	**1 341**

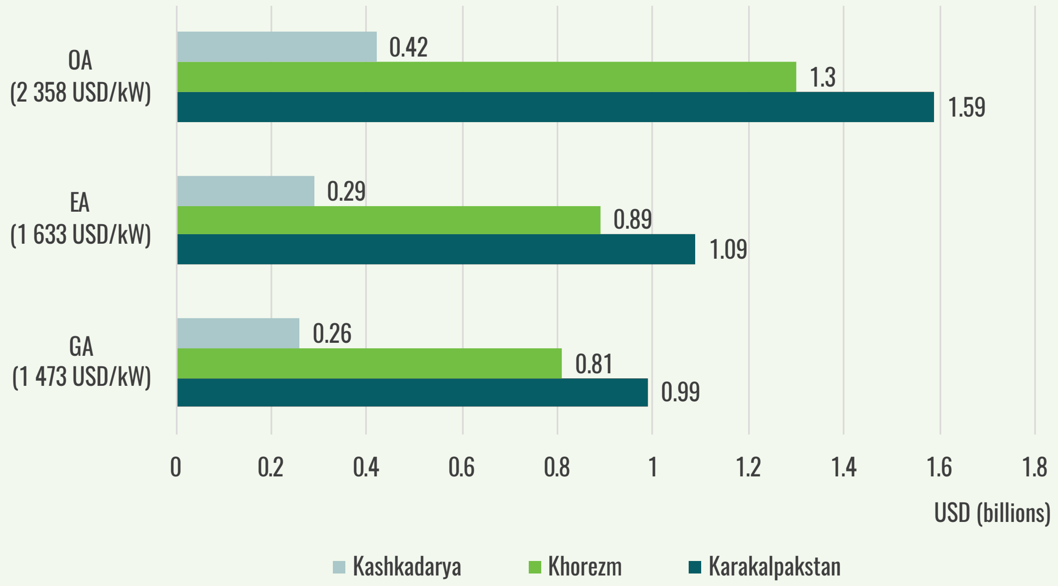
Source: Authors ' own elaboration.

In the Republic of Karakalpakstan, the potential installed capacity for WPP is significantly higher as compared to the other two provinces, due to higher availability of suitable WPP zones. The wind energy potential in Karakalpakstan can completely cover the electricity demand of the province in 2030, requiring an installed capacity of 670 MW. In Kashkadarya, based on the best performing WPP zones the potential installed capacity would be 117 MW, which is sufficient to supply 5 percent of the regional electricity demand in 2030. Lastly, the Province of Khorezm displays a potential deployment of 547 MW for WPPs in the best performing zones. While this is not sufficient to fully cover the electricity demand of the region in 2030, it can contribute to 47 percent of the total.

Taking into account the different capital investments for Eurasia, Other Asia and the equivalent global average price, it is possible to determine the required costs for completely covering the regional electricity demand in 2030, as presented in **Figure 21**. As mentioned previously, for Kashkadarya only 5 percent of the demand can be met using WPPs, while for Khorezm as much as 47 percent. The respective costs for these percentages are given in the graph. For the Republic of Karakalpakstan, the capital costs to fully meet the regional electricity demand in 2030 vary from USD 0.99 billion to USD 1.59 billion. In the case of Kashkadarya, the investment for supplying 5 percent of the regional electricity demand is USD 0.26 billion to USD 0.42 billion, while for Khorezm the range is USD 0.81 billion to USD 1.30 billion to supply 47 percent of the demand.

FIGURE 21.

CAPITAL INVESTMENT REQUIREMENTS FOR SUPPLYING REGIONAL ELECTRICITY DEMAND FROM WPPS IN 2030



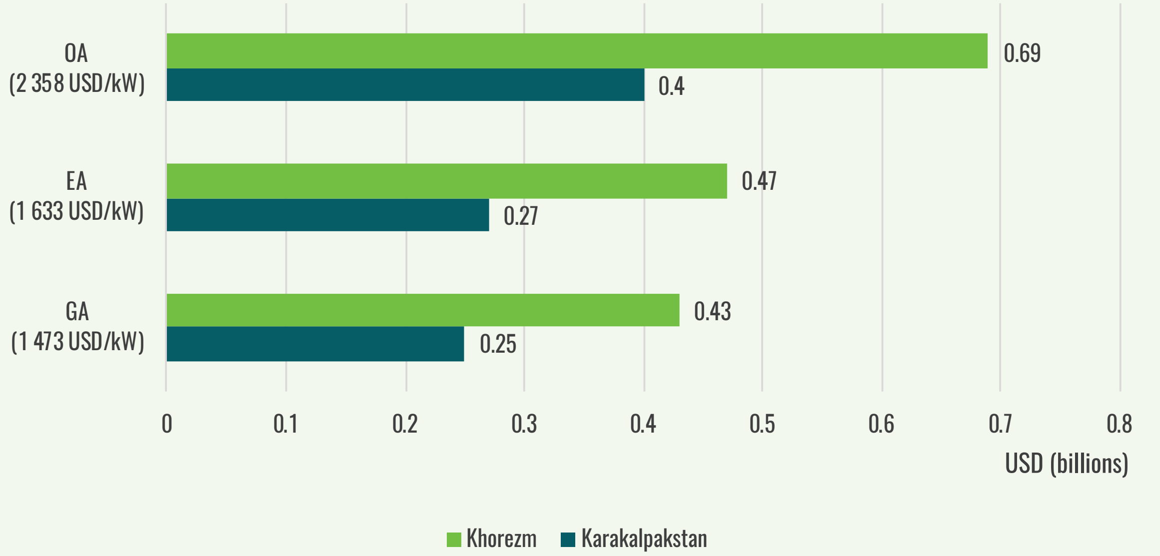
Source: Authors' own elaboration.

SCENARIO 3: ESTABLISHMENT OF WPPs IN EACH REGION AT THE CAPACITY LEVEL THAT WOULD BE SUFFICIENT TO SUPPLY THE 25 PERCENT OF THE REGIONAL ELECTRICITY DEMAND IN 2030

As presented previously, the required WPP installed capacity to supply 25 percent of the regional electricity demand in 2030 for the Republic of Karakalpakstan and Khorezm is 168 MW and 290 MW respectively. Kashkadarya does not have sufficient wind energy potential to meet this demand. As depicted in **Figure 22**, in the Republic of Karakalpakstan the required capital investments for the deployment of WPP are within the range of USD 0.25 billion and USD 0.40 billion. Similarly, in the case of Khorezm the required investments vary between USD 0.43 billion to USD 0.69 billion.

FIGURE 22.

CAPITAL INVESTMENT REQUIREMENTS FOR SUPPLYING 25 PERCENT OF THE REGIONAL ELECTRICITY DEMAND FROM WPPS IN 2030



Source: Authors' own elaboration.

3.2 SOLAR ENERGY POTENTIAL ASSESSMENT

The production of electricity in solar photovoltaic (PV) power plants has been gathering increasing attention in recent years, with the overall installed capacity displaying a continuously upward trend and PV module prices decreasing by 80 percent since 2010 (IRENA, 2020b). In 2019 the global installed capacity for solar PV was 603 GW, generating 665 TWh of electricity annually (IEA, 2020b). Approximately 140 GW are estimated to have been added in 2020, which is the highest addition among all renewable energy technologies for the year (ESMAP, 2020). By 2030, it has been estimated that the overall global installed capacity will increase by more than three-fold, while in 2040 it will reach up to 3 655 GW (IEA, 2020b).

The theoretical solar energy potential of a spatially defined area can be best described by the Global Horizontal Irradiation (GHI), which represents the amount of shortwave radiation received by a surface horizontal to the ground. GHI is comprised of the Direct Normal Irradiation (DNI) and the Diffuse Horizontal Irradiation (DHI), and is measured in kWh/m^2 (Vaisala Energy, 2021). The Global Horizontal Irradiation (GHI) is the most important parameter for determining the potential of a certain location for converting solar energy into useful energy, i.e. generate electricity.

The technical solar PV potential is derived from the theoretical potential and the conversion efficiency of the used PV modules and SPP design. The conversion efficiency of a PV panel is the percentage of solar energy that can be converted into usable electricity. The prevailing environmental conditions at the SPP site also affect the conversion efficiency and therefore should also be considered. The relevant parameters include latitude, terrain elevation and shading, the occurrence of clouds, as well as atmospheric moisture content and aerosol and dust concentration.

In addition, when considering sustainable technical potential for a defined area, regulatory constraints regarding land use, environmental and nature protection as well as good practices in landscape management are taken into account. Finally, the economic potential identifies the proportion of technical potential that can be utilized economically.

The scope of this report is the assessment of the theoretical and sustainable technical solar energy potential for generating electricity in utility level (large scale) PV plants in The Republic of Karakalpakstan, Khorezm and Kashkadarya Provinces. As a baseline, the theoretical potential of Uzbekistan is also described. Finally, the regional potentials were compared with the national renewable energy targets and the necessary capital investments for deployment of SPPs then evaluated.

3.2.1 Approach and methodology

In this desk-based assessment, the baseline data on solar irradiation and technical solar potential were obtained from the “Global Solar Atlas 2.0”. It is a free, web-based application that is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Programme (ESMAP).

This tool offers solar resource mapping at different locations, allowing users to assess the variability of solar resources. Additionally, it offers the possibility to conduct a solar energy assessment for chosen locations, calculating the potential power output of a solar PV installation. The estimated uncertainty of the input solar radiation data is 4 to 8 percent, which can reach up to 10 percent in regions with complex geography.

Auxiliary spatial data and information used in the assessment, as described below, were also obtained from public domain. The spatial analyses were conducted using software application QGIS 3.16.1 – Hannover.

3.2.1.1 Theoretical solar energy potential

The theoretical solar energy potential in Uzbekistan, and the three analysed regions, is presented with GHI maps derived from the Global Solar Atlas. The maps represent a long-term yearly average of the total horizontal irradiation, expressed in kWh/m^2. The temporal coverage used in the GHI modelling was 1999-2018 and the spatial resolution of the maps is around 250 m (Global Solar Atlas, 2021).

3.2.1.2 Sustainable technical solar PV potential

The sustainable technical PV potential was evaluated for the Republic of Karakalpakstan, Khorezm and Kashkadarya Provinces. The assessment was carried out in two steps. First, the area suitable for SPPs was identified through a spatial analysis of the environmental characteristics and technical requirements for SPP establishment. Then, in the second step, the technical solar PV potential was evaluated for a portion of the area suitable for establishment of utility level SPPs.

I. SUSTAINABLE SITING OF SOLAR PV PLANTS

▶ **a. Identification of SPP exclusion zones**

The establishment and operation of ground-mounted PV plants may impose negative environmental impacts, such as impacts on biodiversity (e.g. fragmentation and loss of habitats) and people (visual impacts, land occupation). Therefore, to minimize potential negative effects and ensure sustainable siting of SPPs, potentially vulnerable areas should be avoided at the onset of solar energy planning.

The exclusion areas included nature protected areas and land cover classes potentially vulnerable to negative impacts of SPP establishment. The spatial data of nature protected areas in Uzbekistan was derived from the World Database on Protected Areas (WDPA) (IUCN, 2021), while the land-cover classes were defined based on the ESA Climate Change Initiative Land Cover (CCI-LC) data for Uzbekistan (ESA, 2017). The spatial resolution of CCI-LC raster maps is 300 m that include 22 land cover classes. The following land cover classes were included in the exclusion zones:

- cropland, irrigated or post-flooding;
- mosaic cropland (>50 percent) / natural vegetation (tree, shrub, herbaceous cover) (<50 percent);
- tree cover, broadleaved, deciduous, closed to open (>15 percent);
- tree cover, needleleaved, evergreen, closed to open (>15 percent);
- tree cover, needleleaved, deciduous, closed to open (>15 percent);
- mosaic tree and shrub (>50 percent) / herbaceous cover (<50 percent);
- shrubland;
- urban areas;
- water bodies.

In addition, areas where the slope of terrain is higher than 5 degrees were excluded due to technical constraints for construction on such terrains.

b. Distance to the existing and planned transmission lines

Distance of SPP sites to the electricity grid has a direct effect on the investment costs. The larger the distance, the higher the costs. Therefore, the areas closer to the electricity grid to which a SPP can connect will be preferable for SPP siting.

The preferable areas in the three regions were categorized into two main groups: land around the existing transmission lines and land around the planned transmission lines. In both cases distances up to 40 km from the transmission lines were analysed. Upon initial analysis, the focus was put on the buffer zones up to 20 km.

The analysis is based on the spatial data collected through the project Modernization and Upgrade of Transmission Substations in Uzbekistan and available in the World Bank's online data catalogue (World Bank Group, 2017). It should be noted that the data (vectoral shapefiles) were derived from a digitalized PDF map, which provides rough locations of the power network. Thus, the information is not sufficient for applications requiring high spatial accuracy, however it is sufficient for the analysis presented in this report (resolution of raster maps used for calculating the area of suitable SPP zones is around 250 m).

Finally, the zones suitable for SPP establishment were determined as the areas outside of exclusion zones and within 20 km distance from the existing and planned transmission lines. For the assessment of practical solar potential, it was assumed that up to 30 percent of the SPP suitable zones could be used for the SPP establishment.

II. TECHNICAL SOLAR PV POTENTIAL

The data for estimating technical solar PV potential were obtained from the PV output (technical potential of solar PV system -PVOUT) raster files available from the Global Solar Atlas 2.0. The PVOUT (kWh/kWp) is calculated based on the output of a typical PV system and expresses the average annual power generation of the installation per unit of installed capacity. The Solargis calculations assume a large-scale installation with monofacial crystalline silicon PV modules fixed at optimal tilt angle, so as to ensure a maximized annual energy yield. Moreover, topographic and land use constraints are also considered, as well as other factors affecting the system efficiency. The soiling losses are taken as 3.5 percent, while losses related to interrow shading, mismatching, inverters, cables and transformers as 7.5 percent. The PVOUT data is based on the temporal aggregation of monthly and hourly (12x24) profiles, and the spatial resolution of raster data is around 1 km.

It should be noted that the PVOUT calculations assume system availability of 100 percent, meaning that the profiles of seasonal variability are not fully considered. As solar energy is an intermittent energy source, the fluctuations in operation can pose economic and technological challenges to the exploitation of PV electricity (ESMAP, 2020). Hence, when assessing production potential and economic performance of a particular SPP, a more detailed analysis would be needed.

The area occupied per MW of a constructed ground-mounted solar PV plant depends on several parameters, such as the topography and orography of the site. On average, SPPs occupy 3 ha of land per 1 MW of installed capacity (NREL, 2013; SEIA, 2021). In order to identify the best performing sites within the suitable SPP zones, the overall area that displays potential higher than 1 500 kWh/kWp within a 10 km distance from the transmission lines was summed and expressed in hectares. Combining this result with the PV system output per unit of installed capacity (PVOUT) from the Solargis calculations, the potential installed capacity of SPP and the respective annual energy production (AEP) were calculated.

3.2.2 Solar energy potential

3.2.2.1 Uzbekistan

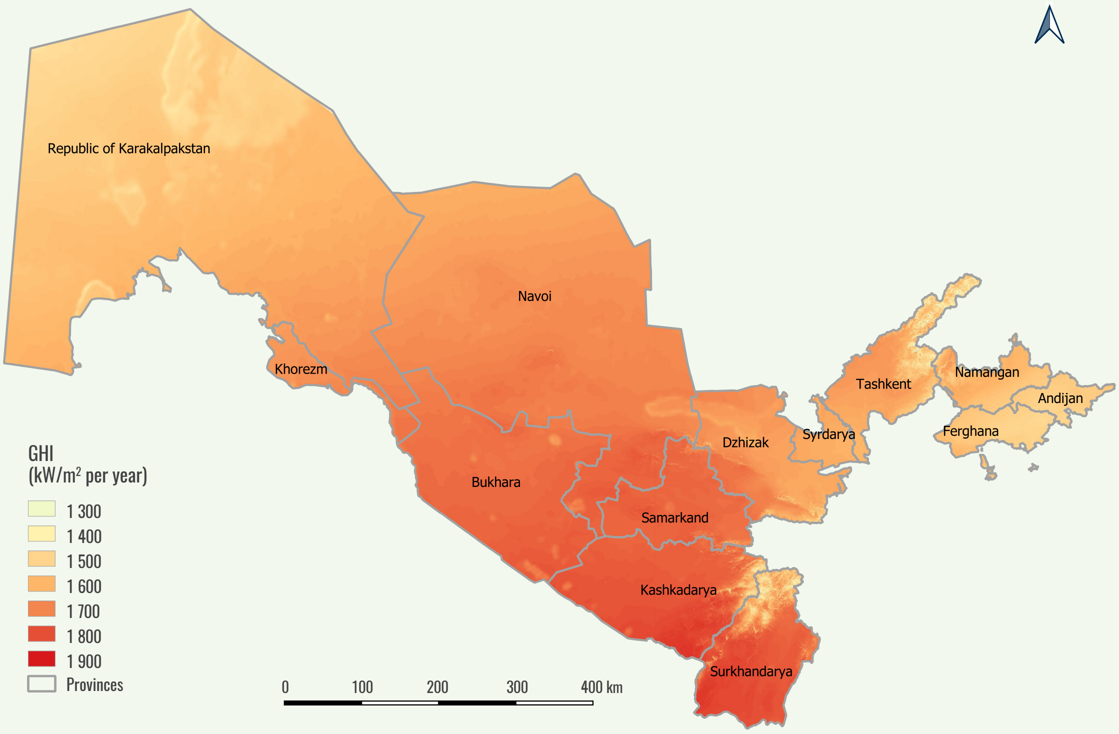
An overview of the Global Horizontal Irradiation (GHI) in Uzbekistan is presented in **Figure 23**. As indicated with the legend, areas marked with lighter colours display a GHI with a magnitude within the range of 1 400 kWh/m^2 and 1 600 kWh/m^2, thus showing the lowest potential in the country. On the contrary, locations with darker colours (dark orange and red shades) have an annual average global horizontal irradiation of approximately 1 800 kWh/m^2 and 1 900 kWh/m^2. This is indicative of a larger amount of available energy for electricity generation in a solar PV power plant. It can be observed that the Province of Kashkadarya appears to have the highest theoretical potential of the three provinces of interest, with an average GHI of nearly 1 900 kWh/m^2, while the Republic of Karakalpakstan has values within the range of 1 500 kWh/m^2 and 1 700 kWh/m^2, stressing its lower potential.

Technical solar energy potential (PVOUT) in Uzbekistan is depicted in **Figure 24**. The PVOUT represents the potential annual electricity production per peak installed capacity of the PV system, taking into account the GHI at the respective location, together with the potential losses and other parameters that affect the efficiency of power generation. Areas highlighted in blue and green have the lowest potentials, with an annual output of up to 1 400 kWh/kWp, while the orange and red coloured areas have the highest potential of up to 1 800 kWh/kWp.

Regarding the provinces of interest, Kashkadarya has the highest average outputs (1 600 kWh/kWp–1 700 kWh/kWp), while Khorezm follows with 1 500 kWh/kWp to 1 600 kWh/kWp. The Republic of Karakalpakstan has the lowest potential with an annual PV output ranging between 1 400 kWh/kWp and 1 600 kWh/kWp.

FIGURE 23.

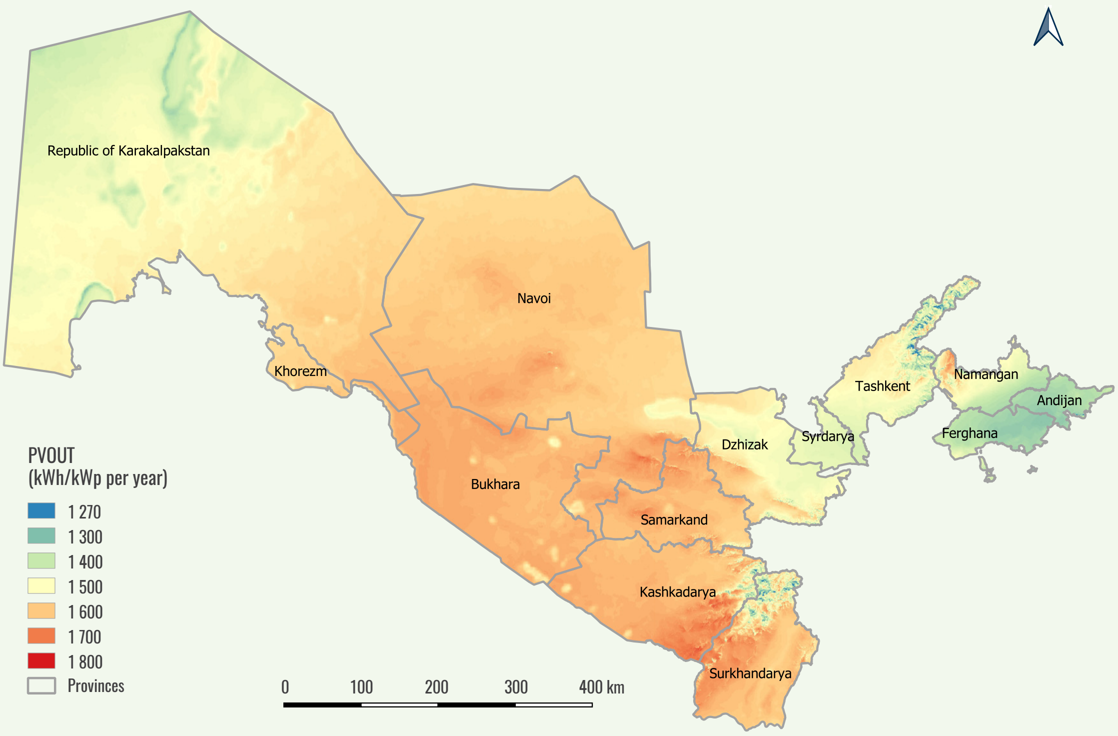
GLOBAL HORIZONTAL IRRADIATION IN UZBEKISTAN



Source: Adapted from Global Solar Atlas. 2021. Data Outputs. In: *Global Solar Atlas*. [Cited 15 April 2021]. https://globalsolaratlas.info/support/data-outputs

FIGURE 24.

TECHNICAL SOLAR PV POTENTIAL (PVOUT) IN UZBEKISTAN



Source: Adapted from Global Solar Atlas. 2021. Data Outputs. In: *Global Solar Atlas*. [Cited 15 April 2021]. https://globalsolaratlas.info/support/data-outputs

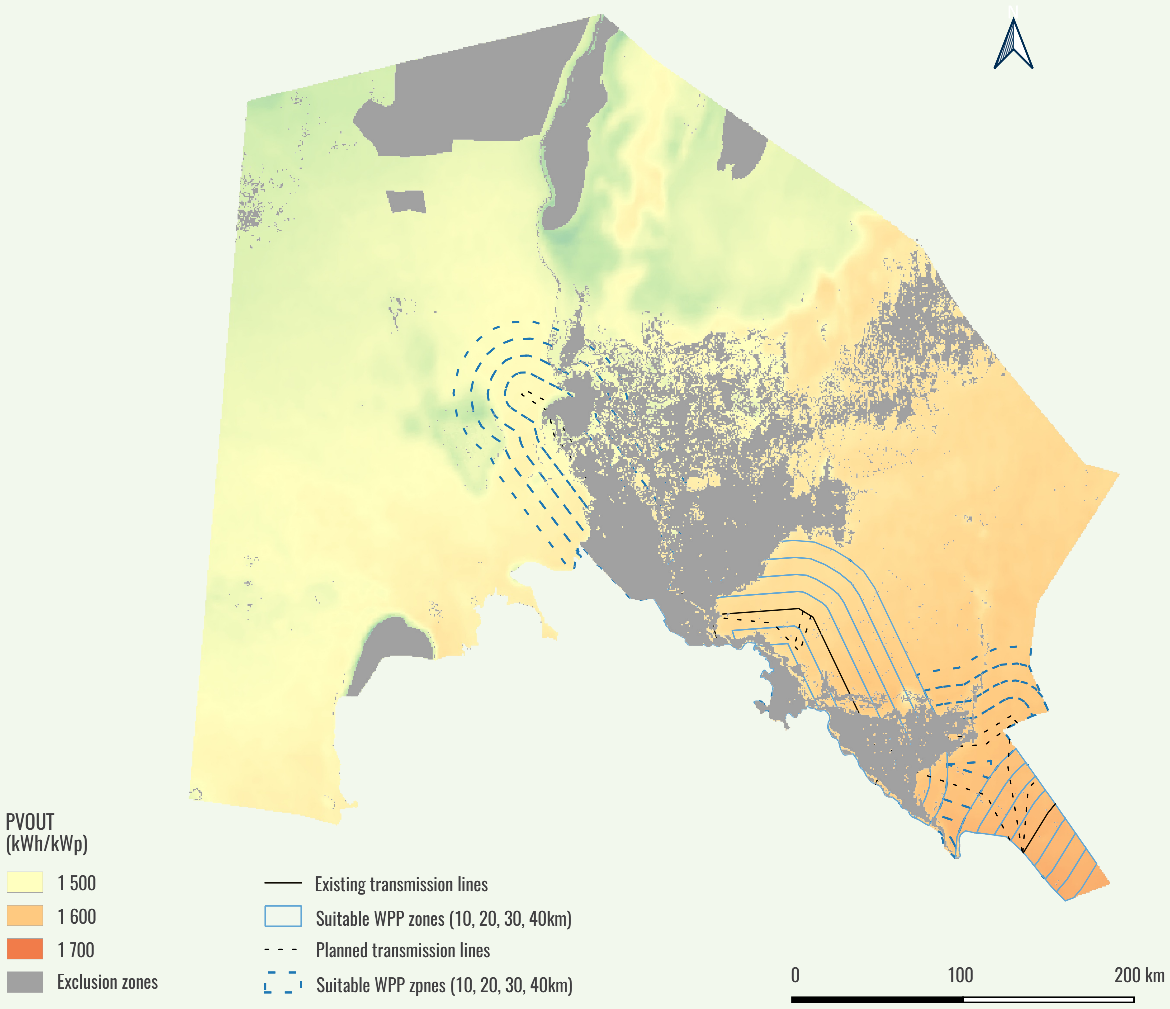
3.2.2.2 The Republic of Karakalpakstan

As mentioned before, the Republic of Karakalpakstan displays the lowest GHI and PVOUT compared to the other two provinces, and therefore has the lowest solar energy potential. The GHI and technical PV potential across the republic range between 1 500 kWh/m² and 1 600 kWh/m² and 1 400 kWh/kWp and 1 500 kWh/kWp, respectively. The western part shows the least promising results, while the potential increases towards the eastern and south-eastern part.

The assessment of land area suitable for SPP siting is presented in **Figure 25**. As indicated in the legend, the grey areas are exclusion zones, while the suitable zones for SPP establishment are delineated with light green lines (full lines represent 10 km, 20 km, 30 km and 40 km buffer zones around the existing transmission lines, while dashed lines the equivalent buffer zones around the planned transmission lines). **Table 10** shows the total area of suitable SPP zones within 20 km along the existing and planned transmission lines grouped in intervals of the practical potential (PVOUT). It is assumed that up to 30 percent of the suitable SPP zone (SPP siting area) could be utilized for establishment of ground-mounted, utility level, PV plants.

FIGURE 25.

THE REPUBLIC OF KARAKALPAKSTAN: SUITABLE ZONES FOR THE ESTABLISHMENT OF SPPS



Source: Adapted from Global Solar Atlas. 2021. Data Outputs. In: *Global Solar Atlas*. [Cited 15 April 2021]. https://globalsolaratlas.info/support/data-outputs.

TABLE 10.

THE REPUBLIC OF KARAKALPAKSTAN: AREA AND PVOUT IN THE SUITABLE SPP ZONE

DISTANCE TO THE TRANSMISSION LINES	PVOUT (kWh/kWp)	EXISTING TRANSMISSION LINES		PLANNED TRANSMISSION LINES	
		SUITABLE SPP ZONE (ha)	SPP SITING AREA (ha)	SUITABLE SPP ZONE (ha)	SPP SITING AREA (ha)
<10 km	1 400–1 500	0	0	29 455	8 837
	1 500–1 600	237 623	71 287	118 481	35 544
	1 600–1 700	68 986	20 696	120 463	36 139
10–20 km	1 400–1 500	0	0	29 290	8 787
	1 500–1 600	192 147	57 644	193 303	57 991
	1 600–1 700	74 932	22 480	42 889	12 867
TOTAL		**573 688**	**172 107**	**533 881**	**160 165**

Source: Authors' own elaboration

Table 11 shows the potential installed capacity and annual electricity production of SPPs established on the best performing areas of suitable SPP zones: PVOUT higher than 1 500 kWh/kWp within 10 km distance to the transmission lines.

TABLE 11.

THE REPUBLIC OF KARAKALPAKSTAN: SOLAR ENERGY POTENTIAL IN THE BEST PERFORMING SITES WITHIN SPP ZONE

DISTANCE FROM THE TRANSMISSION LINES		SUITABLE SPP ZONES AREA (ha)	POTENTIAL INSTALLED CAPACITY (MW)	ANNUAL ELECTRICITY PRODUCTION (GWh/year)
EXISTING TL	**<10 km**	91 983	30 661	48 214
PLANNED TL	**<10 km**	71 683	23 894	38 241
TOTAL		**163 666**	**54 555**	**86 455**

Source: Authors' own elaboration.

As presented above, within the best performing areas for establishment of SPPs in the Republic of Karakalpakstan up to 54.5 GW of ground-mounted PV plants could be installed, resulting in an annual electricity production of 86 455 GWh. In comparison, this is far above the total electricity consumption in Uzbekistan in 2019, which was around 54 174 GWh.

3.2.2.3 Khorezm Province

In Khorezm, typical values for the GHI are within the range of 1 600 kWh/m^2 and 1 800 kWh/m^2, while PVOUT ranges from 1 500 kWh/kWp to 1 600 kWh/kWp, as presented in **Figure 23** and **Figure 24**, respectively. The assessment of solar energy potential assumes that the SPPs are established within the zones suitable for solar siting in the province, as shown in **Figure 26**. The area suitable for SPP within 20 km along the existing and planned transmission lines is classified in intervals according to the PVOUT potential and presented in **Table 12**.

It should be noted that the buffer zones around the planned transmission lines in Khorezm overlap with the buffers of the existing lines, and therefore the suitable SPP zones. It is assumed that up to 30 percent of the suitable SPP zone (SPP siting area) could be utilized for the establishment of ground-mounted, utility level, PV plants.

FIGURE 26.

THE PROVINCE OF KHOREZM: SUITABLE ZONES FOR THE ESTABLISHMENT OF SPPS

Source: Adapted from Global Solar Atlas. 2021. Data Outputs. In: *Global Solar Atlas*. [Cited 15 April 2021]. https://globalsolaratlas.info/support/data-outputs

TABLE 12.

THE PROVINCE OF KHOREZM: AREA AND PVOUT IN THE SUITABLE SPP ZONE

DISTANCE TO THE TRANSMISSION LINES	PVOUT (kWh/kWp)	EXISTING TRANSMISSION LINES	
		SUITABLE SPP ZONE (ha)	SPP SITING AREA (ha)
<10 km	1 400–1 500	0	0
	1 500–1 600	11 121	3 336
	1 600–1 700	24 225	7 267
10–20 km	1 400–1 500	0	0
	1 500–1 600	16 627	4 988
	1 600–1 700	18 499	5 550
TOTAL		**70 472**	**21 141**

Source: Authors' own elaboration.

In line with the described methodology, the potential installed capacity and annual electricity production was estimated for the best performing areas of suitable SPP zones: PVOUT higher than 1 500 kWh/kWp within 10 km distance to the transmission lines. The results are presented in **Table 13**.

TABLE 13.

THE PROVINCE OF KHOREZM: AREA AND PVOUT IN THE SUITABLE SPP ZONE

DISTANCE FROM THE TRANSMISSION LINES	SUITABLE SPP ZONES AREA (ha)	POTENTIAL INSTALLED CAPACITY (MW)	ANNUAL ELECTRICITY PRODUCTION (GWh/year)
<10 km	10 604	3 535	5 721

Source: Authors' own elaboration.

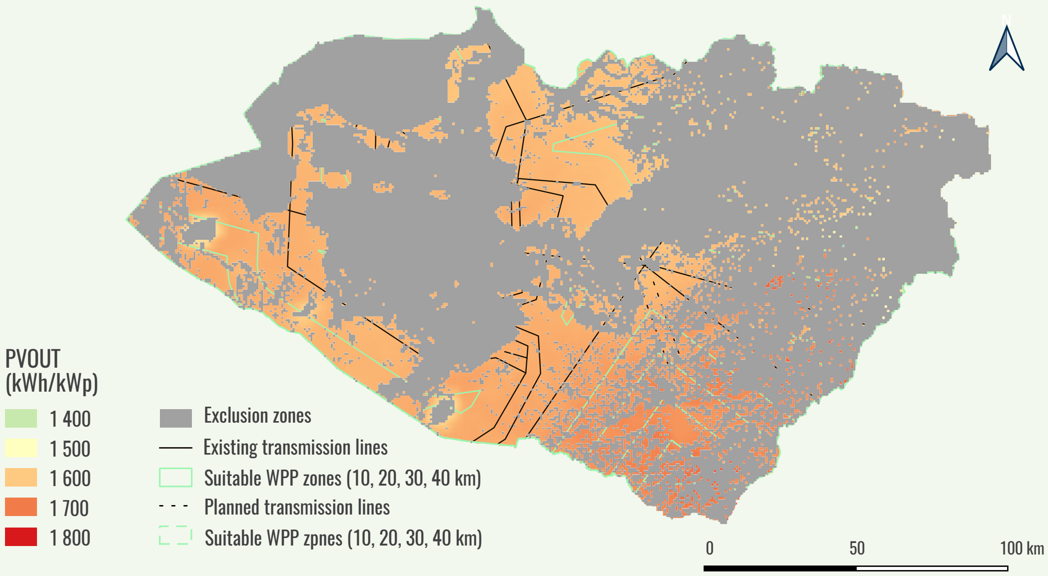
Despite its theoretically high GHI and PVOUT results, Khorezm shows a more limited solar energy potential compared to the Republic of Karakalpakstan due to limited area of suitable zones for SPP establishment. However, the area of the best performing sites is sufficient for establishing SPP with more than 3.5 GW capacity, which is around 70 percent of the national target for the solar production capacities in 2030.

3.2.2.4 Kashkadarya Province

The province of Kashkadarya displays the highest theoretical potential between the three selected provinces, as it has the highest GHI and PVOUT values, as it can be seen in **Figure 23** and **Figure 24**. Typical values for the GHI are in the range of 1 800 kWh/m^2 and 1 900 kWh/m^2, while the technical potential can reach up to 1 700 kWh/kWp year. The suitable zones for SPP siting in Kashkadarya are depicted in **Figure 27**.

FIGURE 27.

THE PROVINCE OF KASHKADARYA: SUITABLE ZONES FOR THE ESTABLISHMENT OF SPPS



Source: Adapted from Global Solar Atlas. 2021. Data Outputs. In: *Global Solar Atlas*. [Cited 15 April 2021]. https://globalsolaratlas.info/support/data-outputs

Taking into account the available area and the PVOUT characteristics of the zones, the suitable area for SPP siting was grouped according to the PVOUT intervals and presented in **Table 14**. It should be noted that the buffer zones around the planned transmission lines in Kashkadarya overlap with the buffers of the existing lines, and are therefore suitable SPP zones.

TABLE 14.

THE PROVINCE OF KASHKADARYA: AREA AND PVOUT IN THE SUITABLE SPP ZONES

DISTANCE TO THE TRANSMISSION LINES	PVOUT (kWh/kWp)	EXISTING TRANSMISSION LINES	
		SUITABLE SPP ZONE (ha)	SPP SITING AREA (ha)
<10 km	1 400–1 500	55	17
	1 500–1 600	2 918	875
	1 600–1 700	521 770	156 531
	1 700–1 800	2 037	611
10–20 km	1 400–1 500	0	0
	1 500–1 600	4 790	1 437
	1 600–1 700	161 425	48 428
	1 700–1 800	551	165
TOTAL		**693 546**	**208 064**

Source: Authors' own elaboration.

The potential installed capacity of SPPs and potential annual electricity production were calculated for the best performing sites. As in the case for the Republic of Karakalpakstan and Khorezm Province, only 30 percent of the suitable SPP zones were considered, including the sites with PVOUT above 1 500 kWh/kWp that are not further than 10 km from the transmission lines. The results are presented in **Table 15**.

TABLE 15.

THE PROVINCE OF KASHKADARYA: SOLAR ENERGY POTENTIAL IN THE BEST PERFORMING SITES WITHIN SPP ZONE

DISTANCE FROM THE TRANSMISSION LINES	SUITABLE SPP ZONES AREA (ha)	POTENTIAL INSTALLED CAPACITY (MW)	ANNUAL ELECTRICITY PRODUCTION (GWh/year)
<10 km	158 017	52 672	86 901

Source: Authors' own elaboration.

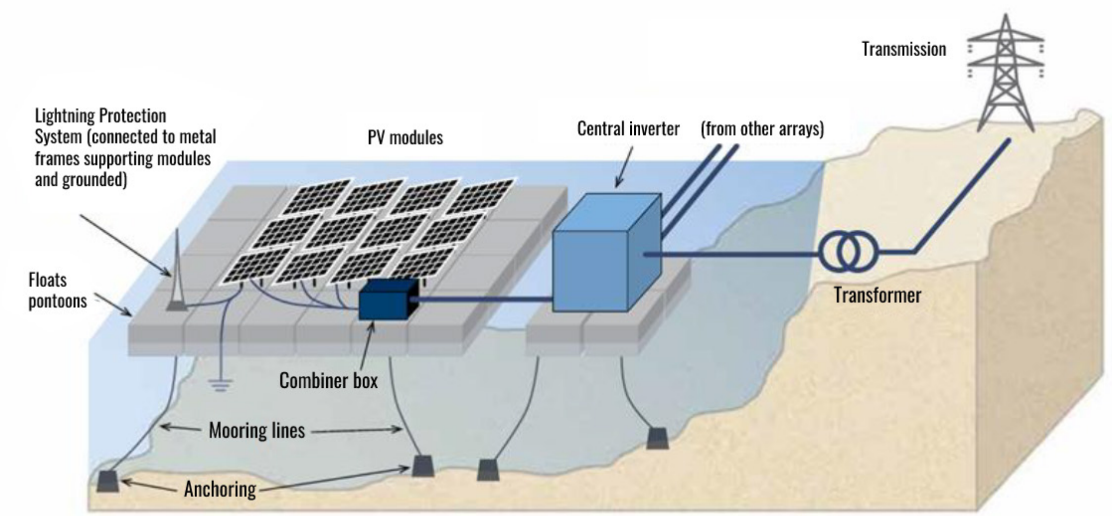
In the Province of Kashkadarya, the potential PV installed capacity in the best performing locations can reach up to 52 GW, producing 86 901 GWh of electricity per year.

BOX 2: FLOATING SOLAR PHOTOVOLTAICS

Floating solar photovoltaics (FSPV) is an innovative solar PV application whereby PV panels and inverters are mounted on a floating platform placed on bodies of water, such as lakes, reservoirs or irrigation ponds. The floating platforms are kept in place by mooring lines and anchoring mechanics, as depicted in **Figure 8** (World Bank, 2018). The floating PV panels have a more compact formation than land-based units, requiring approximately 1.6 ha per MW of installed capacity. Thus, FSPV systems can be a valuable solution for areas with scarce land availability and/or a hybrid option for reducing evaporation and primary production in reservoirs used for hydropower generation, irrigation or water supply. It has been reported that the evaporation reduction can range from 25 to 35 percent (Sahu et.al, 2016; Santafe et.al, 2014), and in some cases values can reach even up to 60 percent (Abdelal, 2021). Additionally, the reduced sunlight within the water body can result in a lower primary production and thus improve the water quality. Due to the cooling effect of the water, the lack of shading and the reduced soiling, the outputs of FSPV are up to 10 percent higher than that of the ground-mounted PV plants (World Bank, 2018; Achraya and Devraj, 2019; Rosa-Clot et.al, 2019). However, due to the higher complexity of installation the capital costs of FSPV systems are up to 25 percent higher as compared to ground-mounted systems, while the expected lifespan of the equipment is shorter because of the exposure to moisture, wind and waves (IFC, 2020).

FIGURE 28.

OUTLINE OF A TYPICAL FSPV SYSTEM



Source: World Bank, ESMAP and SERIS, 2018. *Where sun meets water: floating solar market report*. Washington DC: World Bank

If water reservoirs larger than 2.4 ha in the Republic of Karakalpakstan, Khorezm and Kashkadarya regions were considered for the installation of FSPV systems, more than 3 000 MW could be installed and more than 4 000 GWh of electricity would be produced annually. This estimate assumes that the FSPV systems cover 30 percent of the reservoir area, and that the electricity output of the FSPV plants is 5 percent higher than that of land-based PV units.

Approximately 312 MW of FSPV can be installed on 12 reservoirs in the Republic of Karakalpakstan, producing 505 GWh/year, while the potential capacity of 1 359 MW on 18 reservoirs in Kashkadarya can generate 2 300 GWh/year. The largest FSPV potential is seen in the Province of Khorezm, where 40 reservoirs could be used for 1 885 MW of FSPV, resulting in an annual electricity generation of 3 120 GWh/year.

3.2.3 Investment requirements

The overall capital investment for a ground-mounted PV plant entails several costs categories, which can be divided into hardware, installation and soft costs. The hardware costs include PV modules, inverters, racking and mounting, grid connection, cabling and related safety and security, and monitoring. Installation costs refer to the electrical and mechanical installations and the respective inspection, while the soft costs encompass system design, permitting, customer acquisition, and other costs related to project development and SPP deployment. The investment costs can differ between countries, depending on the site-specific requirements, e.g. logistics and limitations for transportation, locally applicable policies, land-use limitations, and labour costs.

Since the development of utility level SPP in Uzbekistan occurs only at the onset, the information about the country specific investment requirements per capacity unit is limited. Therefore, in this study the estimated range of the investment requirements was determined using specific investment costs for SPPs developed in 2019 in Turkey and the equivalent global average. The specific investment cost in Turkey was 921 USD/kW, while the global weighted average was 995 USD/kW of installed capacity (IRENA, 2020b).

Preventive maintenance and cleaning of PV modules make up between 70 percent and 90 percent of annual operating and maintenance (O&M) costs. The remaining share of the annual O&M expenditures is commonly used for unplanned maintenance (e.g. replacement of broken components), land lease, insurance and asset management costs. The annual O&M costs can vary considerably from one country to another, often depending on the availability of specialized services and components, such as for example how developed the PV market is and the level of know-how in the country. According to the IRENA's report on Renewable Power Generation Costs in 2019 (IRENA, 2020b), the annual O&M costs in OECD countries were 18.3 USD/kW and in non-OECD countries 9.5 USD/kW. The estimated annual O&M costs for Uzbekistan were calculated using the non-OECD values.

In this study, the investment requirements and annual operating and maintenance costs were analysed for tree scenarios related to the national 2030 RES targets:

- scenario 1: establishment of 5 000 MW SPP;
- scenario 2: establishment of SPPs in each region at the capacity level that would be sufficient to supply the whole regional electricity demand in 2030;
- scenario 3: establishment of SPPs in each region at the capacity level that would be sufficient to supply the 25 percent of the regional electricity demand in 2030.

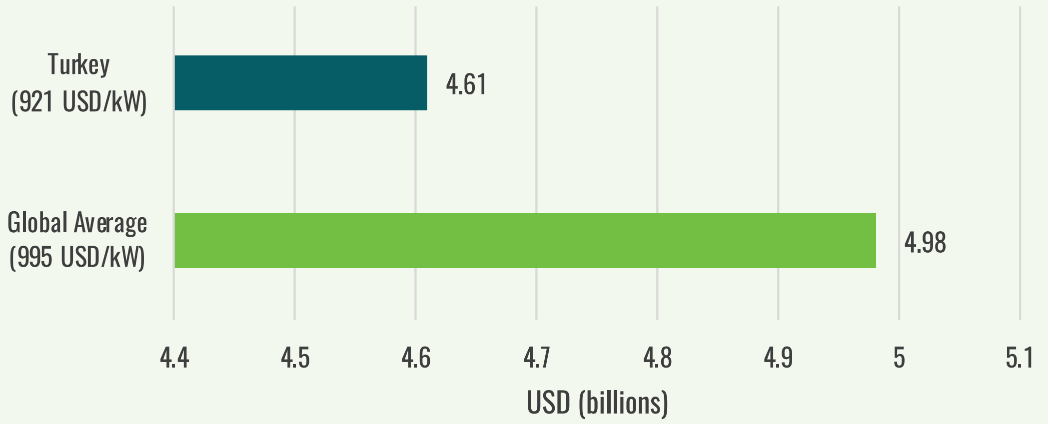
The regional electricity demand in 2030 was estimated based on the projected national consumption in 2030 (MoE of Uzbekistan, 2020), and the regional shares in electricity supplied in 2019 (UZSTAT, 2021a).

SCENARIO 1: ESTABLISHMENT OF SOLAR PV PLANTS WITH A TOTAL INSTALLED CAPACITY OF 5 000 MW

Assuming that the specific capital investment costs for SPP can range between 921 USD/kW and 995 USD/kW, the overall investment requirements for 5 GW would range between USD 4.6 billion and USD 5 billion in the course of nine years (see **Figure 29**).

FIGURE 29.

ESTIMATED INVESTMENT REQUIREMENTS FOR DEPLOYMENT OF 5 GW IN SPPS



Source: Authors' own elaboration.

Since the regulatory framework for RES deployment in Uzbekistan is still being developed, and the PV market development will coincide with its full implementation, the specific investment costs in SPPs are expected initially to be closer to the upper boundaries of the range, decreasing with time. Experience from other countries has shown that by strengthening regulations, together with capacity and market development, result in cost reductions. In addition, if the current downward trend in PV module prices continues, the specific investment costs will also decrease with time. More specifically, the costs of PV panels and other equipment had a considerable share in the total investment costs in 2019.

With the estimated range of annual O&M costs between 9.5 USD/kW and 18.3 USD/kW, the yearly expenditure for operating and maintenance of 5 GW solar PV plants would range between USD 9.5 million and USD 47.5 million per year.

SCENARIO 2: ESTABLISHMENT OF SPPS IN EACH REGION AT THE CAPACITY LEVEL THAT WOULD BE SUFFICIENT TO SUPPLY THE WHOLE REGIONAL ELECTRICITY DEMAND IN 2030

In this scenario, first the projected regional electricity demand in 2030 was calculated, after which the capacity of SPPs required to supply that demand was estimated. The potential solar PV capacity in the three regions, as detailed in **Table 16**, is far above the national targets for installed capacity of solar power plants, and is furthermore above the planned total RES capacity in 2030. In all three regions, the area with the best performing sites within the suitable SPP zones is sufficient for the establishment of SPPs that could supply the entire electricity demand in 2030. In the Khorezm Province the available space for sustainable siting of SPPs is 10 to 15 times smaller as compared to the other regions; the solar energy potential is somewhat lower than in Kashkadarya, ranging between 1 500 kWh/year and 1 630 kWh/year. Nevertheless, the potential is sufficient for supplying the 2030 electricity demand in that region.

TABLE 16.

REGIONAL SOLAR PV POTENTIAL AND REGIONAL ELECTRICITY DEMAND IN 2030

REGION	AREA OF BEST PERFORMING SUITABLE SPP ZONES (ha)	POTENTIAL PV CAPACITY (MW)	ANNUAL ENERGY PRODUCTION (GWh/year)	REGIONAL ELECTRICITY DEMAND IN 2030 (GWh/year)	WIND POWER CAPACITY FOR 2030 DEMAND (MW)	SOLAR PV CAPACITY FOR 25% OF 2030 DEMAND (MW)
KARAKALPAKSTAN	163 666	54 555	86 455	3 769	2 228	571
KHOREZM	10 604	3 535	5 721	3 936	2 385	596
KASHKADARYA	158 017	52 672	86 901	12 475	7 548	1 887
TOTAL	**332 287**	**110 762**	**179 077**	**20 180**	**12 217**	**3 054**

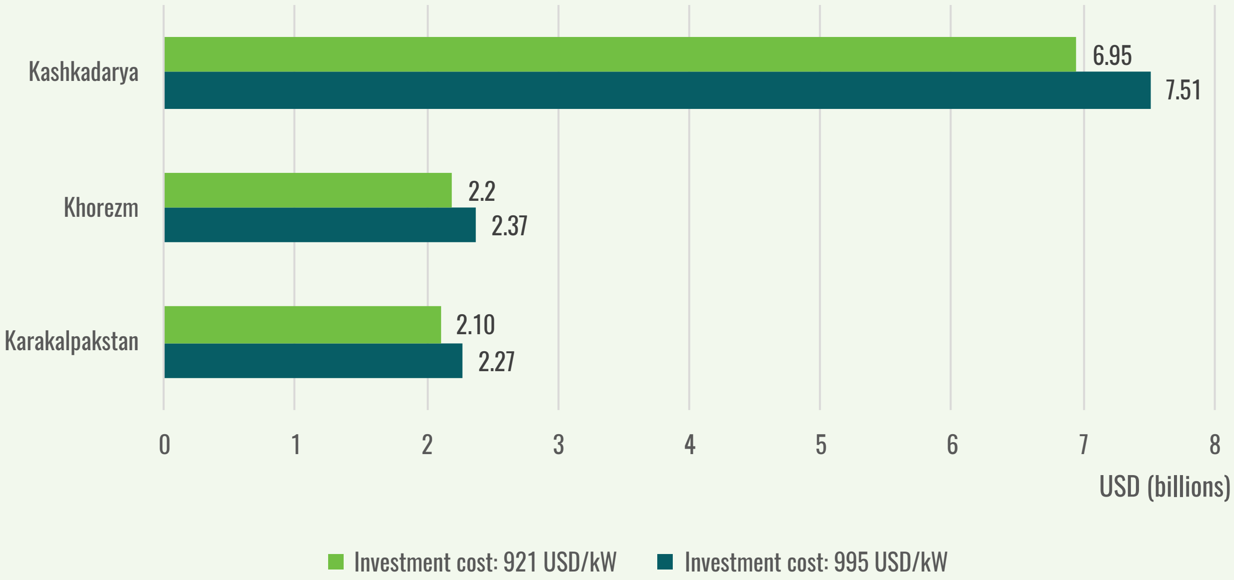
Source: Authors' own elaboration.

Considering the projected electricity demand in 2030 and the potential PV output in the analysed regions, if the entire demand were supplied by solar power, the required capacity of the SPP in the Republic of Karakalpakstan would be approximately 2.3 GW, while in the Khorezm and Kashkadarya Provinces it would be 2.4 GW and 7.5 GW, respectively.

Assuming that the same specific capital investments were between 921 USD/kW and 995 USD/kW, the required capital investments in SPPs in the Republic of Karakalpakstan would be USD 2.1 billion and USD 2.3 billion, in Khorezm between USD 2.19 billion and USD 2.4 billion, and in Kashkadarya between USD 6.9 billion and USD 7.5 billion (see **Figure 30**).

FIGURE 30.

CAPITAL INVESTMENT REQUIREMENTS FOR SUPPLYING REGIONAL ELECTRICITY DEMAND FROM SPP IN 2030



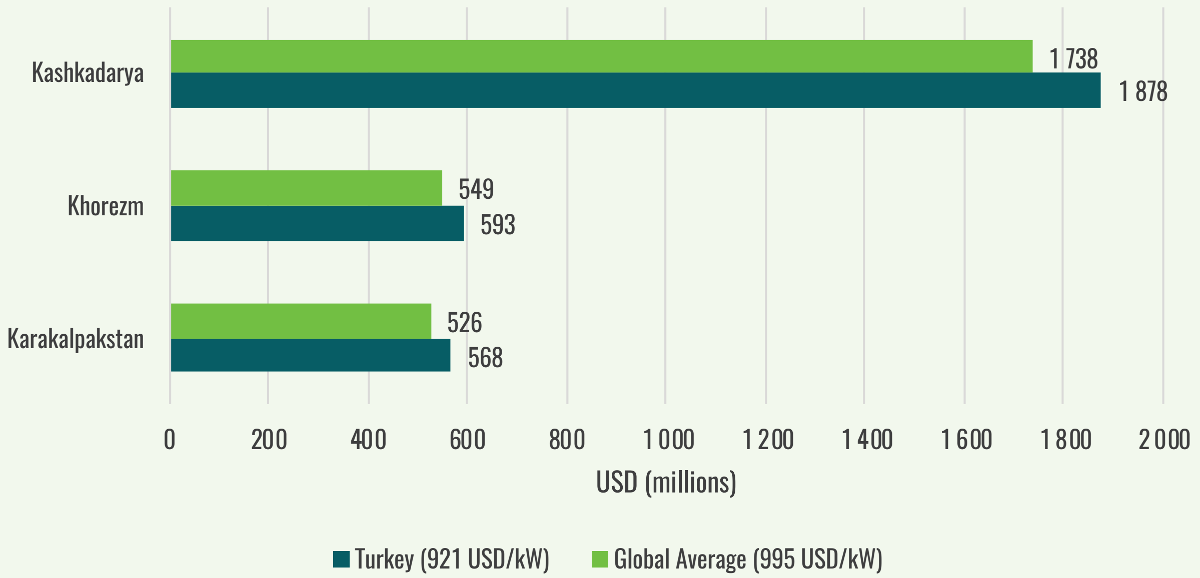
Source: Authors' own elaboration.

SCENARIO 3: ESTABLISHMENT OF SPPS IN EACH REGION AT THE CAPACITY LEVEL THAT WOULD BE SUFFICIENT TO SUPPLY THE 25 PERCENT OF THE REGIONAL ELECTRICITY DEMAND IN 2030

As described in Scenario 2, the technical solar PV potential in all three regions is sufficient for supplying 25 percent of the regional electricity demand in 2030 (see **Table 16**). In order to ensure the equivalent annual electricity generation, the required capacity of the SPP in the Republic of Karakalpakstan would be 571 MW, while in the Khorezm and Kashkadarya provinces 596 MW and around 1.9 GW, respectively. The required capital investments for deployment of SPPs in the Republic of Karakalpakstan would therefore be between USD 526 million and USD 568 million, in Khorezm between USD 549 million and USD 593 million, and in Kashkadarya between USD 1.7 billion and USD 1.9 billion (see **Figure 31**).

FIGURE 31.

CAPITAL INVESTMENT REQUIREMENTS FOR SUPPLYING 25 PERCENT OF THE REGIONAL ELECTRICITY DEMAND FROM SPP IN 2030



Source: Authors' own elaboration.

3.3 BIOMASS AVAILABILITY ASSESSMENT

Biomass based energy is widely used on a global scale, accounting for approximately 10 percent of the primary energy supply, and can be utilized to produce electricity, thermal energy or transport fuels. In 2019 the global installed capacity for bioenergy plants reached 153 GW and it is expected to increase to 218 GW by 2030 (IEA, 2020b). The bioenergy assessment in this report was based on the Bioenergy and Food Security (BEFS) Approach, which was developed by FAO. The objective of BEFS is to help countries design and implement sustainable bioenergy policy, by ensuring that bioenergy development fosters both food and energy security and contributes to agricultural and rural development in a climate-smart way[5].

The biomass available for bioenergy production in the analysed regions is determined based on the crop and livestock production in the respective regions, and the suitability of the specific biomass type to serve as bioenergy feedstock. Livestock manure and crop residues can be used for the production of biogas through anaerobic digestion, while crop residues can be used for production of solid biofuels such as pellets and briquettes, or electricity generation through gasification or combustion technologies. Lignocellulosic feedstock, including crop residues, can also serve as feedstock for the production of liquid biofuels for transport, e.g. second-generation ethanol.

In order to ensure that bioenergy production is sustainable, the amount of crop residues currently used for other purposes is not taken into account. It is also assumed that after harvesting, a certain volume of crop residues is left in the field, thus maintaining soil fertility, stability and biodiversity. This amount is therefore not considered as available for bioenergy production. Therefore, the main steps in this approach can be summarized as follows:

1. **The overall production of residues:** This step includes the assessment of the total amount of agricultural residues that is generated from crop and livestock production. The minimal spatial unit for the assessment is a district, while the results are then aggregated at the province level.
2. **Estimate of the amount of residues available for bioenergy generation**: The amount of residues that can be used for bioenergy production is determined once the share of residues that should be left in the field and all current uses are accounted for and subtracted from the residues generated.

Within the scope of this report, the BEFS assessment was conducted for the Republic of Karakalpakstan and the Khorezm and Kashkadarya Provinces. The analysis encompassed two main categories of bioenergy feedstock groups, namely livestock manure and crop residues, which can be utilized for electricity and heat generation, as well as cooking fuels production.

3.3.1 Livestock residues: approach and methodology

The main objective of the livestock residues assessment was to evaluate the amount of manure that can be collected and subsequently be used for biogas production. The amount of manure generated and the share that can be collected depends on various factors, such as the herd composition, production level and production system.

The scope of the assessment for the three analysed regions included manure availability from cattle and poultry reared by large scale farms (categorized as "big farms" and "agricultural organizations" in the statistical reports on agriculture and fisheries) and small-scale farms, i.e. dehkan farms.

The annual amount of manure potentially available for biogas production was calculated based on the number of animal species considered within the assessment area, and the average daily manure production per head. It is important to note that only the manure generated in stables, i.e. in spaces where manure can easily be collected, was assessed.

Finally, for the available manure, the biogas production potential, i.e. theoretical bioenergy potential was calculated. Biogas is a mixture of methane (CH_4), carbon dioxide (CO_2) and other gases that is generated through the anaerobic digestion of organic matter. The composition of the gas depends on the type of feedstock, as well as the method and equipment used in the production process. Methane is the energy carrier of biogas and thus higher methane content indicates higher energy potential. The methane content of untreated biogas is between 40 to 60 percent, but it is possible to conduct further treatment to remove other gases and increase methane content, resulting in a higher quality fuel (EIA, 2020). Biogas can be used directly for cooking and lighting or to produce

[5] For more details, refer to FAO and Ministry of Energy of Zambia, 2020. Sustainable bioenergy potential in Zambia - An integrated bioenergy and food security assessment.

electricity and/or heat in cogeneration (CHP) or heating plants. Typical calorific values of biogas range between 16 MJ/m³ to 28 MJ/m³ (IEA, 2021b).

The following formulae describes the calculation process:

1. TOTAL MANURE PRODUCTION

$$M_{tot\ (i)} = LVS_{head\ (i)} * M_{head\ (i)}$$

Where:

- $M_{tot\ (i)}$ [tonnes/year]: total amount of manure produced per year within the assessment area;
- $LVS_{head\ (i)}$ [head/year]: number of animals raised per year within the assessment area;
- $M_{head\ (i)}$ [tonnes/head]: amount of manure produced per head per year;
- *(i)*: analysed livestock type – production level category (e.g. commercial cattle production).

Livestock Statistics for 2020 (UZSTAT, 2021d) were used to determine the number of animals per district in the three provinces of interest. The average daily manure production was discussed with and verified by the national livestock experts though questionnaires and technical discussion. When determining the respective values, presented in **Table 17**, the experts considered the herd composition (sex and age) for cattle, and chickens as the main poultry species reared in the three analysed regions.

2. COLLECTIBLE MANURE

$$M_{Collectible\ (i)} = M_{tot\ (i)} \times c_{(i)}$$

Where:

- $M_{Collectible\ (i)}$ [tonnes/year]: amount of manure that can be collected for each analysed livestock type per year, within the assessment area;
- $c_{(i)}$: manure collection efficiency for each livestock type.

The share of manure that can be collected and then used for biogas production usually depends on the level of production and manure management practices. This is accounted for by considering the collection efficiency ($c_{(i)}$), which was determined for each livestock type and the production level through technical consultation with national livestock experts.

As indicated in **Table 17**, it has been estimated that the collection efficiency in commercial cattle farms is around 65 percent, whereas among dehkan farmers it can reach as high as 90 percent. This estimate reflects the fact that in commercial farms animals spend part of the time in the "open" area of the stables, where part of the manure cannot be collected. On the contrary, the dehkan farmers keep on average only a few animals that spend their time indoors, since the country applies a "no grazing" policy.

TABLE 17.

TECHNICAL COEFFICIENTS USED FOR THE LIVESTOCK RESIDUES ASSESSMENT

SPECIES / PRODUCTION LEVEL	FRESH MANURE PRODUCTION (kg/head per day)		COLLECTION EFFICIENCY	
	COMMERCIAL FARM	DEHKAN FARM	COMMERCIAL FARM	DEHKAN FARM
CATTLE	20	20	65%	90%
POULTRY	0.2	0.1	90%	70%

Source: Authors' own elaboration based on technical consultation with national experts

3. MANURE AVAILABLE FOR BIOGAS PRODUCTION

$$M_{Available\ (i)} = M_{Collectible\ (i)} * (1 - u_{(i)})$$

Where:

- $M_{Available\ (i)}$ [tonnes/year]: amount of manure available for bioenergy production, for each analysed livestock type per year, within the assessment area;
- $u_{(i)}$: share of collectible manure that is not available for biogas production.

4. BIOGAS ENERGY POTENTIAL

$$P_{Biogas\,(i)} = \left(\frac{M_{Available\,(i)}}{\rho_{(i)}}\right) * RMP_{(i)} * LHV_{Biogas}$$

Where:

- $P_{Biogas(i)}$ [MJ/year]: biogas energy potential, for each analysed livestock type per year, within the assessment area;
- $\rho_{(i)}$ [tonnes/m³]: density for each analysed livestock type, within the assessment area;
- $RMP_{(i)}$ [m³ biogas/m³ feedstock]: realistic methane potential for each analysed feedstock type, within the assessment area;
- LHV_{Biogas} [MJ/m³ biogas]: lower heating value of biogas.

The biogas potential from livestock residues is determined based on the amount of manure available, the realistic methane potential (RMP) of the feedstock and the calorific value of the produced biogas. RMP is used to express the amount of biogas (in m³) that is produced per m³ of feedstock. RMP is sensitive to the ambient temperature, so it varies between the three provinces based on their respective average annual temperature. For this report, the calorific value of biogas was taken as 20 MJ/m³.

As part of the technical consultation, the current use of livestock manure has also been discussed. Currently, manure is mainly used for the fertilisation of arable land. The farmers either use the manure on their own land or they sell it. In addition, dehkan farmers use up to 30 percent of cattle manure as fuel for cooking and heating. The cattle manure currently used as cooking fuel and 30 percent of collectible poultry manure was considered as used ($u_{(i)}$), that is, as not available for biogas production, under the premise that diverting this manure to biogas production may impose negative socio-economic impacts on the users in the short-term. However, biogas production should not undermine the use of manure for land fertilisation since bio-slurry can be used as fertiliser and potentially bring additional benefits to farmers. It should be noted that substituting dry manure with modern cooking fuels could bring positive health and energy access benefits to the farmers, while at the same time increase the volume of manure that can be used for biogas production. Therefore, in the medium to long term, the volume of manure available for biogas production could be higher.

3.3.2 Livestock residues: bioenergy potential

The number of animals for each province, type of livestock and level of production is presented in **Table 18**. It can be seen that within the three regions the largest number of cattle are found in Kashkadarya, with nearly 1.6 million heads, followed by the Republic of Karakalpakstan with 1.1 million heads. Regarding poultry, Kashkadarya has approximately 6 million heads, while Khorezm and Karakalpakstan have 5.9 million and 4.5 million, respectively. It should be noted that livestock production is dominated by small-scale farmers. In the case of cattle in particular, dehkan farms raise between 94 percent and 96 percent of all animals in the three provinces.

TABLE 18.

NUMBER OF ANIMALS PER PROVINCE AND PER LEVEL OF PRODUCTION

	CATTLE			POULTRY		
	TOTAL	DEHKAN FARM	COMMERCIAL FARMS	TOTAL	DEHKAN FARM	COMMERCIAL FARMS
REPUBLIC OF KARAKALPAKSTAN	1 110 586	1 045 311	65 2750	4 524 714	3 858 652	666 062
KHOREZM	923 755	855 742	68 013	5 964 810	3 869 369	2 095 441
KASHKADARYA	1 598 748	1 504 372	94 376	6 049 111	4 279 630	1 769 481
TOTAL	3 633 089	3 405 425	227 664	16 538 635	12 007 651	4 530 984

Source: State Committee of the Republic of Uzbekistan on Statistics. 2020. Number of livestock (as of January 1, 2020). In: *Open Data Portal of the Republic of Uzbekistan*. [Cited 27 April 2021]. https://data.gov.uz/en/datasets/12844

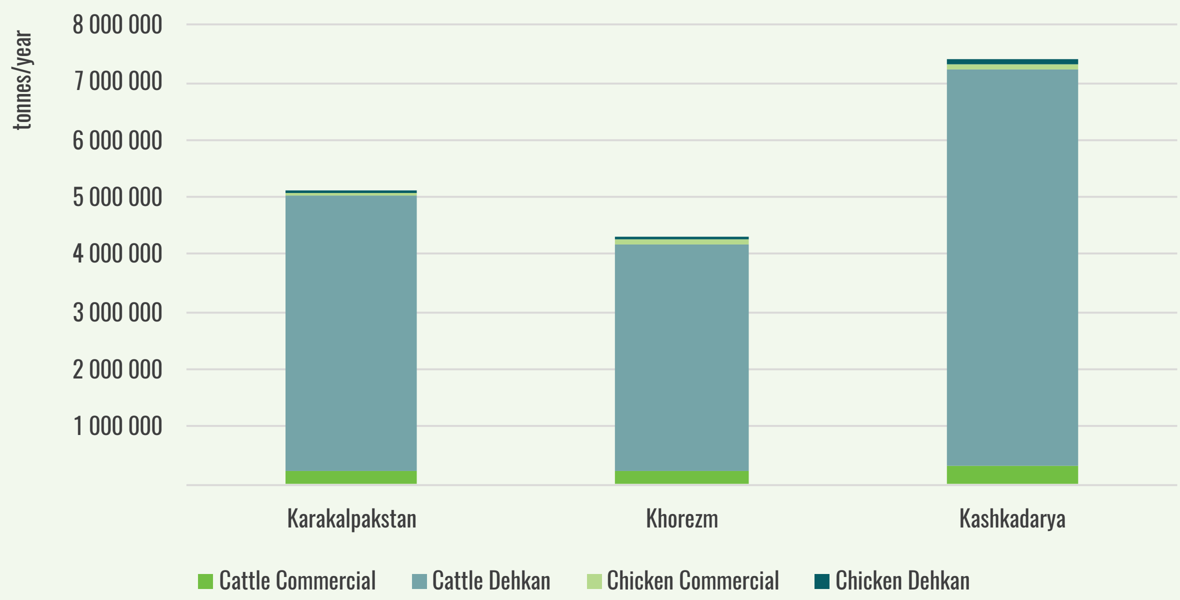
By applying the methodology described above, the annual amount of manure potentially available for biogas production was estimated. Based on the assumption that 70 percent of the collectible cattle manure can be used for bioenergy applications, the available manure was calculated and is presented in **Figure 32**.

In Kashkadarya approximately 7.2 million tonnes per year of cattle manure are available at the province level. In the case of poultry manure, 158 thousand tonnes per year could be used for biogas generation, with commercial farms generating 52 percent of the total. In the case of the Republic of Karakalpakstan, nearly 5 million tonnes of cattle manure and 100 thousand tonnes of poultry manure could be used annually for biogas production. Lastly, in Khorezm, more than 4.3 million tonnes of manure are available for biogas production annually, comprising 4.1 million tonnes of cattle manure and 165 thousand tonnes of poultry manure. Based on these findings it can be concluded that the Kashkadarya Province displays the highest potential for biogas production, while Khorezm the lowest.

In all three provinces around 95 percent of the available manure is located on dehkan farms. In the Republic of Karakalpakstan, the major part of poultry manure potentially available for biogas production is also generated on dehkan farms, 70 percent. In contrast, in Khorezm and Kashkadarya Province commercial farms dominate the poultry production with 58 percent and 51 percent, respectively.

FIGURE 32.

AVAILABLE MANURE PER PROVINCE



Source: Authors' own elaboration.

3.3.2.1 The Republic of Karakalpakstan

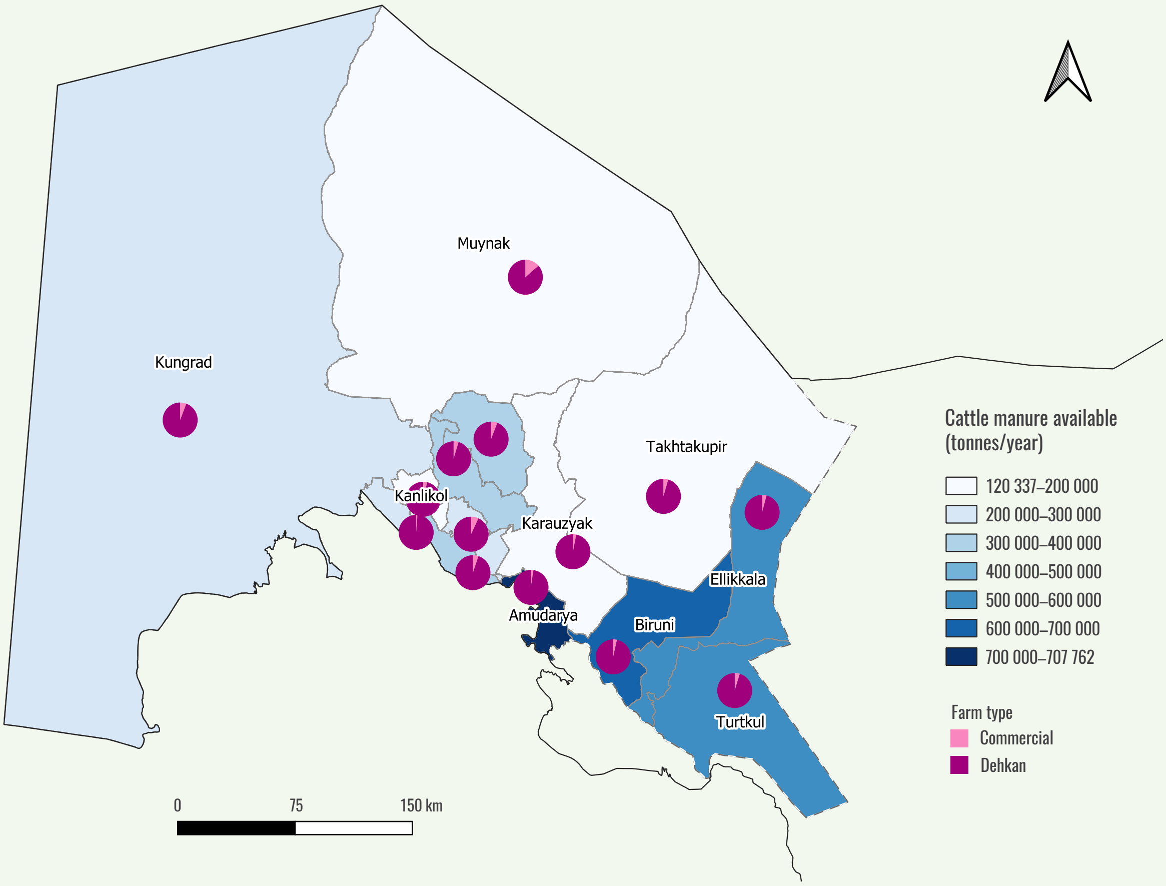
The geographical distribution of the available cattle manure for biogas production in the Republic of Karakalpakstan is shown in **Figure 33**.

As indicated with the legend of the map, darker blue colours represent higher manure availability. Moreover, a distinction is made according to the production level varying between commercial and dehkan farms, which is presented with pie charts.

With an overall 5 million tonnes of available manure at the province level annually in the Republic of Karakalpakstan, the Amudarya and Biruni districts display the highest potential, with approximately 700 thousand tonnes per year. Ellikkala and Turkul districts follow with more than 500 thousand tonnes per year, while the lowest potentials can be found in Muynak, Takhtukupir and Krauzjak, where the available manure is within the range of 120 thousand and 200 thousand tonnes per year. Lastly, it should be noted that dehkan farms dominate production in all the districts within the Republic of Karakalpakstan.

FIGURE 33.

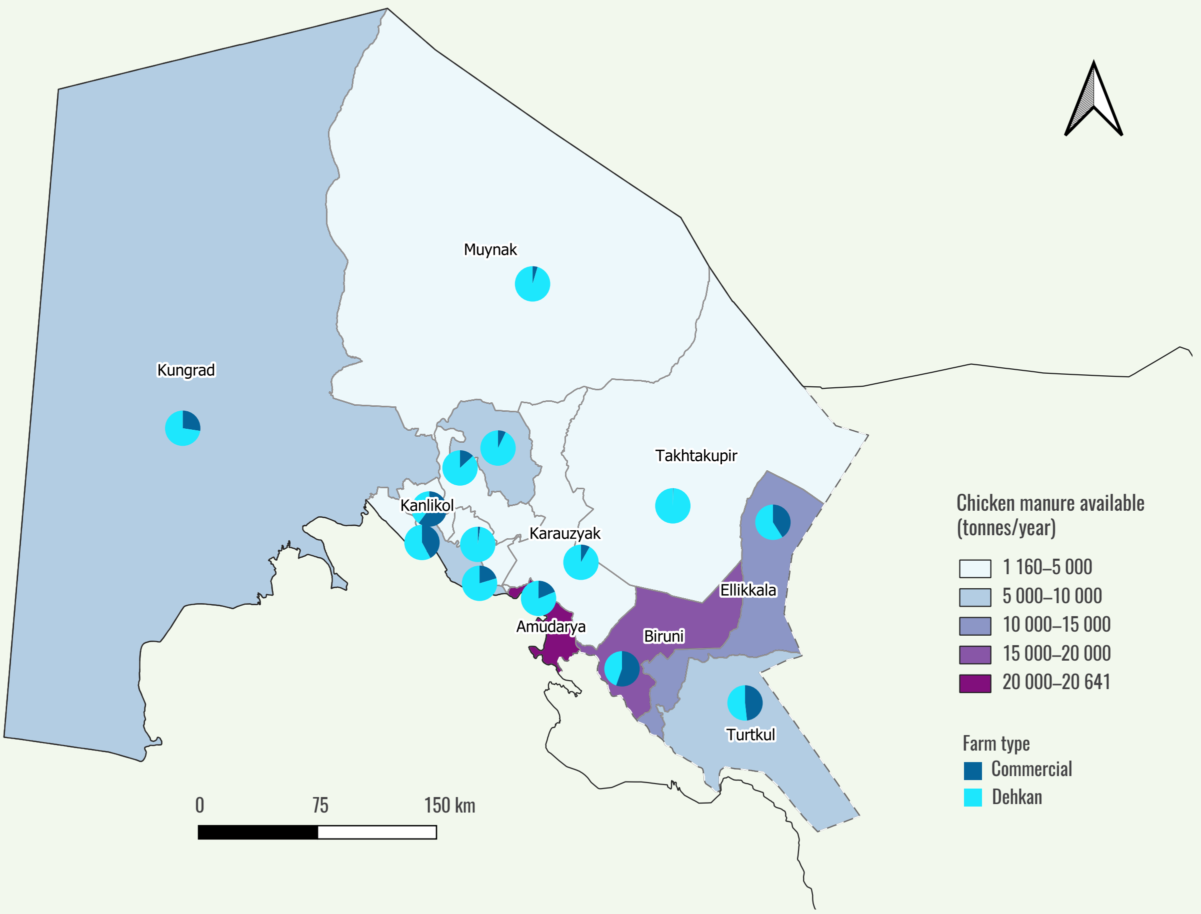
SPATIAL DISTRIBUTION OF AVAILABLE CATTLE MANURE IN THE REPUBLIC OF KARAKALPAKSTAN



Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors based on BEFS Assessment Results.*

FIGURE 34.

SPATIAL DISTRIBUTION OF AVAILABLE CHICKEN MANURE IN THE REPUBLIC OF KARAKALPAKSTAN



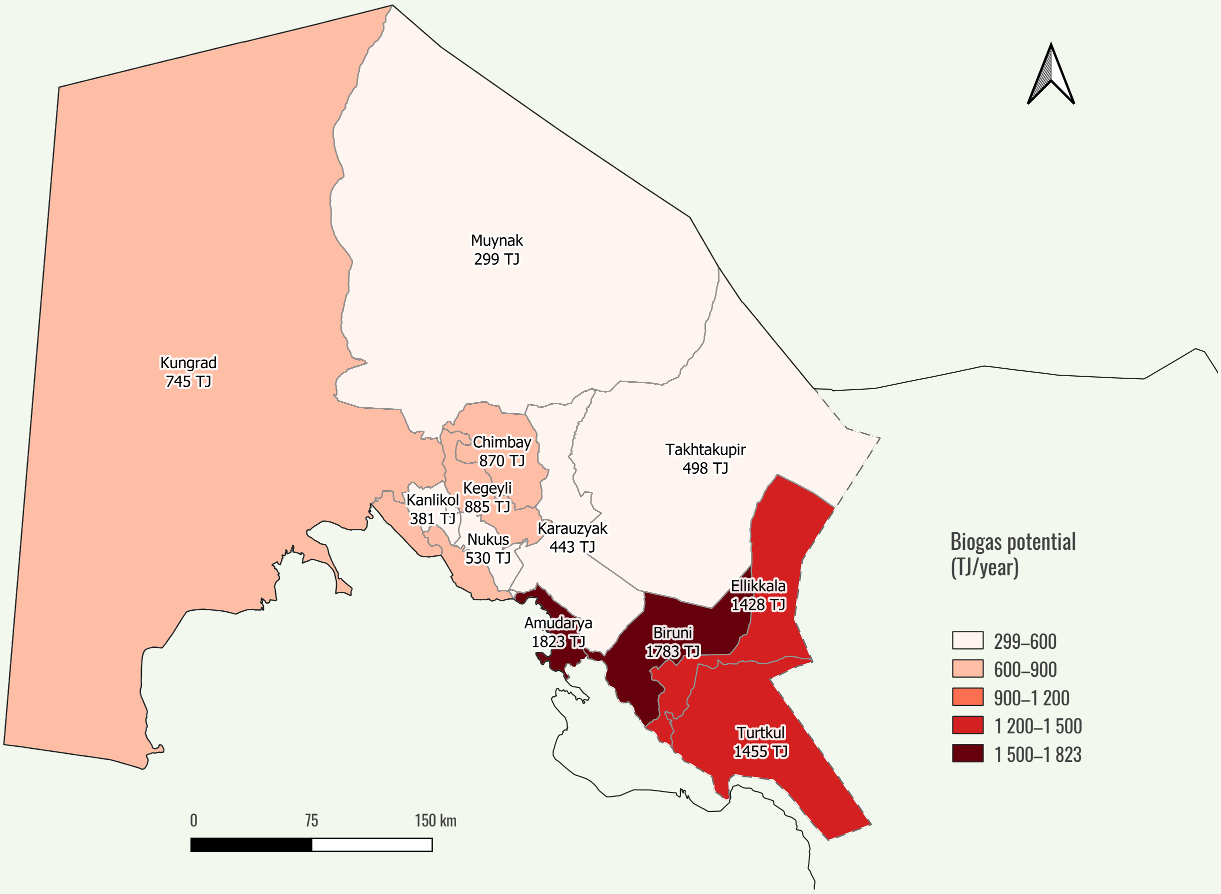
Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors based on BEFS Assessment Results.*

Figure 34 shows the spatial distribution of the available poultry manure in the Republic of Karakalpakstan. Three districts display the highest availability of poultry manure. These are Amudarya, Biruni and Ellikkala, where more than 14 thousand tonnes are available per year, while the remaining districts have a limited potential. Dehkan farms again are the most common in nearly all of the districts, with the exception of Biruni, where more than 50 percent of the poultry are raised on commercial farms. More detailed data for the available manure in the Republic of Karakalpakstan on a district level can be found in the Appendix B.

The spatial distribution of the biogas potential in the Republic of Karakalpakstan is presented in **Figure 35**. As described in the legend of the map, areas marked with a darker colour have a higher biogas potential, while lighter colours are indicative of less promising results. Overall, approximately 12 thousand TJ can be produced annually on a province level. Amudarya and Biruni, the two most prominent districts, can potentially generate 1 823 TJ and 1 783 TJ respectively, while Turkul and Ellikkala follow with 1 455 TJ and 1 428 TJ per year. The Khodjeyli, Kegeyli and Chimbay districts also display a significant biogas potential, as each can generate more than 850 TJ on an annual basis.

FIGURE 35.

SPATIAL DISTRIBUTION OF BIOGAS POTENTIAL IN THE REPUBLIC OF KARAKALPAKSTAN



Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. Cited 19 April 2022. https://www.diva-gis.org/gdata – *Modified by the authors based on BEFS Assessment Results.*

3.3.2.2 Khorezm Province

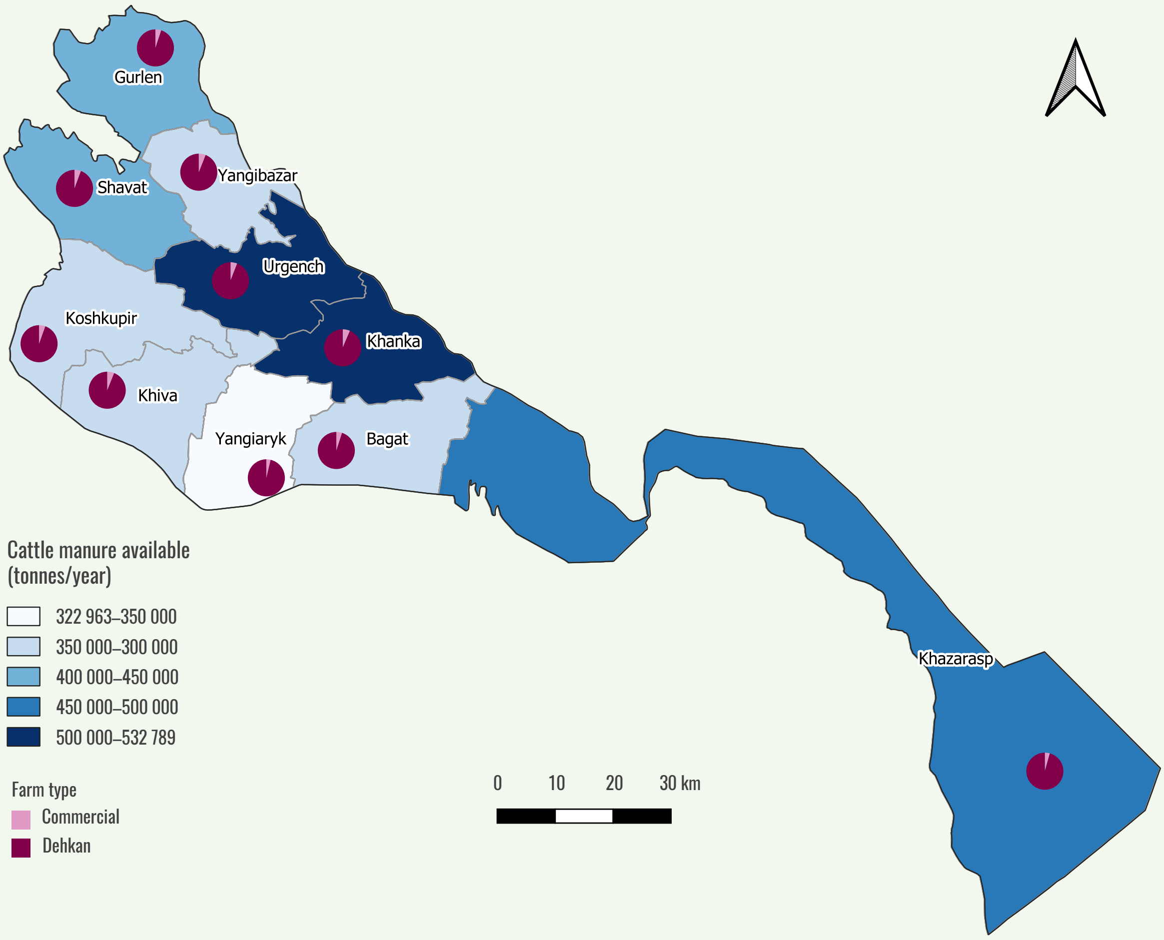
The geographical distribution of the available cattle manure for biogas production in the Khorezm Province is shown in **Figure 36**. As described with the legend of the map, darker blue colours represent higher manure availability, while light colours are indicative of a lower potential. Moreover, a distinction is made according to the production level varying between commercial and Dehkan farms, which is presented with pie charts.

In Khorezm, the Urganch and Khanka districts have the highest amounts of available cattle manure, more than 500 thousand tonnes per year in each. Other districts typically have 300 thousand to 400 thousand tonnes of manure available for biogas production each year. As indicated in the map, dehkan farms dominate the production in all districts.

The spatial distribution of the available poultry manure for biogas production in the Khorezm Province is presented in **Figure 37**. In the Urgench and Khanka districts, more than 35 thousand and 27 thousand tonnes of poultry manure could be used for biogas production annually. For the rest of the province, typical values of the available manure range between 10 thousand and 17 thousand tonnes per year. The production is evenly distributed between commercial and dehkan farms, with commercial farms assuming a much higher percentage compared to the Republic of Karakalpakstan.

FIGURE 36.

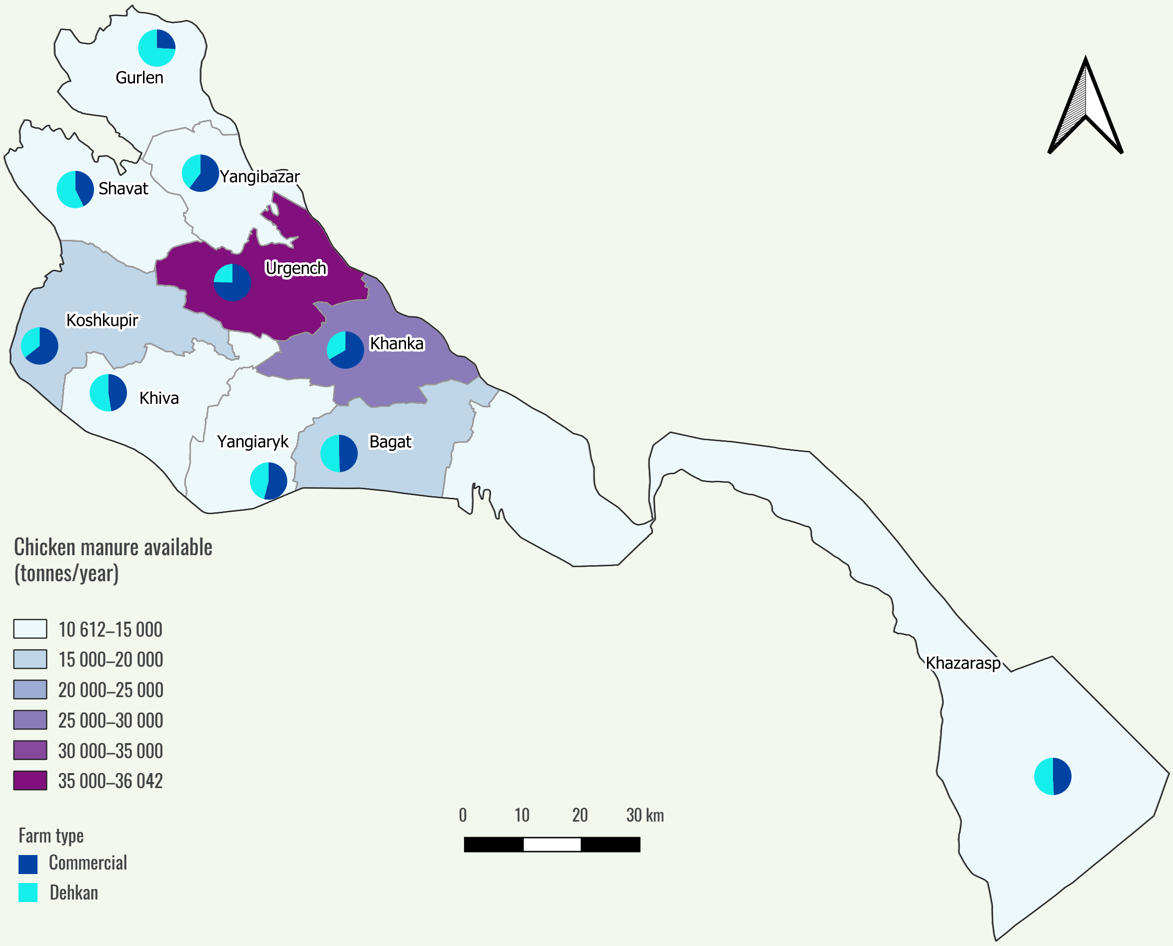
SPATIAL DISTRIBUTION OF AVAILABLE CATTLE MANURE IN THE KHOREZM PROVINCE



Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors based on BEFS Assessment Results.*

FIGURE 37.

SPATIAL DISTRIBUTION OF AVAILABLE CHICKEN MANURE IN THE KHOREZM PROVINCE

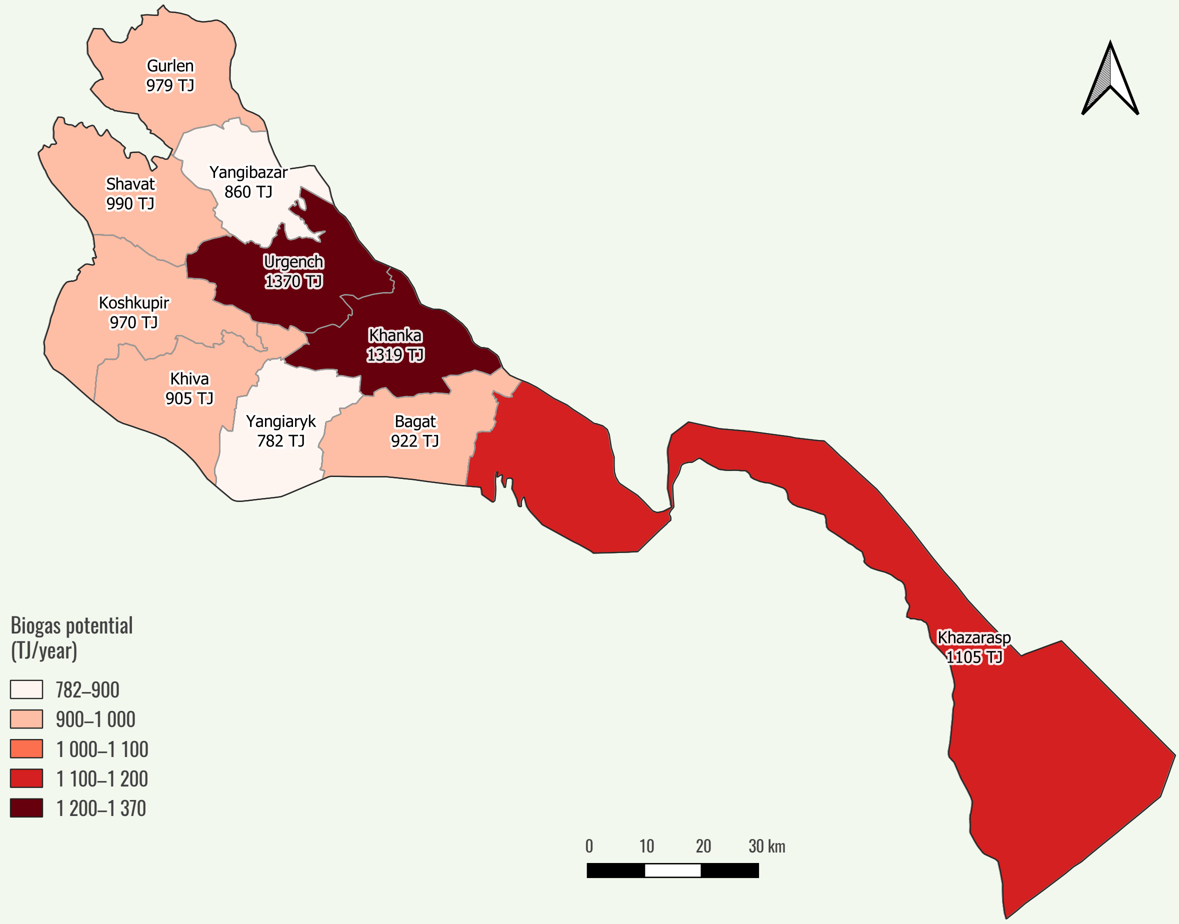


Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors based on BEFS Assessment Results.*

Figure 38 shows the spatial distribution of the biogas potential from livestock residues in the Khorezm Province, where more than 10 thousand TJ can potentially be produced annually. Based on the legend of the map, dark red areas are linked with higher potentials, while light coloured districts display a lower biogas potential. All districts within the province can produce more than 780 TJ per year and Urgench and Khanka display the most promising results, generating 1 370 TJ and 1 319 TJ respectively. Khazarasp also has a significant potential for biogas production, resulting in approximately 1 100 TJ per year. A more detailed description of the methodology, data and results of the biogas potential assessment on a district level can be found in the Appendix B.

FIGURE 38.

SPATIAL DISTRIBUTION OF BIOGAS POTENTIAL IN THE KHOREZM PROVINCE



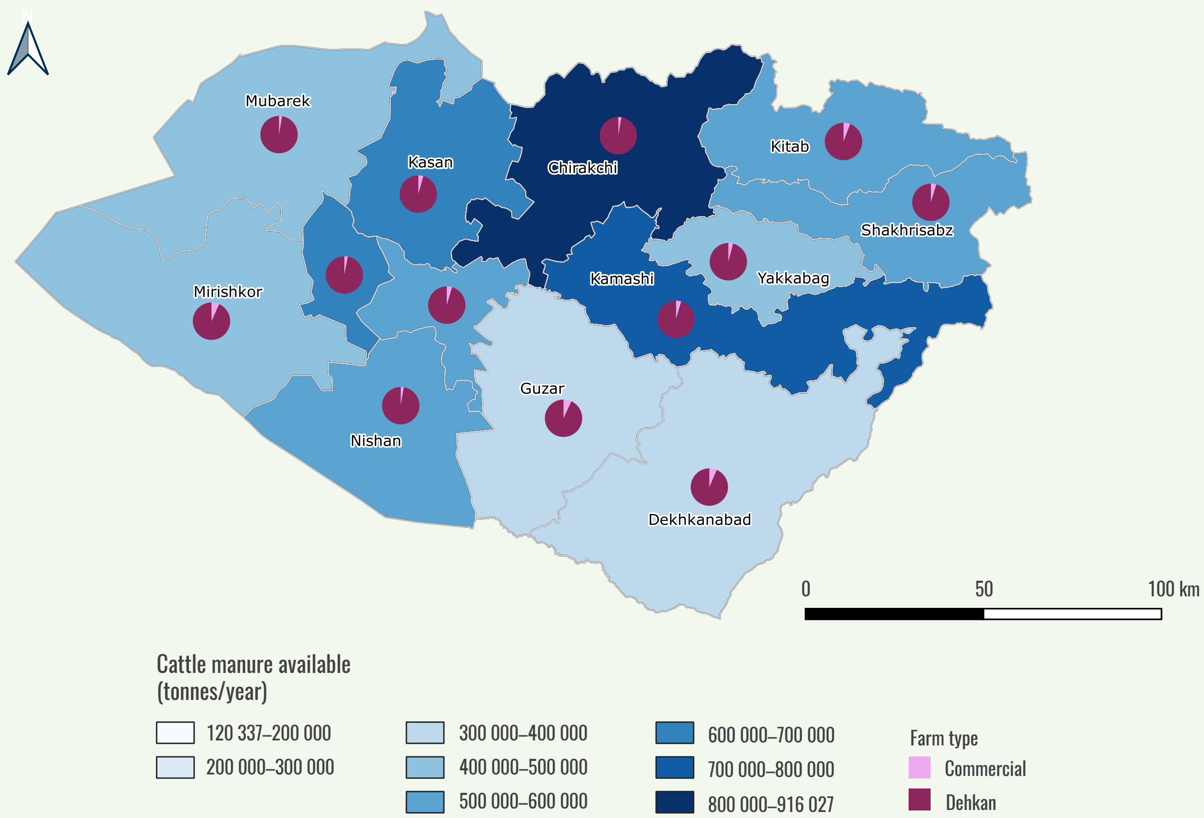
Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors based on BEFS Assessment Results.*

3.3.2.3 Kashkadarya Province

Figure 39 displays the geographical distribution of the available cattle manure in the province of Kashkadarya. From the legend it can be seen that the areas marked with a darker colour indicate higher amounts of available manure and thus higher biogas prospects for the region. Additionally, the distinction between commercial and dehkan farm production is presented using pie charts. The Chikarchi district has the highest potential of the province, with more than 900 thousand tonnes of available cattle manure per year. Kamasi and Kasan districts follow, with 770 thousand and 700 thousand tonnes per year, respectively. The lowest potential is found in the Guzar and Dekhkanabad districts, with the annual availability ranging between 300 thousand and 400 thousand tonnes per year. The Kashkadarya Province has the overall highest potential regarding manure availability. It should be noted that dehkan farmers dominate production in all districts inside the province.

FIGURE 39.

SPATIAL DISTRIBUTION OF AVAILABLE CATTLE MANURE IN THE KASHKADARYA PROVINCE

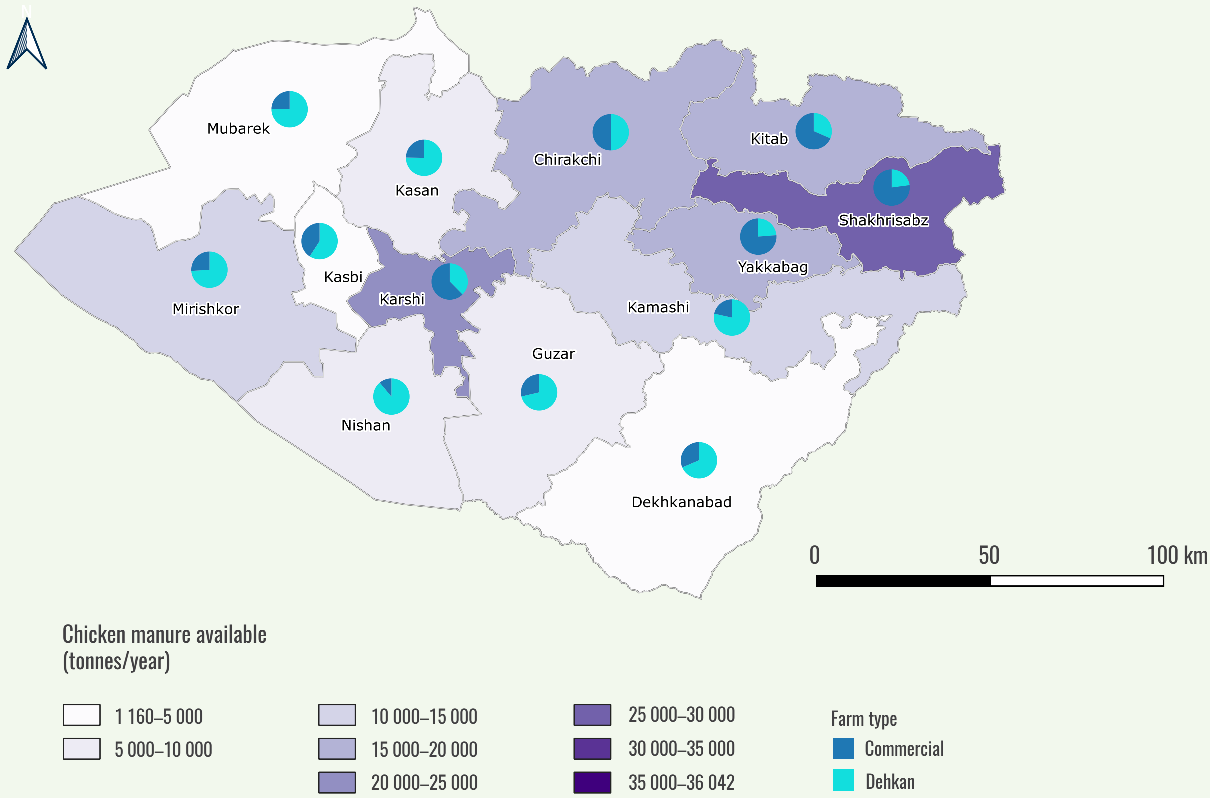


Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors based on BEFS Assessment Results.*

The spatial distribution of the available poultry manure in the Kashkadarya Province is presented in **Figure 40**. The Shakhrisabz, Karshi and Chirakchi districts display the highest availability, more than 20 thousand tonnes per year in each district – commercial farms dominate the production in these districts. On the other hand, in districts with the lowest potential, dehkan farms have a more dominant role. These districts are the Nishan, Mubarek, Kasbi and Dekhkanabad, where the availability of poultry manure ranges between 3.6 thousand and 5.6 thousand tonnes per year.

FIGURE 40.

SPATIAL DISTRIBUTION OF AVAILABLE CHICKEN MANURE IN THE KASHKADARYA PROVINCE



Source: DIVA-GIS. 2023. Download data by country – Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata – *Modified by the authors based on BEFS Assessment Results.*

The spatial distribution of the biogas potential in the Kashkadarya Province is depicted in **Figure 41**. As seen in the legend of the map, areas marked with a darker colour are indicative of a higher biogas potential. Annually more than 25 thousand TJ can be generated within the province, with Chirakchi being the most prominent district, as it is responsible for 13 percent of the total (3 176 TJ). Nearly 2 700 TJ per year can be generated in Kamashi, with Kasan, Kasbi and Kitab following with 2 387 TJ, 2 079 TJ and 2 046 TJ, respectively. All other districts inside Kashkadarya also display a significant potential, generating more than 1 200 TJ on an annual basis each.

A detailed description of the methodology, the data and the results of the biogas potential assessment on a district level can be found in the Appendix B.

3.3.2.4 Livestock residues - Summary of results

Based on the livestock production in three provinces in 2020, it can be concluded that cattle manure is the dominant livestock residue with a potential for biogas production. With the assumption that 70 percent of collectible manure can be mobilized for biogas production, the total amount reaches more than 16 million tonnes annually.

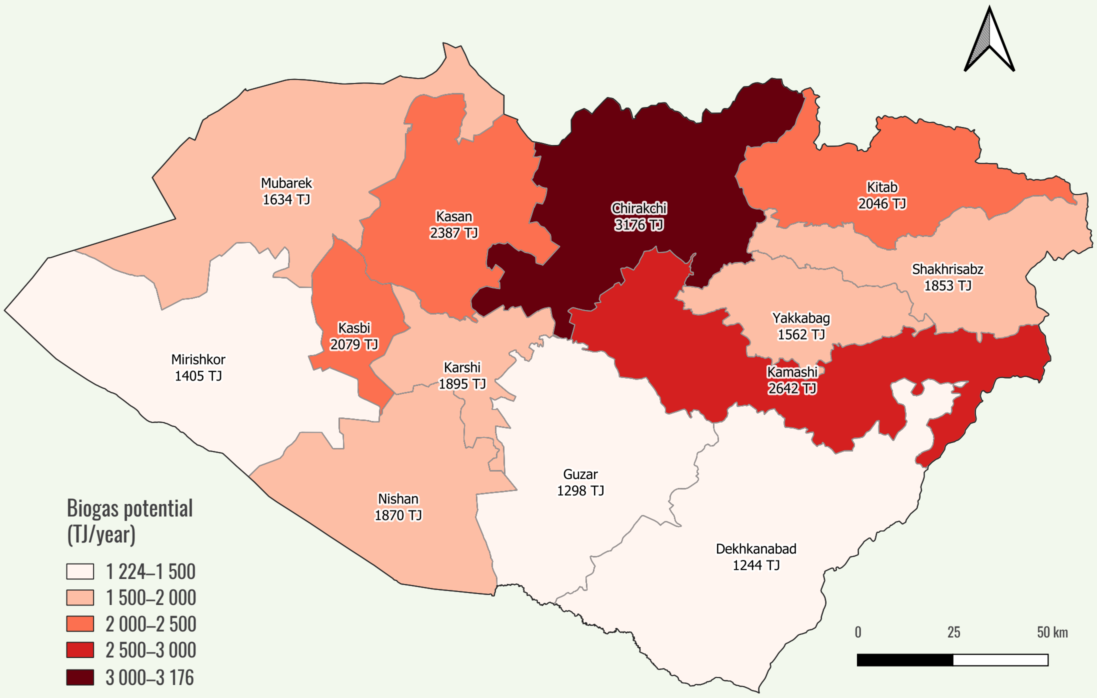
It is important to note that approximately 95 percent of this originates from dehkan farmers, who on average own three to seven animals. This means that a dehkan farmer could supply between 25.2 kg and 88 kg of fresh manure daily, i.e. between 9.1 tonnes and 32.2 tonnes annually, to a biogas plant.

This could be sufficient for operating a small, household level, biogas digestor supplying biogas for cooking and/or lighting. Another option for the utilisation of manure would be the establishment of larger biogas plants, which would be supplied jointly by farmers living in regions near the plant. The size of such a plant will depend on the number of animals held by the farmers. Regarding poultry manure, more than 400 thousand tonnes are available per year and the production is split evenly between commercial and dehkan farms. The Kashkadarya Province has the highest potential with annual availability of 7.4 million tonnes. The Republic of Karakalpakstan and the Khorezm Province follow with 5.1 million and 4.3 million tonnes per year, respectively.

All three provinces display a significant biogas potential and Kashkadarya has by far the most promising results, with more than 25 thousand TJ per year. The Republic of Karakalpakstan and the Khorezm Province show similar biogas potential, with nearly 13 thousand TJ and 11 thousand TJ on an annual basis, respectively. Biogas production from cattle and poultry manure can have multiple benefits. First, clean fuel for cooking and heating can be provided to rural households that currently have limited access to clean cooking fuels. Additionally, the utilization of biogas in cogeneration (CHP) systems can result in electricity and heat production, covering the energy demand of the farms and/or supply the electricity to the grid. Lastly, reduction of methane emissions can be achieved through the environmentally sound management of livestock waste.

FIGURE 41.

SPATIAL DISTRIBUTION OF BIOGAS POTENTIAL IN THE KASHKADARYA PROVINCE



Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors based on BEFS Assessment Results.*

3.3.3 Crop residues: approach and methodology

The aim of the crop residues assessment was to determine the quantity and availability of residues that are suitable for bioenergy production. From a total of eight of the most produced crops in the Republic of Karakalpakstan, Khorezm Province and Kashkadarya province, 16 residue types were identified as suitable for the production of modern solid biofuels and/or electricity generation, and included in the BEFS assessment. The analysis was carried out on a district level, the lowest spatial level for which statistical data on crop production was available. Later the results were aggregated to the province level. Moreover, the theoretical bioenergy potential from the available crop residues was also studied. The calculation is based on the amount of available crop residues and their respective lower heating values (LHV).

1. TOTAL PRODUCTION OF CROP RESIDUES

The total production of crop residues is indicative of the theoretical bioenergy potential of a region. This amount does not take into account whether a type of residue can be collected or for what purpose it is already being used. The total production of residues is determined using the following equation:

$$CR_{Tot(i-j)}=C_{Prod(i)}\ {*}RCR_{(i-j)}$$

Where:

- $CR_{Tot(i-j)}$ [tonnes/year]: the total amount of residues produced from crop (i) and type of residue (j) per year;
- $C_{Prod(i)}$ [tonnes/year]: the average production of crop (i) per year;
- $RCR_{(i-j)}$: the residue to crop ratio of the specific crop (i) and type of residue (j).

The agricultural statistics for the period 2010 to 2020 were used to determine the average annual crop production per district in the three provinces, while the amount of crop residues generated were calculated using the residue-to-crop ratio (RCR) coefficients that were provided and/or verified by national experts. **Table 19** provides an overview of the analysed crop-residue types and the respective RCRs.

The amount of each type of residue in every district of the three provinces of interest.

2. CROP RESIDUES AVAILABLE FOR BIOENERGY

Agricultural residues can be utilized for different purposes, such as soil amendment, animal feed, animal bedding, construction material and other material uses. Therefore, the availability of a certain residue type for bioenergy will vary across different districts, depending on the existing uses. The residues available for bioenergy can be determined using the following equation:

$$CR_{available\ (i-j)}=CR_{Tot(i-j)}-CR_{Used(i-j)}$$

Where:

- $CR_{available(i-j)}$ [tonnes/year]: the total amount of available residues for bioenergy production from the crop (i) and type of residue (j) per year;
- $CR_{Used(i-j)}$ [tonnes/year]: The total amount of already used residues from the crop (i) and type of residue (j) per year;

The information about if and how farmers use crop residues in the three provinces and what share is being used was obtained through technical consultations with national experts. The summary of gathered information is presented in **Table 19**.

TABLE 19.

RCR AND CURRENT USES OF THE DIFFERENT RESIDUE TYPES

CROP TYPE	RESIDUE TYPE	RCR	CURRENT USES	SHARE OF USED RESIDUES
WHEAT	STRAW	1.1	CATTLE FEED, MULCHING/FERTILIZER	100%
	HUSK	0.28	NA	NA
COTTON	STALK	5.5	MULCHING/FERTILIZER, FUEL, MATERIALS	10%
	HUSK	0.26	NA	NA
RICE	STRAW	1.2–1.5	CATTLE FEED, MULCHING/FERTILIZER	100%
	HUSK	0.15	CATTLE BEDDING	80%
CORN	STOVER	1.4	CATTLE FEED	100%
	HUSK	0.1	CATTLE FEED	100%
	COB	0.18	CATTLE FEED	50%
MUNGBEAN	STRAW	1.4	CATTLE FEED	100%
SOYBEAN	STRAW	0.85	CATTLE FEED	100%
SESAME	STALK	5	MULCHING/FERTILIZER	10%
	PODS	0.1	CATTLE FEED	100%
SUNFLOWER	STALK	1.29	CATTLE FEED, MULCHING/FERTILIZER	60%
	HEADS	1.17	CATTLE FEED	100%
	HULLS	0.25	CATTLE FEED	100%

Source: Author's own elaboration based on technical consultation with national experts.

3. THEORETICAL BIOENERGY POTENTIAL

$$P_{Bioenergy(i-j)}=CR_{available(i-j)}*LHV_{(i-j)}$$

Where:

- $P_{Bioenergy(i-j)}$ [MJ/year]: the theoretical bioenergy potential from crop residues from crop (i) and type of residue (j) per year;
- $LHV_{(i-j)}$ [MJ/tonne]: the lower heating value for crop (i) and type of residue (j).

3.3.4 Crop residues: bioenergy potential

Table 20 presents the overall crop production, harvested area and crop yield in the Republic of Karakalpakstan, Khorezm and Kashkadarya. Wheat is the most produced crop, with an average annual production of 1.5 million tonnes, while cotton follows with approximately 930 thousand tonnes per year in the three provinces. Additionally, on average 135 thousand tonnes of rice and 34 thousand tonnes of maize are produced each year, with the average production area of 44 thousand and 6 thousand hectares, respectively. Other important crops, although with much lower outputs are sunflower, mungbeans, sesame and soybeans, all displaying an annual production smaller than 12 thousand tonnes. The production of these crops in the three provinces is given in **Figure 42**.

TABLE 20.

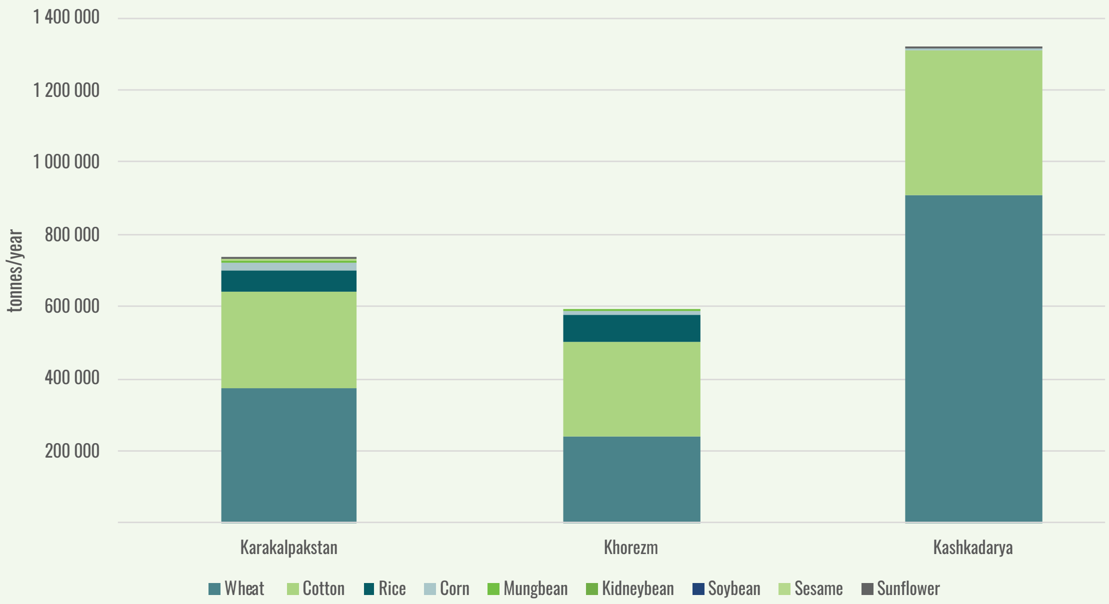
OVERALL CROP PRODUCTION, AREA AND YIELD IN THE THREE PROVINCES

CROP TYPE	AVERAGE ANNUAL PRODUCTION 2010 – 2020		
	PRODUCTION (tonnes/year)	AREA (ha)	YIELD (tonnes/ha)
WHEAT	1 522 149	348 206	4.37
COTTON	929 496	348 206	2.28
RICE	134 859	43 355	3.11
MAIZE	34 056	6 540	5.21
SUNFLOWER	11 416	15 929	0.72
MUNGBEANS	7 026	3 521	2.00
SESAME	4 458	3 823	1.17
SOYBEANS	2 256	1 888	1.19

Source: Authors' own elaboration.

FIGURE 42.

CROP PRODUCTION PER PROVINCE



Source: Authors' own elaboration.

Based on the methodology described above, the amount of residues generated and the share available for bioenergy production in the three provinces were calculated.

The overall production of residues in the Republic of Karakalpakstan, Khorezm and Kashkadarya is presented in **Table 21**. It should be noted that the crop residues are grouped into two main categories: those that are generated in the field at the time of harvest (primary residues), and those that are co-produced during processing (secondary residues).

TABLE 21.

OVERALL ANNUAL CROP RESIDUE PRODUCTION IN THE THREE PROVINCES

PRIMARY RESIDUES (IN THE FIELD)		SECONDARY RESIDUES (AT THE PROCESSING PLANT)	
CROP RESIDUE TYPE	ANNUAL PRODUCTION (tonnes/year)	CROP RESIDUE TYPE	ANNUAL PRODUCTION (tonnes/year)
COTTON STALK	5 112 228	COTTON HUSK	241 669
WHEAT STRAW	1 674 364	RICE HUSK	20 229
RICE STRAW	180 226	CORN COB	6 130
CORN STOVER	47 678	SESAME PODS	446
SESAME STALK	22 290	SUNFLOWER HEADS	13 357
SUNFLOWER STALK	14 727	SUNFLOWER HULLS	2 854
MUNGBEAN STRAW	9 836		
CORN HUSK	3 406		
SOYBEAN STRAW	1 918		

Source: Authors' own elaboration.

Figure 43 shows the disaggregation of the crop residue production between the three provinces. More than 3.5 million tonnes of crop residues are generated in Kashkadarya. Thereby, as much as 60 percent of the total is cotton stalk, while wheat straw follows with 28 percent. Additionally, 254 thousand tonnes of wheat husk are generated annually in Kashkadarya, making it the largest producer of this particular residue. In the Republic of Karakalpakstan 1.4 million tonnes of cotton stalk is generated per year. Wheat straw and wheat husk are also generated in significant volumes: 413 thousand and 105 thousand tonnes, respectively. Karakalpakstan has the highest production of rice among the three provinces. Around 92 thousand tonnes of rice straw are generated annually in this province.

FIGURE 43.

CROP RESIDUE PRODUCTION PER PROVINCE

Source: Authors' own elaboration.

The technical consultation showed that crop residues are used extensively for animal feed or bedding, and/or green fertilisation of the fields. Taking this into account, the available residues that could be used for bioenergy production in the three provinces were calculated. The results are shown in **Figure 44**.

Cotton stalk is the most abundant crop residue in all the three provinces. Kashkadarya has the overall highest bioenergy potential, with approximately 2.3 million tonnes of residues available. Nearly 85 percent of that is cotton stalk, with wheat husk and cotton husk making up 11 percent and 4 percent of the overall availability in the province respectively. The Republic of Karakalpakstan and Khorezm have similar potentials, which are significantly lower compared to Kashkadarya. In both provinces around 1.3 million tonnes of cotton stalk are available to be used in bioenergy applications, while wheat husk is the second most important residue, with the Republic of Karakalpakstan being the most prominent location between the two. Lastly, both provinces display a cotton husk availability of approximately 69 thousand tonnes per year.

FIGURE 44.

AVAILABLE RESIDUES PER PROVINCE

Source: Authors' own elaboration.

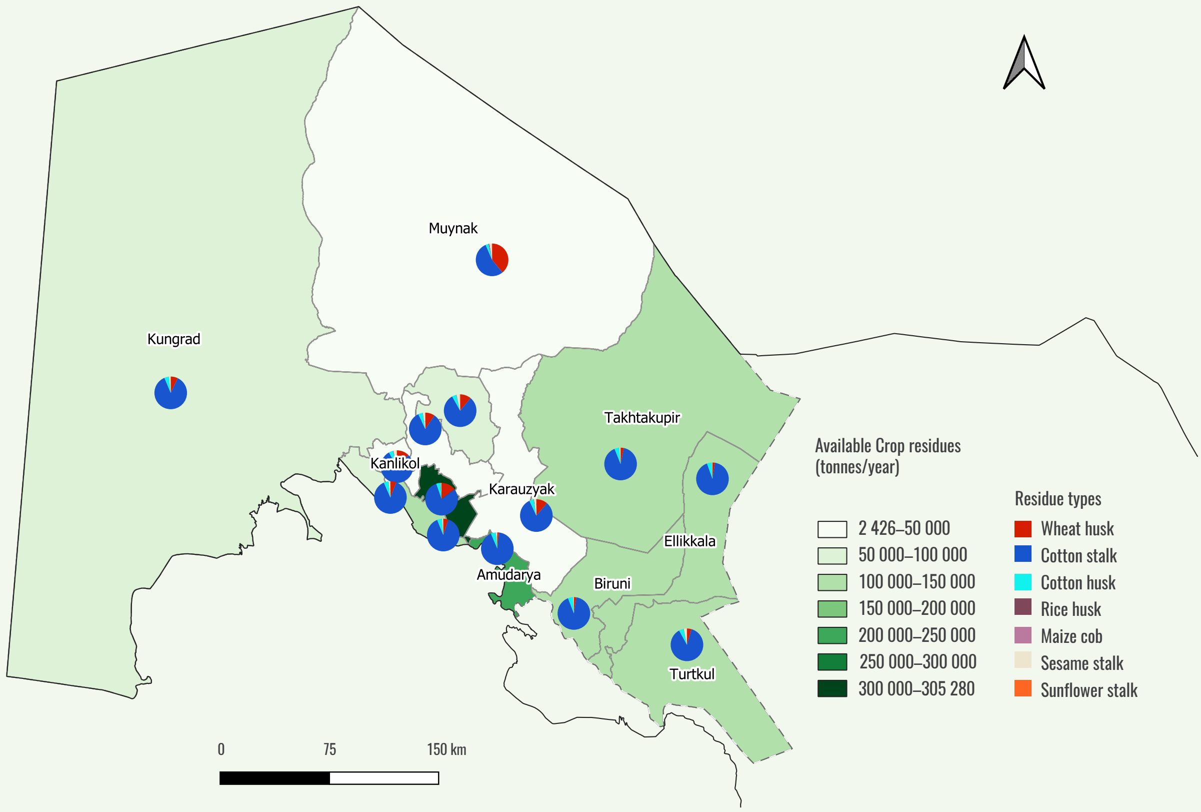
3.3.4.1 The Republic of Karakalpakstan

Figure 45 displays the spatial distribution of the available crop residues in the Republic of Karakalpakstan. Areas marked with a darker green colour display a higher crop-residue availability. Additionally, the distinction between the different types of crop residues is depicted with pie charts.

The highest potential in the Republic of Karakalpakstan can be seen in the Nukus and Amudarya districts, which have 305 thousand and 212 thousand tonnes of residues available per year, respectively. In both cases, the most dominant residue is cotton stalk, while residue density in these regions ranges between 3 tonnes/ha and 4.5 tonnes/ha. The Kazauryak and Kegeyli districts are characterized by a relatively limited potential, with less than 50 thousand tonnes of residues available annually. Lastly, the Muynak district has by far the lowest amount of available residues, which is around 2 thousand tonnes per year.

FIGURE 45.

SPATIAL DISTRIBUTION OF THE AVAILABLE CROP RESIDUES IN THE REPUBLIC OF KARAKALPAKSTAN

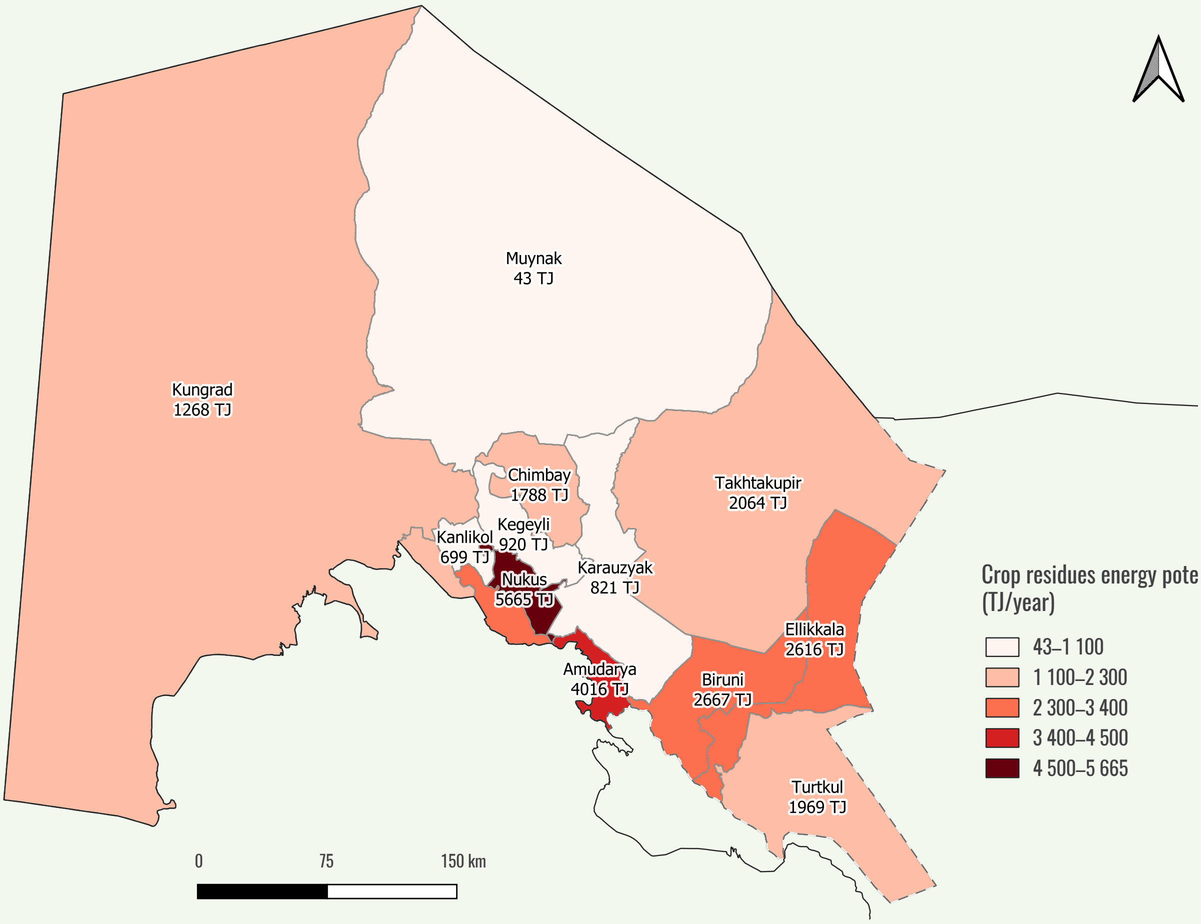


Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors based on BEFS Assessment Results.*

The theoretical bioenergy potential from crop residues can be determined based on the amount of available feedstocks and their respective lower heating values (LHV). **Figure 46** displays the spatial distribution of the theoretical bioenergy potential from crop residues in the Republic of Karakalpakstan. Based on the legend of the map, dark red areas are linked with a higher theoretical bioenergy potential, while light colours are indicative of less promising results. More than 28 thousand TJ can be generated annually in the province and Nukus is the most promising district, generating 5 665 TJ/year on an annual basis. Amudarya follows with 4 016 TJ/year, while Biruni, Ellikkala and Khodjeyli also display significant potentials within the range of 2 500 TJ/year-2 700 TJ/year. The Muynak district has by far the lowest bioenergy potential inside the province, producing only 43 TJ per year.

FIGURE 46.

SPATIAL DISTRIBUTION OF THEORETICAL ENERGY POTENTIAL FROM CROP RESIDUES IN THE REPUBLIC OF KARAKALPAKSTAN



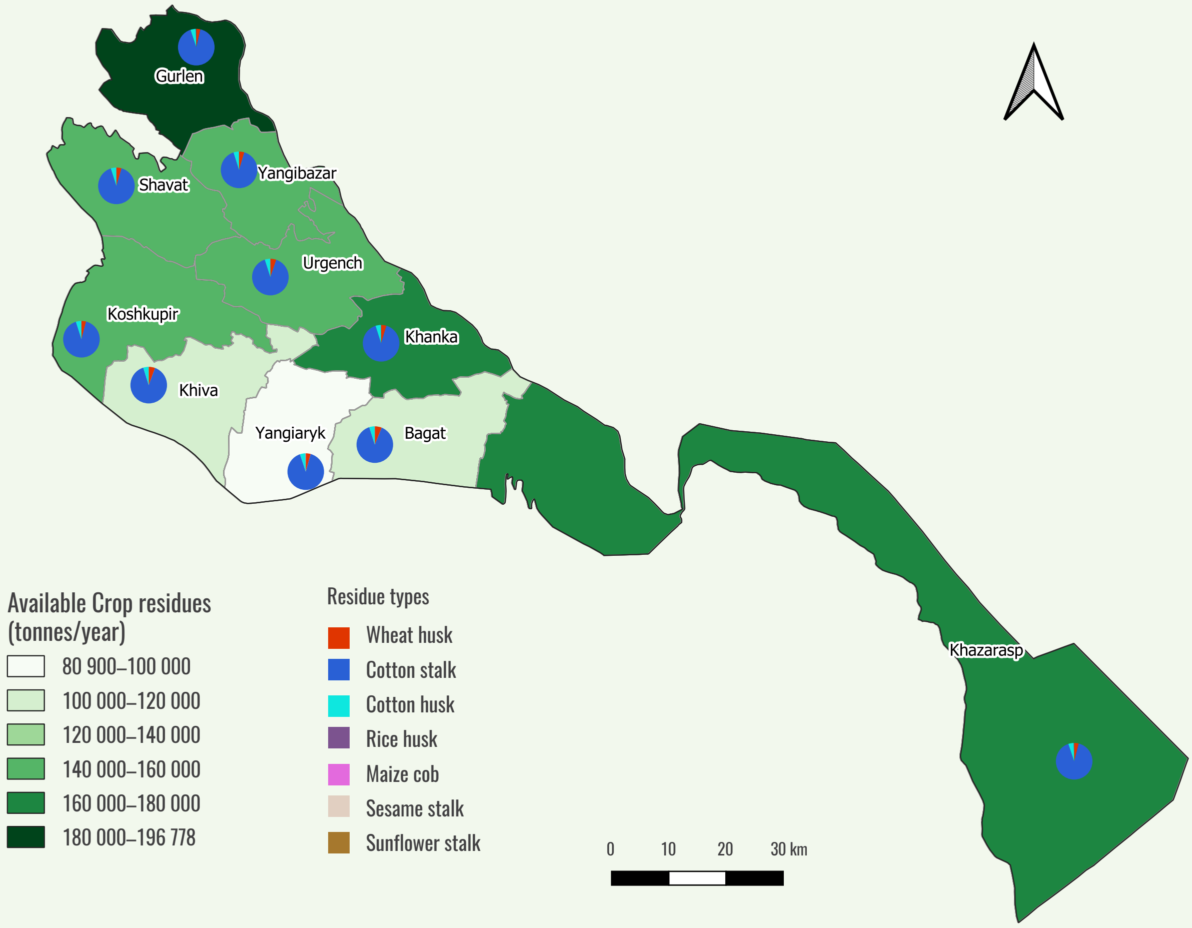
Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors based on BEFS Assessment Results.*

3.3.4.2 Khorezm Province

The spatial distribution of the available crop residues in the Khorezm Province is depicted in **Figure 47**. As described in the legend of the map, darker green colours are indicative of a higher crop-residue availability. Additionally, the distinction between the different types of crop residues is depicted with pie charts. The Gurlen district is the most promising region with nearly 200 thousand tonnes of crop residues available on an annual basis, while Khazarasp and Khanka follow, generating approximately 180 thousand tonnes per year each. In most districts within the Khorezm Province there are more than 100 thousand tonnes per year of crop residues available, and the crop residue density is higher than 3 tonnes/ha. In all districts, cotton stalk is by far the most dominant crop residue available. Cotton husk and wheat husk follow, but with much lower amounts available.

FIGURE 47.

SPATIAL DISTRIBUTION OF THE AVAILABLE CROP RESIDUES IN THE KHOREZM PROVINCE

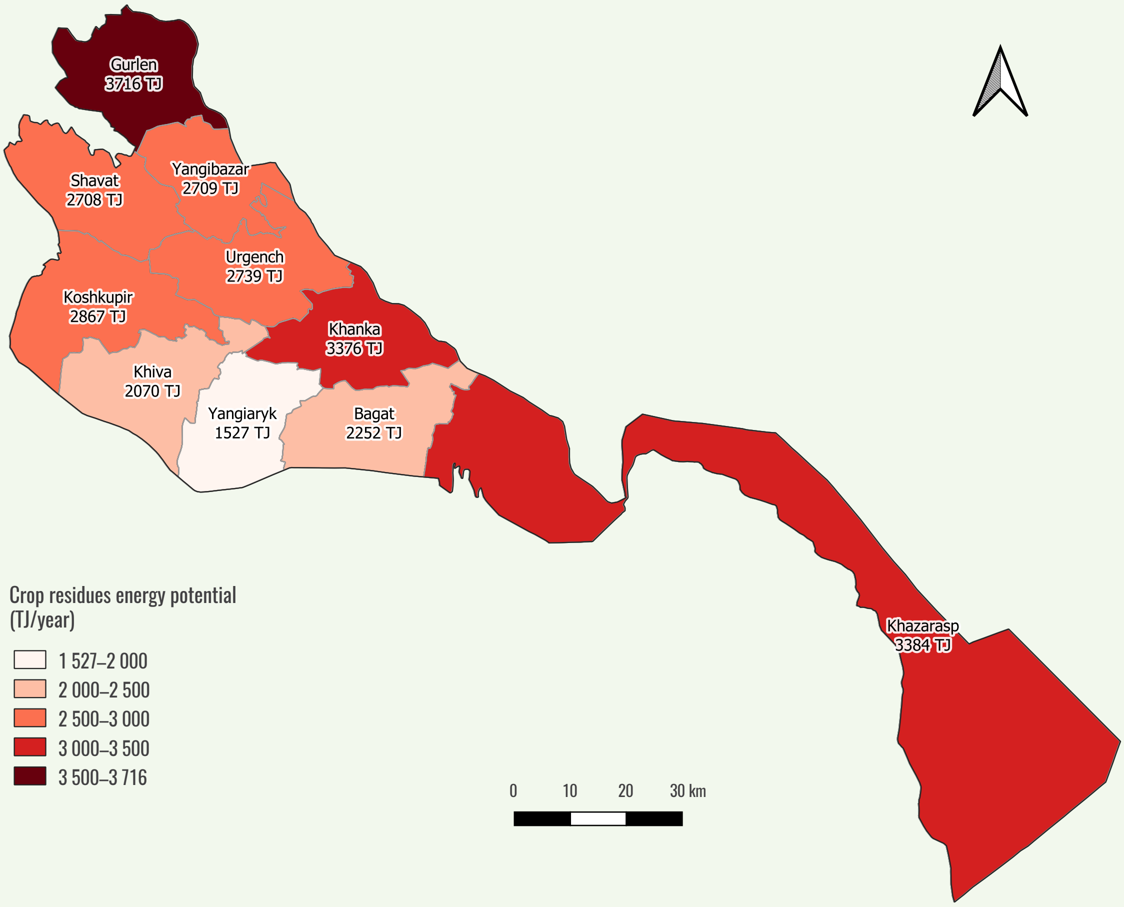


Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors based on BEFS Assessment Results.*

Figure 48 presents the spatial distribution of the theoretical bioenergy potential from crop residues in the Khorezm Province, where more than 27 thousand TJ can be generated annually. In Gurlen, the bioenergy potential reaches 3 716 TJ per year, making it the most prominent district of the province. Khazarasp and Khanka also display significant results, generating 3 384 TJ and 3 376 TJ respectively. All other districts in Khorezm can produce more than 2 thousand TJ per year, stressing the bioenergy potential inside the province. Yangiaryk is the only exception, presenting an annual potential of 1 527 TJ. A more detailed description of the methodology, the data and the results of the crop residues bioenergy potential assessment for Khorezm on a district level can be found in the Appendix B.

FIGURE 48.

SPATIAL DISTRIBUTION OF THEORETICAL ENERGY POTENTIAL FROM CROP RESIDUES IN THE KHOREZM PROVINCE



Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors based on BEFS Assessment Results.*

3.3.4.3 Kashkadarya Province

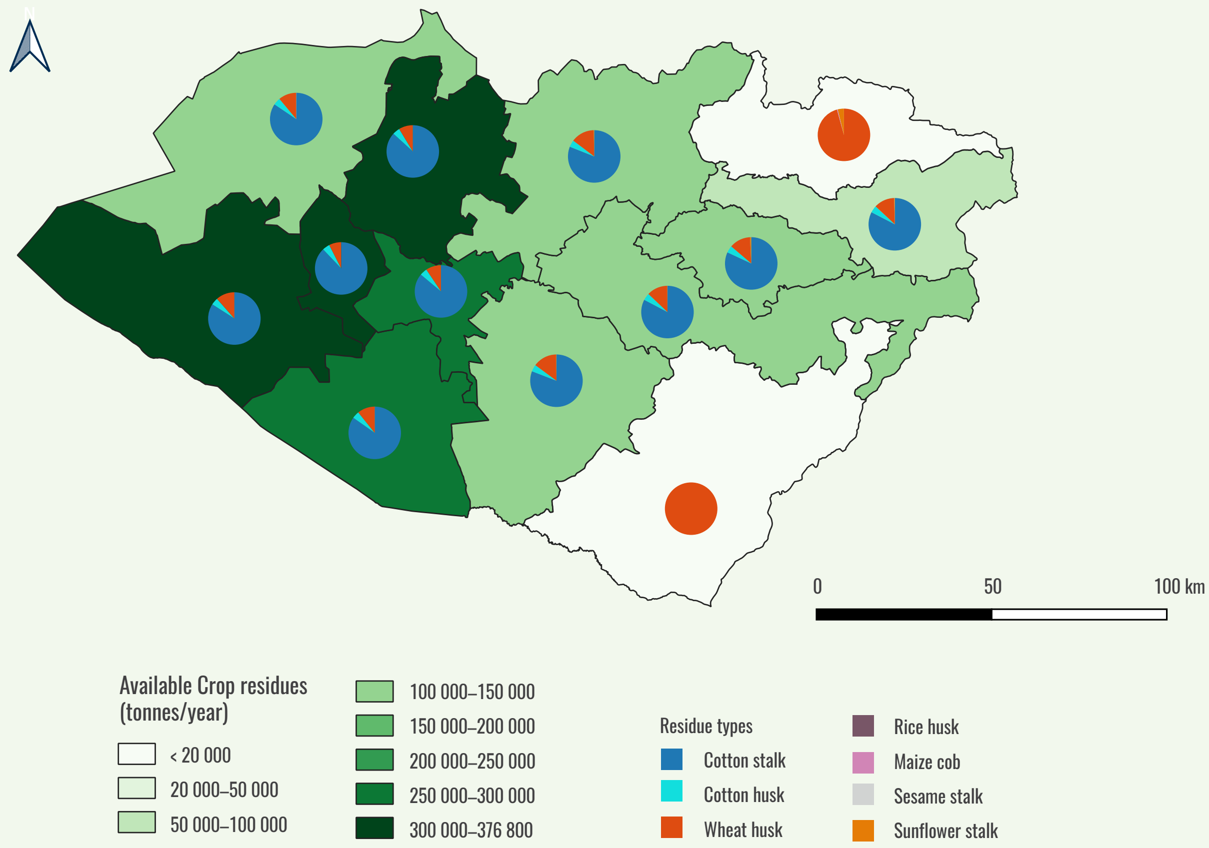
The spatial distribution of the available crop residues in the Province of Kashkadarya is presented in **Figure 49**. As noted in the legend of the map, dark green areas have the highest residue availability. On the other hand, light coloured areas have much lower amounts of residues available and thus a significantly smaller potential. The distinction between the different crop residue types is shown with pie charts.

The highest residue availability can be seen in the Minishokor, Koson and Kesbi districts, where more than 300 thousand tonnes of crop residues are available per year. The Dehkanabad and Kitob districts have limited residue availability; sunflower stalk is the dominant crop residue type within these two districts. Generally, other districts in the Kashkadarya province display an availability of more than 100 thousand tonnes per year, with cotton stalk and wheat husk being the most abundant residue type. The Kamashi district displays the highest residue density with more than 4 tonnes/ha, while in the majority of other districts it ranges between 3 tonnes/ha and 4 tonnes/ha.

A detailed overview of the available crop residues in the districts of Kashkadarya Province can be found in the Appendix B.

FIGURE 49.

SPATIAL DISTRIBUTION OF THE AVAILABLE CROP RESIDUES IN THE KASHKADARYA PROVINCE

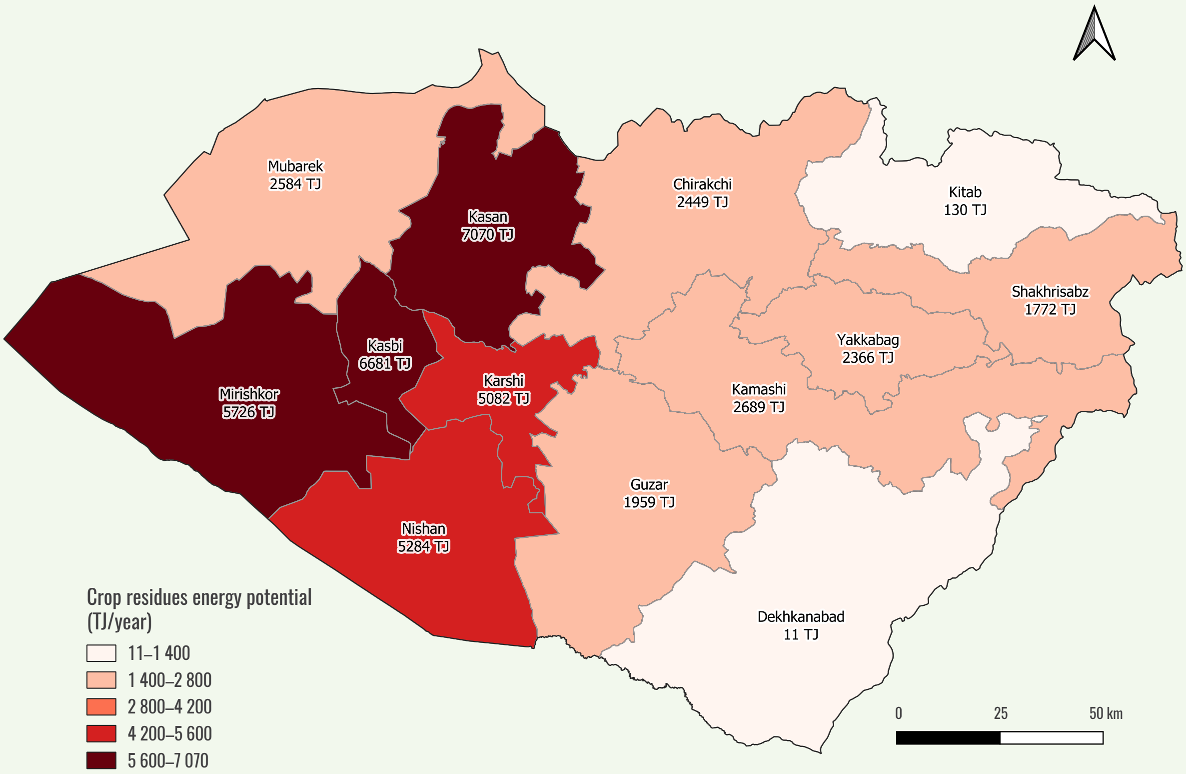


Source: DIVA-GIS. 2023. Download data by country – Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata – *Modified by the authors based on BEFS Assessment Results.*

The theoretical bioenergy potential from crop residues is determined based on the amount of available feedstocks and their respective lower heating values (LHV). **Figure 50** shows the spatial distribution of the theoretical bioenergy potential from crop residues for the Kashkadarya Province. On a province level, more than 43 thousand TJ can be generated per year, emphasizing the significant bioenergy potential of the region. Kasan is the most prominent district, with approximately 7 thousand TJ annually, while Kasbi and Mirishkor follow with 6 681 TJ and 5 726 TJ respectively. Karshi and Nishan also show promising results, producing more than 5 thousand TJ on a yearly basis. Contrary to all other districts, Kitab and Dekhkanabad display limited bioenergy potential, with only 130 TJ and 11 TJ respectively.

FIGURE 50.

SPATIAL DISTRIBUTION OF THEORETICAL ENERGY POTENTIAL FROM CROP RESIDUES IN THE KASHKADARYA PROVINCE



Source: DIVA-GIS. 2023. Download data by country - Uzbekistan. In: *DIVA-GIS*. [Cited 19 April 2022]. https://www.diva-gis.org/gdata - *Modified by the authors based on BEFS Assessment Results.*

A detailed overview of the available crop residues in the three analysed regions can be found in the Appendix B.

3.3.4. Summary of results

The analysis showed that the most dominant crop residue type in the three provinces is cotton stalk, with more than 4.6 million tonnes available per year. Wheat husk and cotton husk follow with an annual availability of 426 thousand and 241 thousand tonnes per year respectively. The remaining crop residues potentially available for bioenergy generation, namely sesame stalk, sunflower stalk, rice husk and corn cob, amount to less than 35 thousand tonnes per year. The Kashkadarya Province has the highest potential, with 45 percent of the total available residues in the three provinces. The Republic of Karakalpakstan and the Khorezm Province have similar potentials, with approximately 28 percent of the total available residues each.

It should be noted that in the base scenario presented above, it was estimated that 90 percent of the produced cotton stalk is potentially available for bioenergy generation. However, upon initial review of the results, the national experts indicated that part of the cotton stalk production is currently used as fuel and also as a feedstock in the wood processing industry. Therefore, the detailed results given in the Appendix in addition to the base scenario, a scenario assuming that 50 percent of cotton stalk is potentially available for production of modern solid biofuels and/or electricity.

The most important secondary residues, which are generated at processing plants, are cotton husk, wheat husk, rice husk and maize cob. These offer the possibility for mobilisation at low costs. On the other hand, primary crop residues that are left in the field after harvesting require collection and transportation to the processing plants. Moreover, it should be noted that mobilisation of residues from the areas with high residue density would require lower collection costs and less complex mobilisation logistics. Lastly, all residues that were considered within the scope of this analysis are suitable for the production of solid modern biofuels, such as pellets and briquettes, as well as for electricity generation using gasification and/or combustion technologies. Furthermore, they have a significant potential to substitute traditional biofuels, such as firewood and dry dung.

All three provinces have a significant bioenergy potential from the available crop residues. The Kashkadarya province is the most promising location, as approximately 44 thousand TJ can be generated annually. The Republic of Karakalpakstan also has an important potential, with more than 28 thousand TJ per year, while Khorezm follows with 27 thousand TJ on a yearly basis.

CHAPTER

4

RENEWABLE ENERGY INTERVENTIONS IN THE WHEAT CHAIN

4.1 WHEAT CHAIN

Wheat is a major crop both nationally and in the three regions selected under the project (Kashkadarya, Khorezm and the Republic of Karakalpakstan). At the national level, wheat is the most widely grown crop in the country with an estimated production of 1.7 million tonnes in 2018 (FAOSTAT, 2020). All three selected regions also produce wheat albeit in varying quantities. Kashkadarya leads the three regions in wheat production with 141 000 ha dedicated to irrigated and 63 000 ha dedicated to rainfed wheat production. **Table 22** details the area cultivated and yields of wheat in the three study regions.

TABLE 22.

WHEAT PRODUCTION IN THE THREE REGIONS

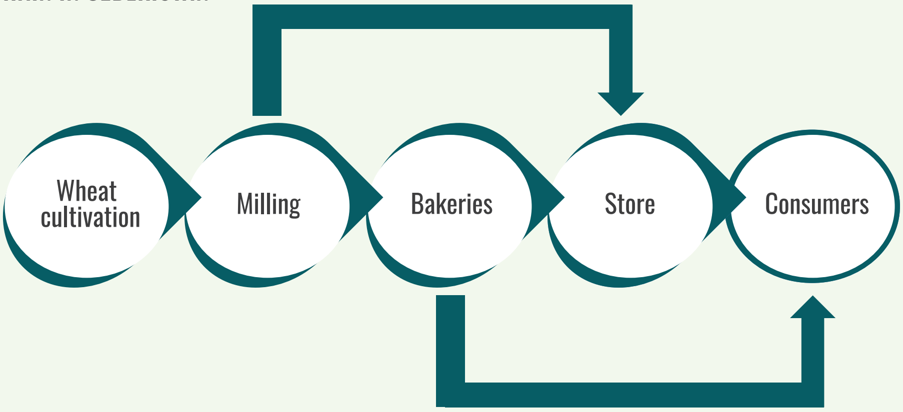
CROP	KASHKADARYA				KHOREZM		KARAKALPAKSTAN	
	IRRIGATED		RAINFED					
	AREA (ha)	YIELD (tonnes/ha)	AREA (ha)	YIELD (tonnes/ha)	AREA (ha)	YIELD (tonnes/ha)	AREA (ha)	YIELD (tonnes/ha)
WHEAT	141 000	6.5	63 000	11	33 200	6.1	53 000	4.81

Source: Republic of Uzbekistan. 2020. Open data portal. [Cited 15 April 2021]. https://data.gov.uz/en

The wheat value chain in Uzbekistan is vertically coordinated by the State and the movement on the wheat products is mainly on contract basis (Akbarov et. al. 2016). After cultivation, the wheat goes through physical processing by milling, being the average processing capacity 1 216 tonnes/day. At this stage, the product can be stored or transformed in local bakeries. Both ways, leads to the final consumers as show in **Figure 51**.

FIGURE 51.

WHEAT VALUE CHAIN IN UZBEKISTAN



Source: Adapted from Akbarov, A.et. al. 2016. Comparative Analysis of Wheat Supply Chains in Armenia and Uzbekistan (No. 923-2016-72962). https://ageconsearch.umn.edu/record/249963?ln=en

4.2 ENERGY INTERVENTIONS IN THE WHEAT VALUE CHAIN

To identify where and at which stages of the value chain renewable energy interventions should be introduced, it is imperative to understand which energy types and fuels are currently used in the wheat value chain. **Figure 52** details the energy types and fuels that are generally used to power operations at the various stages of the wheat value chain.

Based on the energy uses suitable to intervention shown in **Figure 52**, renewable energy interventions along wheat value chain can potentially be performed by using solar powered systems instead of diesel/electricity

FIGURE 52.

CURRENT ENERGY USE AND FUEL TYPES IN THE WHEAT VALUE CHAIN

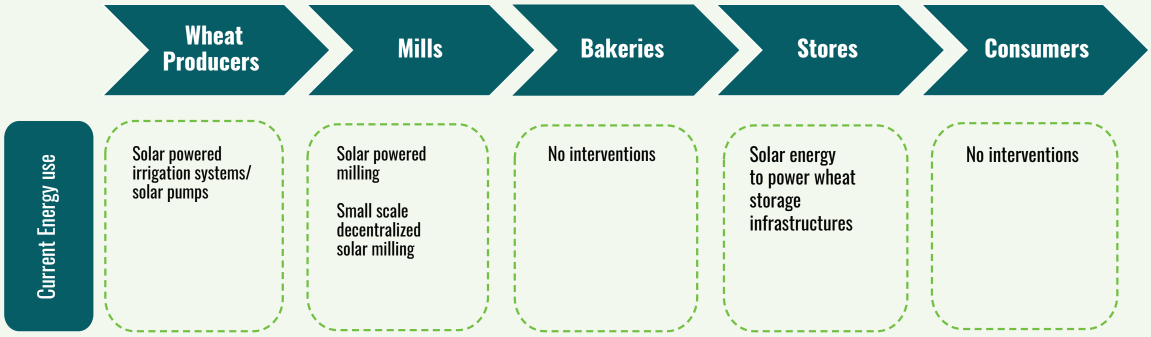
	Wheat Producers	Mills	Bakeries	Stores	Consumers
Current Energy use	Diesel/grid electricity to pump water for irrigation Fuels (diesel) used in machinery for sowing and harvesting.	Heat for drying harvested wheat grain before milling. Grid Electricity (or diesel generators) for milling Grid Electricity for packaging	Fire for baking (rural small scale) Grid Electricity used for baking (urban mid large scale)	Diesel/grid electricity for ventilation	N/A

Source: Authors' own elaboration.

systems (see **Figure 53**). Therefore, irrigation can be improved using solar PV pumps. At storage stage, ventilation and other processes in elevators and warehouses can be solar powered at large-scale as well. Conversely, farmers at small-scale can use solar powered mills.

FIGURE 53.

POSSIBLE CLEAN ENERGY INTERVENTIONS IN THE WHEAT VALUE CHAIN



Source: Authors' own elaboration.

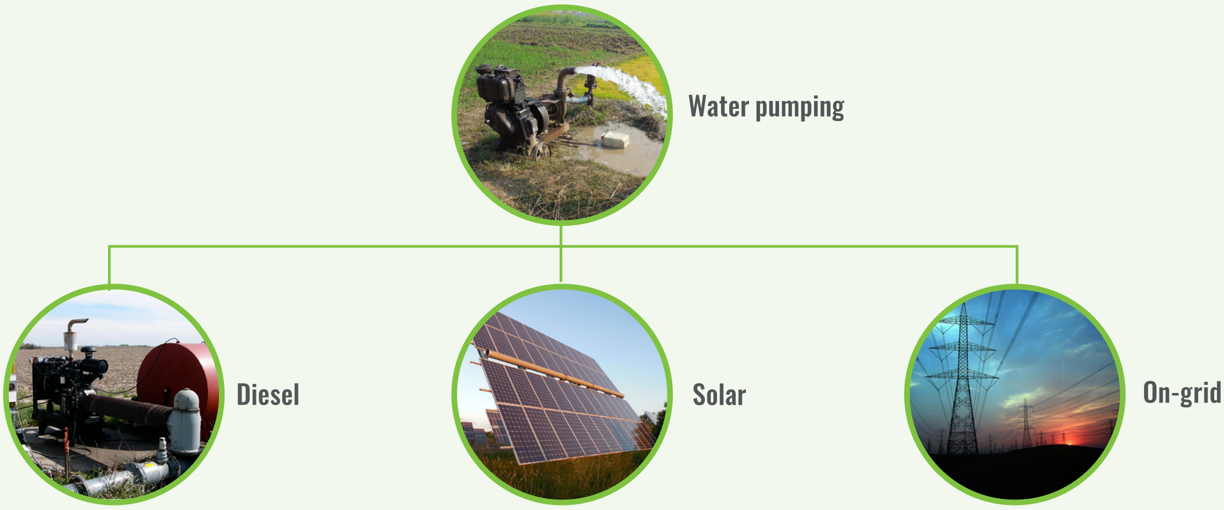
4.3 ENERGY FOR PUMPING WATER

Given that large parts of wheat production, at least in Kashkadarya is irrigated, and assuming that the irrigation systems are currently powered by fossil fuels, deploying solar water pumping systems can reduce GHG emissions from the wheat value chain (see **Figure 54**). Additionally, where wheat production is currently rainfed, introducing solar water pumps can increase productivity and reduce farmers' reliance on precipitation, which is vulnerable to climate change. There are several solar water pumping systems already available in the market that can be deployed. The analysis estimates the potential to deploy solar powered pumps to irrigate wheat fields in the three regions and compares the GHG emission savings and diesel powered pumping and grid connected pumping.

The demand and potential for solar water pumps is linked to the water requirement that is needed to be pumped and the share of total wheat production that is currently irrigated. **Table 23** details the area under wheat production that is irrigated and under a rainfed system.

FIGURE 54.

THREE ENERGY SOURCES FOR PUMPING WATER



Source: Authors' own elaboration.

Images source:
Surajmondol. 2014. *Water pump set. In: Wikimedia Commons. Cited 8 June 2022. https://commons.wikimedia.org/wiki/File:Water_pump_set.JPG*
Eliot Phillips. 2007. *Stationary engine. In: Flickr. Cited 8 June 2022. https://www.flickr.com/photos/hackaday/482209112/*
Pxhere. 2017. n.n. In: Pxhere. Cited 8 June 2022. https://pxhere.com/en/photo/720578
AshrafChemban. 2019. *Torre de Electricidad. In: Pixabay. Cited 8 June 2022. https://pixabay.com/es/photos/torre-de-electricidad-red-el%C3%A9ctrica-3916954/*

TABLE 23.

AREA UNDER IRRIGATION AND UNDER RAINFED PRODUCTION

		IRRIGATED PRODUCTION			RAINFED PRODUCTION		
		HECTARES (ha)			HECTARES (ha)		
		FARMERS	DEHKAN	LARGE SCALE	FARMERS	DEHKAN	LARGE SCALE
		Hectares per tonne			Hectares per tonne		
	KARAKALPAKSTAN	0.22	0.27		0	0	0
	KASHKADARYA	0.18	0.20		0.94	1.17	0
	KHOREZM	0.19	0.19	0.24	0	0	0
	tonnes/year	ha	ha	ha	ha	ha	ha
KARAKALPAKSTAN	254 930	51 895	4 367	0	0	0	0
KASHKADARYA	1 609 500	167 646	33 705	0	406 041	57 522	0
KHOREZM	202 520	24 946	12 995	288	0	0	0
TOTAL PROVINCES	2 066 950	244 487	51 067	288	406 041	57 522	0

Source: Authors' own elaboration.

Surface irrigation is prevalent in the regions that require water to be pumped and subsequently distributed by using gravity. The energy demand for pumping is dependent on both the efficiency of the pumps and the total amount of water to be pumped. Based on consultations with the national experts, the water demands of the wheat crop have been estimated to be 3 100 m^3/ha (478 m^3 per tonne of wheat produced). Water pumps can be powered by a diesel generator, or they can be directly connected to the electricity grid. Energy demands for diesel powered pumps differ from grid connected pumps. Electric pumping is more energy efficient than diesel pumping. Solar powered pumps are essentially electric pumps wherein, instead of the grid supplying electricity to the water pump, the solar panels are used to power the motor.

The total energy required to pump the required quantity of water depends on the efficiency of the pumping system as well as the water transport efficiency of surface irrigation. The first step of the analysis estimates the total energy required to pump the water needed to irrigate wheat by both a diesel-powered pumping system and a grid connected pumping system. This process is detailed in **Table 24**.

Based on the data outlined in **Table 24**, the total energy demand for pumping the required amount of water within the production period of wheat was estimated (See **Figure 55**).

TABLE 24.

TECHNICAL DATA USED TO ESTIMATE ENERGY DEMAND FOR PUMPING WATER

PARAMETER	VALUE	UNIT
TARGET WATER DEMAND	4 200	m^3/tonne of wheat produced
IRRIGATION METHOD	SURFACE IRRIGATION	-
AREA UNDER IRRIGATION	40	%
WATER TRANSPORT EFFICIENT	55	%
DIESEL PUMP EFFICIENCY	0.75	-
DIESEL MOTOR EFFICIENCY	0.4	-
PUMPING HEAD	10	m
ELECTRIC MOTOR EFFICIENCY	0.9	-
HOURS OF PUMPING NEEDED PER DAY	12	h/day
NUMBER OF DAYS IRRIGATED	123	day

Sources: Rkahimov, O., Obidjon H, K. & Cuesta, T.S. 2020. *Improvement and Modernization of Agricultural Irrigation. Uzbekistan Case Study. European Journal of Agriculture and Food Sciences, 2(4): 5.*

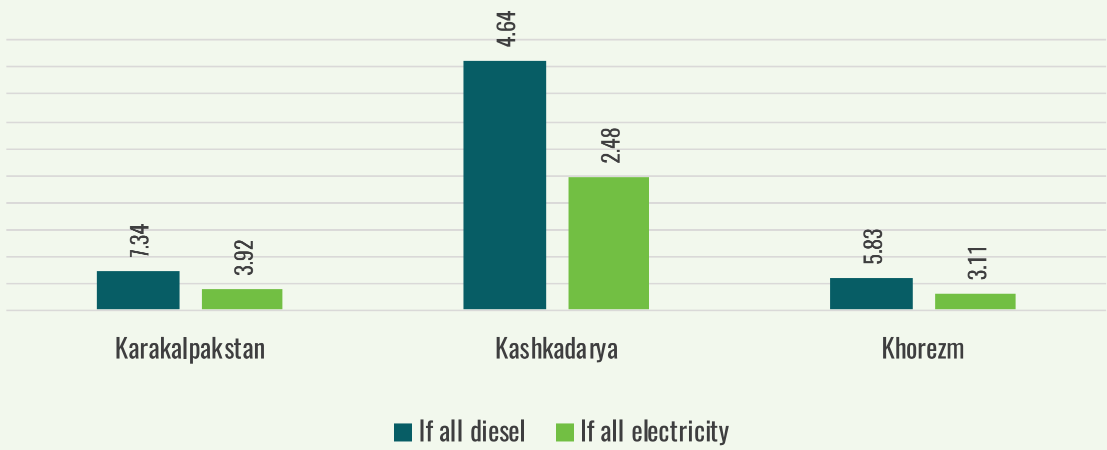
Swinkels, R., Romanova, E. & Kochkin, E. 2016. *Exploratory assessment of factors that influence quality of local irrigation water governance in Uzbekistan. Washington, USA102 pp. (also available at https://documents1.worldbank.org/curated/en/590421472098503155/pdf/108006-REPLACEMENT-PUBLIC-Local-Irrigation-Governance-UZ-Eng-FINAL-08092016.pdf).*

McKenzie, R.H. & Woods, S.A. 2011. *Crop Water Use and Requirements. Agri Facts, 100(561): 4. (also available at https://open.alberta.ca/dataset/9a017865-5692-464d-92ac-93b5d50558db/resource/cod20eoc-9f14-4f6d-8144-b8a6bc3452ba/download/5485851-2011-agri-facts-crop-water-use-requirements-revised-100-561-1-2011-11.pdf).*

Brouwer, C., Hoevenaars, J.P.M., van Bosch, B.E., Hatcho, N. & Heibloem, M. 1992. *Irrigation Water Management: Training Manual No. 6 – Scheme Irrigation Water Needs and Supply [online]. [Cited 15 June 2020]. https://www.fao.org/3/u5835e/u5835e00.htm#Contents*

FIGURE 55.

ENERGY DEMAND FOR PUMPING - ELECTRICITY VS DIESEL (MILLION kWh/year)



Source: Authors' own elaboration.

The results show that the energy demand for pumping for irrigation is the highest in Kashkadarya followed by the Republic of Karakalpakstan and Khorezm. This is due to both the relatively high share of irrigated land in Kashkadarya and the larger total production of wheat compared to the other two regions (see **Table 25**).

PV pumping systems use electricity pumps and therefore require the same amount of energy as the grid connected pumps. Based on the estimation of the total energy demand for water pumping outlined in the previous section, this section estimates the total capital cost of installing PV pumping system in the three regions.

TABLE 25.

ENERGY DEMAND FOR SOLAR PV SYSTEM (kWh)

REGION	FARMERS	DEKHKANS	LARGE SCALE
KARAKALPAKSTAN	90 849 098	6 170 882	0
KASHKADARYA	528 927 574	84 344 091	0
KHOREZM	51 109 020	25 503 196	461 828

Source: Authors' own elaboration.

For this analysis, a 166 m³/h capacity solar pump was used as the benchmark. The pump can work with both grid electricity and solar power. The technical data for the pump is detailed in **Table 26**.

TABLE 26.

TECHNICAL PARAMETERS OF THE SOLAR PUMP

PARAMETER	VALUE	UNIT
POWER	25	kW
INPUT VOLTAGE	850	V
MOTOR CURRENT	40	A
HEAD	MAX 40	m
FLOW RATE	MAX 166	m^3/h
COST OF PUMP	10 000	USD
PUMPING HEAD	1 045	USD/kW

Source: Lorenz Pumps. 2015. Technical specifications for solar surface pump systems. In: *Lorenz Pumps*. [Cited 20 April 2021]. https://lorentzpumps.co.za/wp-content/uploads/2017/10/PSK2-25-CS-G100-402.pdf

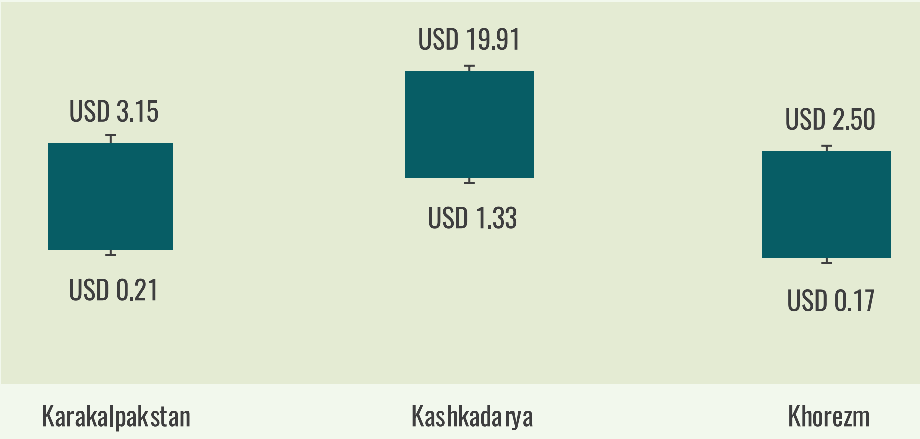
It is unlikely that all the irrigation pumps in the three regions will use solar power systems to pump water to irrigate wheat. The regions will most likely use a combination of grid connected, diesel powered and PV solar pumps to irrigate wheat. Therefore, adoption rates between 5 percent and 75 percent were used to estimate the investment required to install solar pumps to irrigate wheat. A 5 percent adoption rate implies that 5 percent of the water pumps needed are solar water pumps, while the adoption rate of 75 percent implied that 75 percent of the water pumps needed to irrigate wheat are solar pumps.

The same range of adoption rates were also used to estimate investment costs for grid connected and diesel-powered pumps as well, to allow for comparison between the three pumping systems.

The results suggest that the capital cost requirement to install PV pumps is at its highest in the Kashkadarya region ranging from USD 1.33 million (5 percent adoption rate) to USD 19.91 million (75 percent adoption rate). This is followed by the Republic of Karakalpakstan (USD 0.21 million–USD 3.15 million) and Khorezm (USD 0.17 million–USD 2.5 million). See **Figure 56**.

FIGURE 56.

CAPITAL INVESTMENT RANGE FOR INSTALLING SOLAR PV PUMPS IN THE THREE REGIONS (MILLION USD)



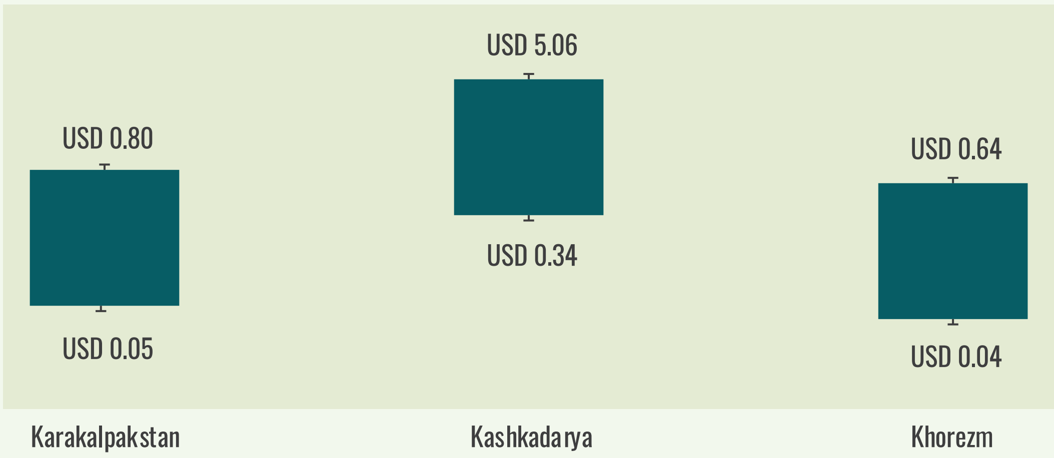
Source: Authors' own elaboration.

The same estimation was also done for grid connected pumps and diesel-powered pumps. The analysis suggests that the capital cost for installing diesel power pumps is lower than the PV pumps and grid connected pumps (see **Figure 57**).

The capital costs in Kashkadarya are the highest ranging from USD 0.34 million to USD 5.06 million, followed by the Republic of Karakalpakstan (USD 0.05 million–USD 0.80 million) and Khorezm (USD 0.04 million–USD 0.64 million). As show in **Figure 58** for grid connected pumps, the capital costs are also the highest in Kashkadarya, ranging from USD 0.42 million to USD 6.23 million, followed by the Republic of Karakalpakstan (USD 0.07 million–USD 0.99 million) and Khorezm (USD 0.05 million–USD 0.78 million).

FIGURE 57.

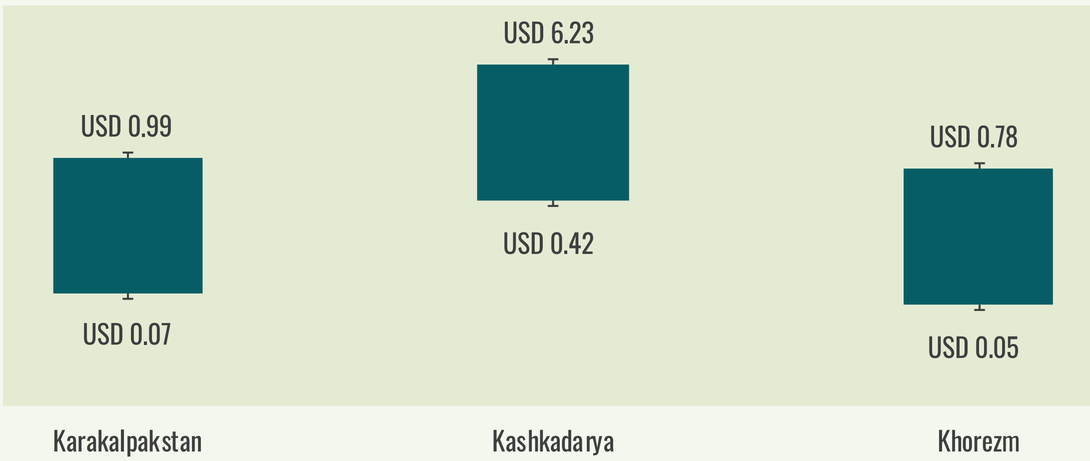
CAPITAL INVESTMENT RANGE FOR INSTALLING DIESEL PUMPS IN THE THREE REGIONS (MILLION USD)



Source: Authors own elaboration

FIGURE 58.

CAPITAL INVESTMENT RANGE FOR INSTALLING GRID CONNECTED PUMPS IN THE THREE REGIONS (MILLION USD)



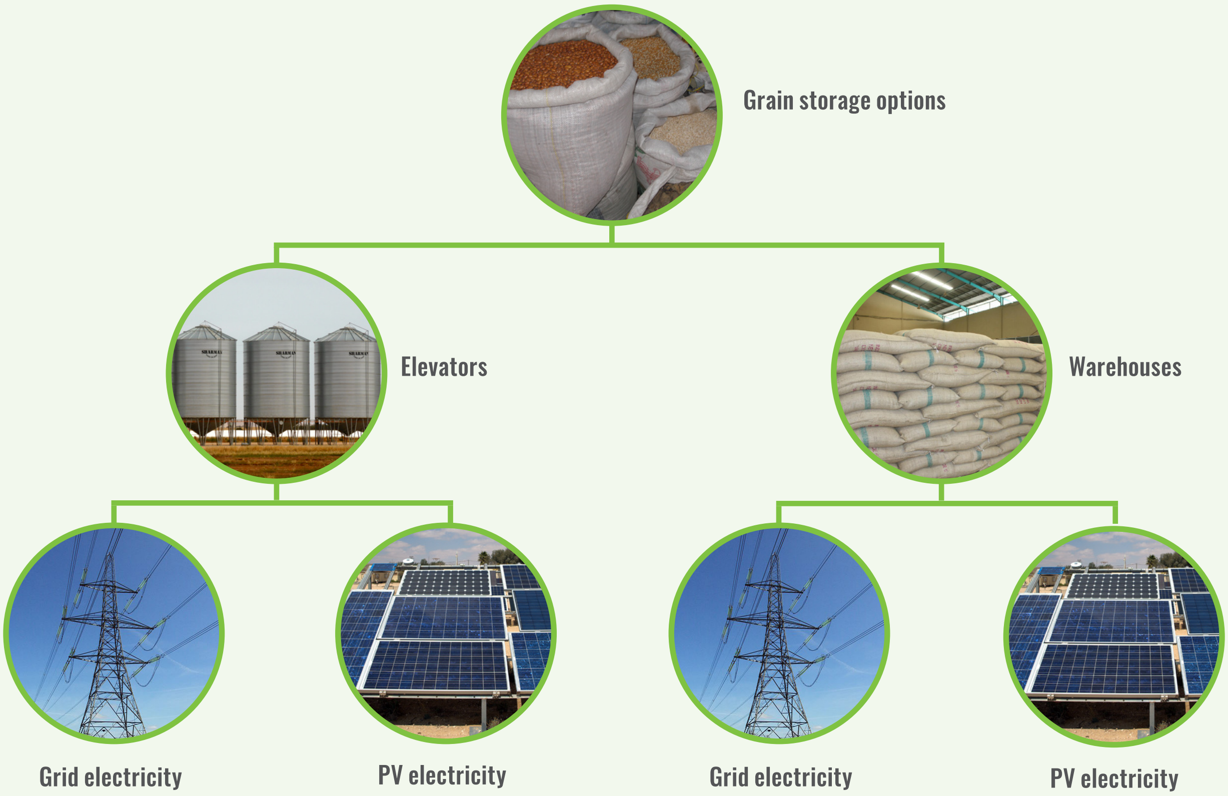
Source: Authors own elaboration

4.4 ENERGY FOR STORING WHEAT

After wheat is harvested it is transported and stored either to be milled or to be sold. There are two main ways to store wheat – in elevators or in warehouses. In both cases electricity is required to ensure ventilation and for other processes. In both cases, solar PV systems can be used to power the storage infrastructure reducing GHG emissions. **Figure 59** shows the interventions that are analysed at the storage stage of the value chain.

FIGURE 59.

STORAGE OPTIONS AND SOURCES OF ENERGY



Source: Authors' own elaboration.

Images source:

Thomas Quine. *2006. Peruvian market goods. In: Flickr. Cited 13 June 2022. https://www.flickr.com/photos/quinet/94848374*

Pxhere. 2017. n.n. In: Pxhere. [Cited 13 June 2022]. https://pxhere.com/en/photo/773868

S. Mittal/CIMMYT. *2012. Open grain storage in India. In: Flickr. Cited 14 June 2022. https://www.flickr.com/photos/cimmyt/8622125349*

Repton1x. *2009. Current. In: Wikimedia Commons. Cited 14 June 2022. https://commons.wikimedia.org/wiki/File:Benkid77_Puddington-Shotwick_footpath_27_110809.JPG*

David Shankbone. 2009. Photovoltaic arrays at the Israeli National Solar Energy Center. In: Wikimedia Commons. [Cited 14 June 2022]. *https://commons.wikimedia.org/wiki/File:Benkid77_Puddington-Shotwick_footpath_27_110809.JPG*

Most government mills in the country store grains in elevators while the private mills have warehouses for storage. However, the aggregate energy consumption at the storage stage of the wheat chain depends on the total storage capacity installed in the three regions. Furthermore, storage capacity for wheat is closely linked to the total installed processing capacity for wheat in the three regions. However, in all three regions, there is a difference between the quantity of wheat produced in the regions and the installed processing capacity (see **Table 27**)..

TABLE 27.

PRODUCTION AND PROCESSING OF WHEAT IN THE THREE REGIONS

REGION	WHEAT PRODUCED (tonnes/year)	INSTALLED PROCESSING CAPACITY (tonnes/year)
KARAKAPAKSTAN	254 930	135 000
KASHKADARYA	1 644 435	626 000
KHOREZM	202 520	186 000

Source: Republic of Uzbekistan. 2020. Open data portal. [Cited 15 April 2021]. https://data.gov.uz/en

Furthermore, wheat processing factories are either owned by the government which are called the "Uzdonmahsulot" or are managed by private companies. **Table 28** provides the installed processing capacity by Uzdonmahsulot and private companies, respectively.

TABLE 28.

TARGET STORAGE CAPACITY IN EACH REGION

REGIONS	STORAGE AT UZDONMAHSULOT (tonnes/month)	STORAGE AT PRIVATE MILLS (tonnes/month)	TOTAL TARGET STORAGE CAPACITY (tonnes/month)
KARAKAPAKSTAN	8 617	2 430	1 1047
KASHKADARYA	23 312	59 945	8 3257
KHOREZM	6 126	5 012	1 1138

Source: Estimates based on our own calculations

In addition to the installed storage capacity, the total energy demand also depends on how many days wheat is stored in a year. Therefore, based on wheat harvesting schedules in the three regions, the analysis estimated the total energy demand for storing the harvested wheat until the next harvesting season. It should be noted that the analysis assumed a safety stock rate of 30 percent, which means that at any given time the wheat stock in any storage facility is not allowed to fall below 30 percent. **Table 29** details the harvesting schedule for wheat in the three regions and **Figure 60** estimates the energy demand for storing the harvested wheat.

TABLE 29.

ENERGY STORAGE CAPACITY CALCULATIONS

FLOUR MILLS							
PRIVATE MILLS							
		KARAKALPAKSTAN		KASHKADARYA		KHOREZM	
		8 617	tonnes/year	23 312	tonnes/year	6 126	tonnes/year
HARVEST MONTH	STORAGE MONTH	CUMULATIVE STORAGE (tonnes)	STORAGE DEPLETION (tonnes/ month)	CUMULATIVE STORAGE (tonnes)	STORAGE DEPLETION (tonnes/ month)	CUMULATIVE STORAGE (tonnes)	STORAGE DEPLETION (tonnes/ month)
JANUARY	0	0	37 052	0	100 242	0	26 343
FEBRUARY	0	0	28 435	0	76 930	0	20 217
MARCH	0	0	19 818	0	53 618	0	14 090
APRIL	0	0	11 202	0	30 306	0	7 964
MAY	0	0	2 585	0	6 994	0	1 838
JUNE	1	28 435	28 435	76 930	76 930	20 217	20 217
JULY	2	54 285	54 285	146 866	146 866	38 595	38 595
AUGUST	3	80 135	80 135	216 802	216 802	56 974	56 974
SEPTEMBER	0	0	71 518	0	193 490	0	50 848
OCTOBER	0	0	62 901	0	170 178	0	44 721
NOVEMBER	0	0	54 285	0	146 866	0	38 595
DECEMBER	0	0	45 668	0	123 554	0	32 469
MAX. STORAGE CAPACITY (tonnes)			80 135		216 803		56 974
MIN. SAFETY STORAGE (tonnes)			2 585		6 994		1 838

Source: Authors' own elaboration.

TABLE 29.

ENERGY DEMAND AT STORAGE STAGE

FLOUR MILLS							
UZDONMAHSULOT							
		KARAKALPAKSTAN		KASHKADARYA		KHOREZM	
		2 430	tonnes/year	59 945	tonnes/year	5 012	tonnes/year
HARVEST MONTH	STORAGE MONTH	CUMULATIVE STORAGE (TONNES)	STORAGE DEPLETION (TONNES/ MONTH)	CUMULATIVE STORAGE (TONNES)	STORAGE DEPLETION (TONNES/ MONTH)	CUMULATIVE STORAGE (TONNES)	STORAGE DEPLETION (TONNES/ MONTH)
JANUARY	0	0	10 450	0	257 765	0	21 553
FEBRUARY	0	0	8 020	0	197 820	0	16 541
MARCH	0	0	5 590	0	137 874	0	11 528
APRIL	0	0	3 159	0	77 929	0	6 516
MAY	0	0	729	0	17 984	0	1 504
JUNE	1	8 020	8 020	197 820	197 820	16 541	16 541
JULY	2	15 311	15 311	377 656	377 656	31 578	31 578
AUGUST	3	22 602	22 602	557 492	557 492	46 615	46 615
SEPTEMBER	0	0	20 172	0	497 547	0	41 603
OCTOBER	0	0	17 741	0	437 601	0	36 590
NOVEMBER	0	0	15 311	0	377 656	0	31 578
DECEMBER	0	0	12 881	0	317 710	0	26 566
MAX. STORAGE CAPACITY (tonnes)			22 603		557 492		46 616
MIN. SAFETY STORAGE (tonnes)			730		17 984		1 504

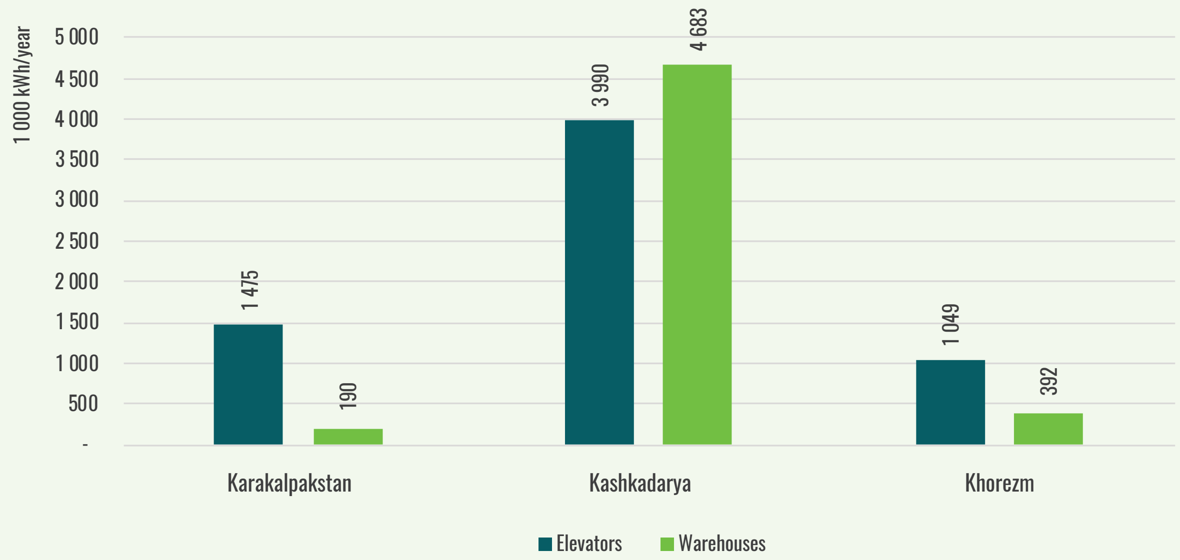
Source: Authors' own elaboration.

Solar PV systems can be used to power storage infrastructure for wheat in the three regions. Two distinct PV configurations can be used. The first is an off-grid PV system where the system is completely independent from the national or regional electricity grid. In this case, PV panels produce DC electricity, which is converted to AC using an inverter and is then directly used on site.

The second configuration is an on-grid system where the PV system is connected to the grid. This allows the user to use both PV electricity as well as the grid electricity. Additionally, if local laws permit, the user can also sell PV electricity to the grid.

FIGURE 60.

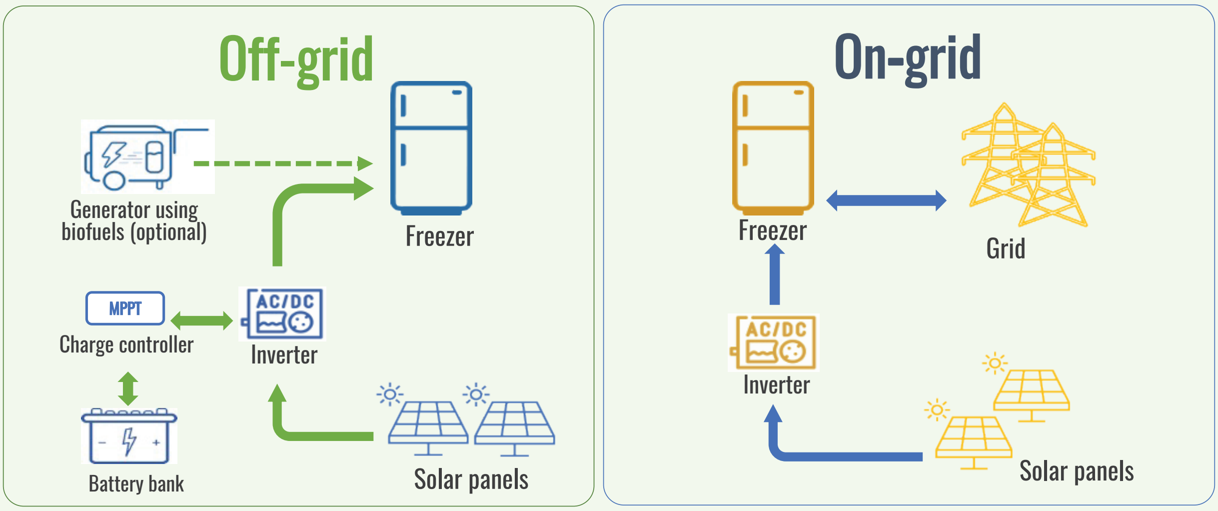
ELECTRICITY DEMAND FOR WHEAT STORAGE



Source: Authors' own elaboration.

FIGURE 61.

TWO TYPES OF TYPE 2 INTERVENTIONS



Source: Adapted from Paradise energy. Undated. The Difference Between Off-Grid and On-Grid Solar Energy. In: *Paradise Energy*. [Cited 15 July 2021]. *www.paradisesolarenergy.com/blog/difference-between-off-grid-and-on-grid-solar-energy*

Based on the electricity demand estimated in **Figure 60**, the analysis further estimated the total capital investment required to install both on-grid and off-grid PV systems in the three regions (see **Figure 61**). It is unlikely that all elevators and warehouses will opt to install solar PV systems to power their facilities. Some will continue to be powered by grid. To account for this fact the analysis estimated the investment cost to install solar PV systems based on a range of adoption rate. The adoption rate refers to that share of the total electricity demand that is satisfied by the solar PV systems.

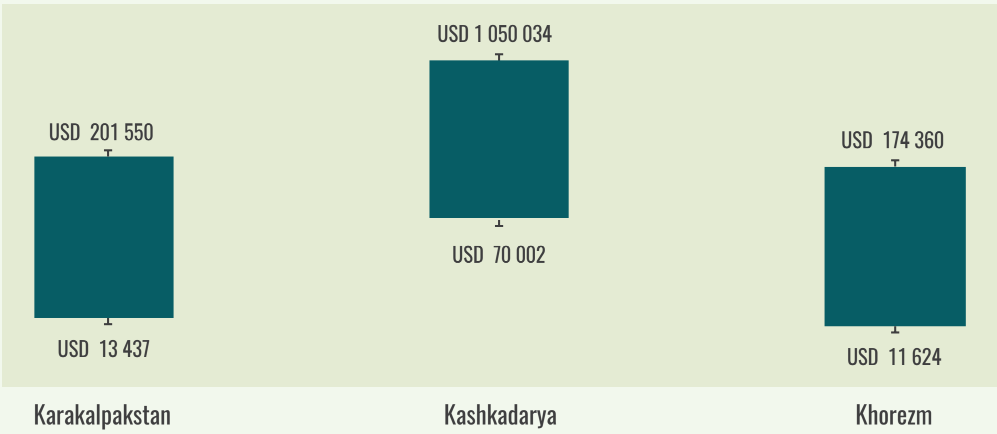
In this analysis, the range used is 5 percent (Low Adoption Rate - LAR) to 75 percent (High Adoption Rate - HAR). Consequently, the analysis estimates the capital costs of installing solar PV system to satisfy 5 percent of the total electricity demand to 75 percent of the total electricity demand (see **Figure 62**).

Using solar energy is an alternative to the use of grid power. Therefore, it also offers the potential to reduce GHG emissions. **Figure 63** estimates the GHG reduction potential resulting from using solar power to power wheat storage infrastructure. The results correspond to the adoption rate of 5 to 75 percent.

The results suggest that the highest potential to deploy solar PV systems at storage stage is in Kashkadarya region.

FIGURE 62.

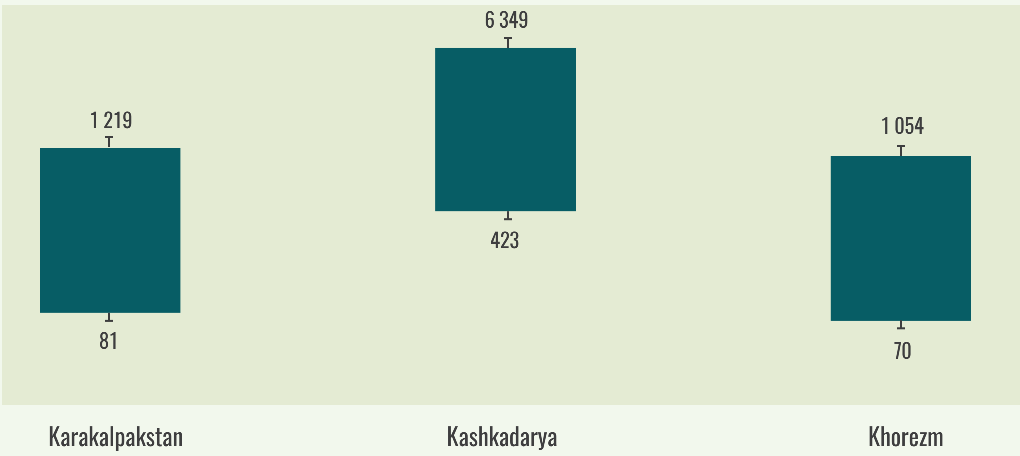
CAPITAL COST ELECTRICITY SYSTEMS (USD)



Source: Authors' own elaboration.

FIGURE 63.

GHG SAVINGS (ELEVATORS AND WAREHOUSES) - DIESEL VS PV (tonnes CO_2 eq/year)



Source: Authors' own elaboration.

4.5 ENERGY FOR WHEAT MILLING

Milling wheat grain into wheat flour is the essential processing activity in the wheat value chain. In many countries, milling is done both on an industrial scale and a small village level artisanal scale. Both require access to electricity to power mills that grind wheat grain to produce flour. At the small to mid-scale, solar-powered wheat mills can prove effective in increasing the local milling capacity, reducing emissions, and increasing local rural entrepreneurship. There are a few solar powered mills that exist in the market that can be analysed to understand their potential to be used in the wheat value chain in the three regions.

Large wheat mills are often connected to the grid to power the milling operation. In Uzbekistan, the milling operation is carried out by a mix of large-scale private mills, state owned Uzdonmahsulot as well as few small-scale mills. In terms of energy use, both the private mills as well as the Uzdonmahsulot can be powered by grid electricity as well as PV electricity. The primary benefit of using PV electricity at large scale milling factories (both private mills and Uzdonmahsulot) is the reduction in GHG emissions compared to grid electricity. For small scale systems, using PV powered mills can have the dual benefit of expanding milling capacity in rural areas while minimising the GHG emissions from milling activity. **Figure 64** details the main energy interventions analysed at the milling stage of the wheat value chain. Based on the scale of milling operation, the intervention is divided into two groups – large scale that focus on large private mills and the Uzdonmahsulot and small scale that focuses on small scale PV powered mills.

Milling capacity of the mills is a key factor that defines the energy demand of the mills. In the three regions, around 60 percent of the wheat is milled in large scale mills while the remaining 40 percent is used for several purposes including being milled in traditional small mills, sold directly or it is used for feed or other local purposes. As regards the large mills the analysis compares the GHG reduction potential of using PV electricity to power the milling factory and estimates the investment required. Since it is not exactly clear how the 40 percent of the wheat produced is used, and due to the lack of any official directive, three scenarios have been created to analyse opportunities for small-scale milling.

FIGURE 64.

ENERGY INTERVENTIONS ANALYSED AT THE MILLING STAGE OF THE WHEAT VALUE CHAIN

Source: Authors' own elaboration.

Images source:

Nickj. 2004. *Flour Mill, Summer Hill, NSW, Australia. In: Wikimedia Commons. Cited 14 June 2022. https://commons.wikimedia.org/wiki/File:Flour_Mill,_Summer_Hill,_NSW,_Australia.jpg*

Engineering for change.n.d. Solar Milling Small-Scale System. In: Engineering for change. Cited 14 June 2022. *https://www.engineeringforchange.org/solutions/product/solar-milling-small-scale-system/uzbekistan*

IMAS. 2021. IMAS completes flour, feed mills in Uzbekistan. In: World-Grain. Cited 14 June 2022. https://www.world-grain.com/articles/15216-imas-completes-flour-feed-mills-in-uzbekistan

Ekaterina Kvelidze. 2022. Uzbekistan sees bread prices skyrocket. In: Eurasianet. Cited 14 June 2022. *https://www.bne.eu/uzbekistan-sees-bread-prices-skyrocket-246394/?source=uzbekistan*

Repton1x. 2009. Current. In: Wikimedia Commons. Cited 14 June 2022. *https://commons.wikimedia.org/wiki/File:Benkid77_Puddington-Shotwick_footpath_27_110809.JPG*

David Shankbone. 2009. Photovoltaic arrays at the Israeli National Solar Energy Center. In: Wikimedia Commons. Cited 14 June 2022. *https://commons.wikimedia.org/wiki/File:Benkid77_Puddington-Shotwick_footpath_27_110809.JPG*

The analysis estimates the investment required to use small-scale PV powered milling machines to mill 15, 25 and 50 percent of the remaining 40 percent wheat produced that is not milled in large milling factories. **Table 30** shows the quantity of wheat milled by the different milling factories in the three study regions.

TABLE 30.

QUANTITY OF WHEAT MILLED IN THE 3 REGIONS

	FLOUR MILLS		SMALL SCALE SOLAR MILLS		
	UZDONMAHSULOT	PRIVATE MILL	15%	25%	50%
	PRODUCTION (tonnes flour/year)	PRODUCTION (tonnes flour/year)	PRODUCTION (tonnes flour/year)	PRODUCTION (tonnes flour/year)	PRODUCTION (tonnes flour/year)
KARAKALPAKSTAN	78 975	22 275	18 355	30 592	61 183
KASHKADARYA	131 460	338 040	147 815	246 359	492 717
KHOREZM	76 725	62 775	10 329	17 214	34 428

Source: Authors' own elaboration

Based on the data depicted in **Table 31** and the milling capacity in each region, Kashkadarya has the highest electricity demand followed by the Republic of Karakalpakstan and Khorezm (see **Figure 65**).

TABLE 31.

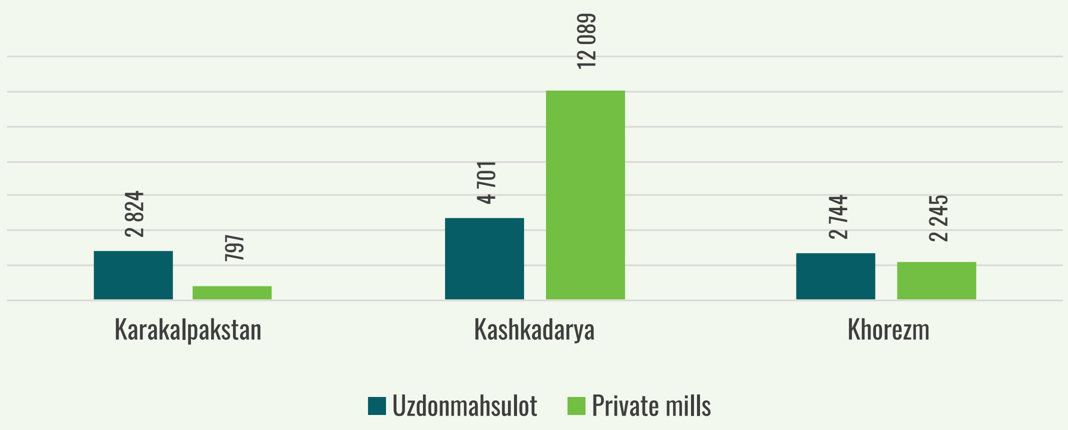
TECHNICAL DATA USED FOR ANALYSIS

ITEM	UZDONMAHSULOT	PRIVATE MILLS
ELECTRICITY DEMAND	26.82 kWh/tonne	26.82 kWh/tonne
OPERATING HOURS PER DAY	24	16
OPERATING HOURS PER YEAR	6 288	4 192

Source: Author' calculations and information gathered from Alapala. 2015. Grain handling and storage systems. *Alapala*. [Cited 25 July 2021]. *https:// www. alapala.com/uploads/en/grain_handling.pdf*

FIGURE 65.

ELECTRICITY DEMAND FOR LARGE-SCALE MILLING IN THE THREE REGIONS (1 000 kWh/h)



Source: Authors' own elaboration.

4.5.1 Potential to use solar PV for milling.

Given that most of the large mills in the three regions are already connected to the grid, it is unlikely that all of them would switch to solar energy. To account for this fact, the analysis works with a range that estimates the capital costs requirements and GHG mitigation benefits resulting from 5 (low penetration) to 75 percent (high penetrations) of the total processing capacity being powered by solar PV. Furthermore, solar PV systems can be installed under two configurations. The first configuration is a grid connected solar PV system where PV systems are installed on site but are connected to the national or regional grid. In this case, the system does not require batteries to be installed on site to store energy. The second configuration is a non-grid connected system that includes batteries to store the energy for use at night.

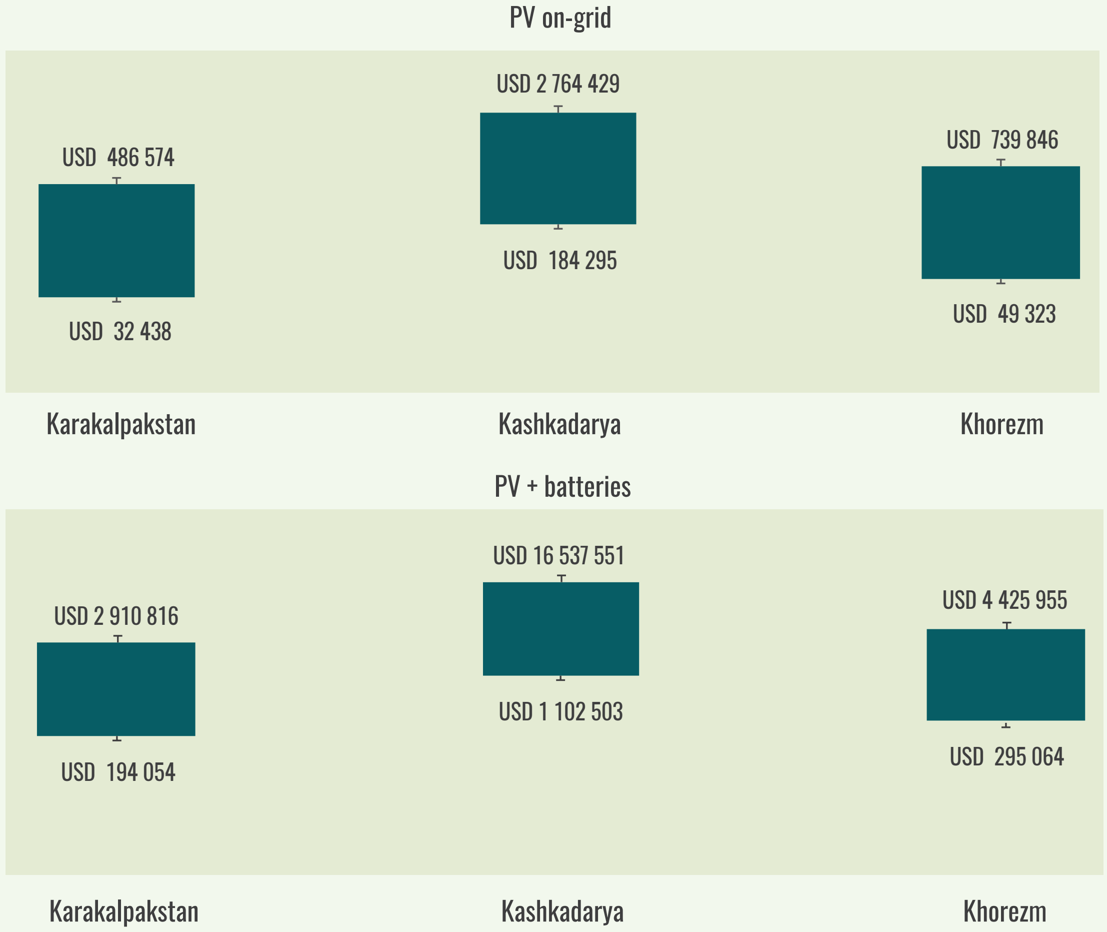
4.5.2 Capital costs requirement for installing solar PV systems for milling

4.5.2.1 Large scale systems

Based on these factors, **Figure 66** depicts the capital costs requirement for installing the two configurations of PV systems to power large scale milling operations. The range presented corresponds to the adoption range of 5–75 percent.

FIGURE 66.

CAPITAL COST FOR USING ON GRID PV SYSTEMS OR PV WITH BATTERIES (USD)

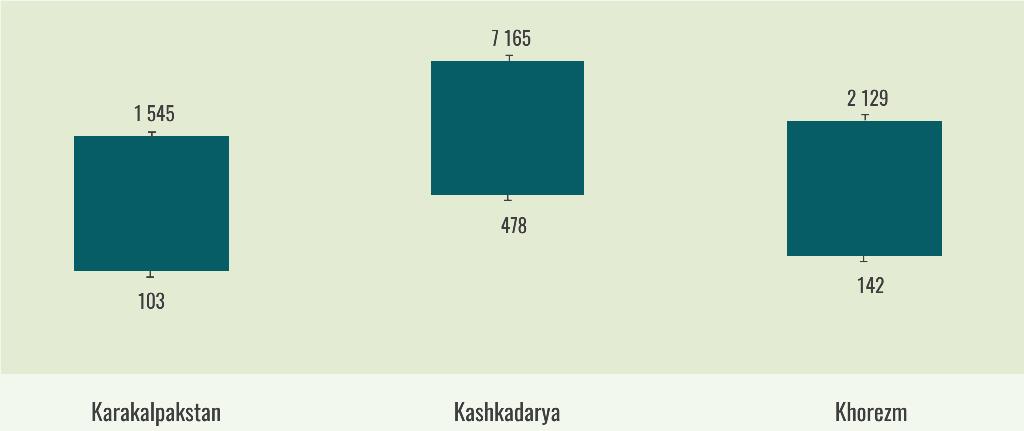


Source: Authors' own elaboration.

A primary benefit of using PV systems is the overall reduction in GHG emissions as compared to the baseline, which in this case is the grid electricity. Based on the total energy demand and the emission factor of Uzbekistan grid electricity, **Figure 67** presents the potential GHG mitigation possible corresponding the adoption range.

FIGURE 67.

GHG SAVINGS (UZDONMAHSULOT AND PRIVATE MILLS) GRID ELECTRICITY VS PV (tonnes CO_2eq/year)



Source: Authors' own elaboration.

4.5.2.2 Small scale systems

Small-scale solar milling systems are ideal for deployment that is decentralsed in rural areas to expand local milling capacity. In the case of Uzbekistan, while it is known that 60 percent of the wheat is produced in large mills, it is unclear whether the share of the remaining 40 percent of the wheat produced is the actual volume of wheat milled by small-scale mills. Due to this lack of information, the analysis estimates the potential to use solar mills by taking three distinct adoption rates of small-scale solar mills. These rates are 15 percent, 25 percent and 50 percent of the total wheat that is not milled by the large-scale mills. Additionally, several small solar mills are available in the market. This analysis uses one type of solar mill as a benchmark, and uses the data depicted in **Table 32** to estimate the capital costs and market size for deploying the small-scale mill corresponding to the three levels of adoption rates in the three study regions.

TABLE 32.

DATA USED FOR THE ANALYSIS

COMPONENT	VALUE	UNITS
TOTAL COST OF SOLAR CEREAL MILLING SYSTEM	3 650	USD
MILLING CAPACITY	20	kg of flour per hour

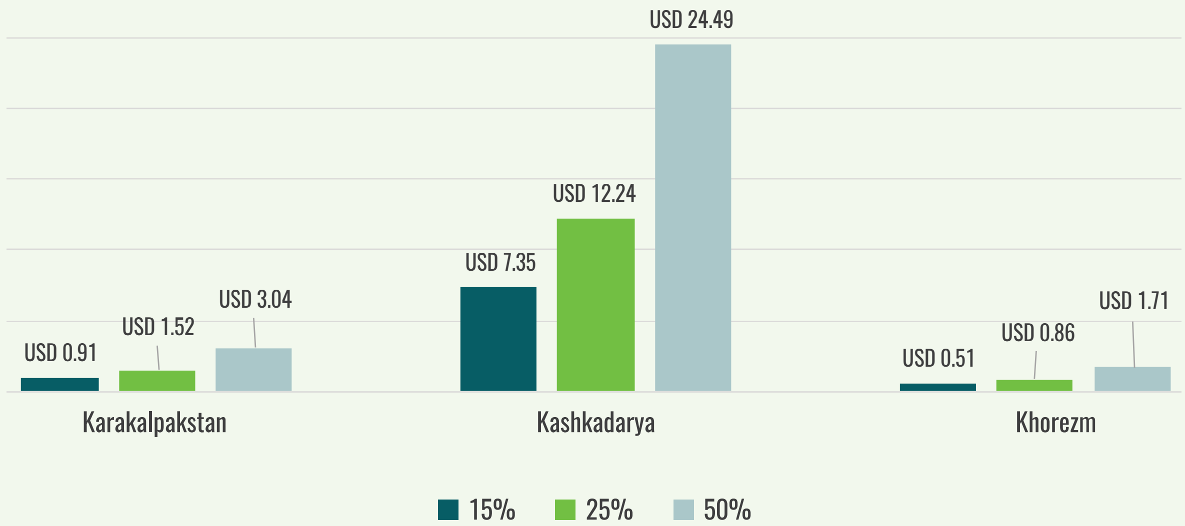
Source: SolarMilling. 2022. In: *SolarMilling*. https://solarmilling.com/

The results of the analysis are presented in **Figure 68** and suggest that Kashkadarya has the most potential to deploy small-scale solar PV mills.

The market size of the solar PV mill can range from USD 7.35 million to USD 24.49 million in Kashkadarya, followed by the Republic of Karakalpakstan (USD 0.91 million to USD 3.04 million) and finally, Khorezm (USD 0.51 million to USD 1.71 million.)

FIGURE 68.

MARKET SIZE FOR SMALL SOLAR MILLS (MILLION USD)

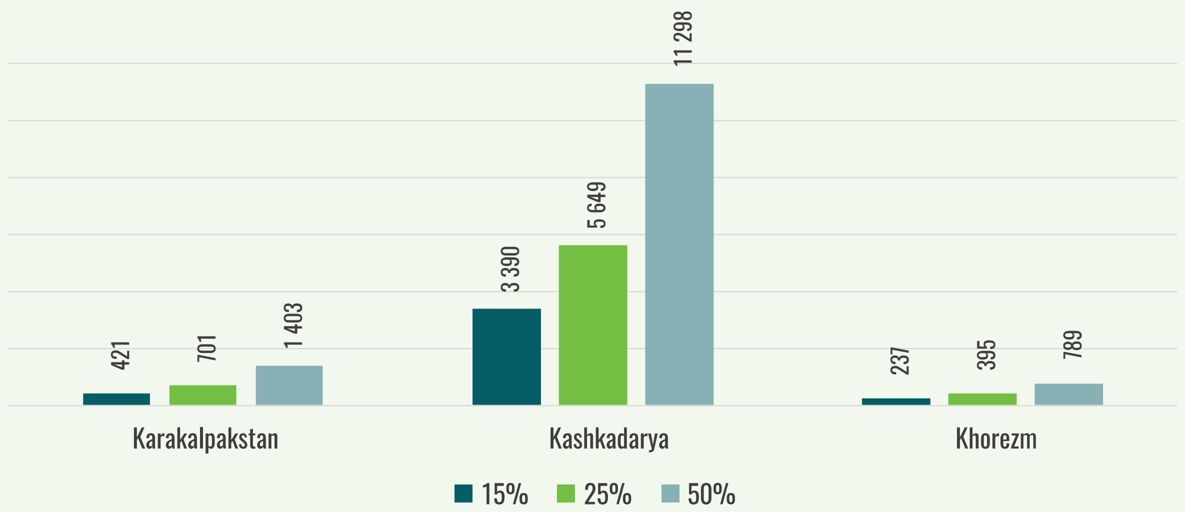


Source: Authors' own elaboration.

In terms of GHG mitigation potential, **Figure 69** shows the potential reduction in GHG emissions should the expansion of milling capacity in rural areas of the country come from small-scale solar mills, as opposed to grid powered milling equipment. Here again, the greatest GHG reduction potential is located in Kashkadarya, since these regions have the largest potential to deploy solar mills.

FIGURE 69.

GHG REDUCTION POTENTIAL GRID ELECTRICITY VS PV (tonnes CO_2 eq/year)



Source: Authors' own elaboration.

4.6 SUMMARY

By combining the results of all energy interventions along the wheat value chain, the aggregate results provide the potential to use renewable energy along the whole chain. The main interventions assessed along the wheat chain were

- a. Energy for pumping water
- b. Energy needed to store cereals
- c. Energy for milling of cereals.

For pumping water, the results show that the demand for irrigation is the highest in Kashkadarya region, followed by the Republic of Karakalpakstan and finally Khorezm. If solar energy is used to pump water for irrigation in these regions, the capital investment can range from USD 0.17 million (in Khorezm region) to USD 19.91 million (in Kashkadarya region).

The results of energy interventions for long term storage of wheat considered the possibility of using solar energy in both elevator type storage as well as in warehouses. The total storage capacity needed is closely linked to the total installed processing capacity for wheat in the three regions. Furthermore, the energy demand also changes depending on weather wheat is stores in elevators or warehouses. For elevators, the energy demand to store wheat is highest in Kashkadarya, followed by the Republic of Karakalpakstan and Khorezm. For warehouses, the energy demand is highest in Kashkadarya followed by Khorezm and the Republic of Karakalpakstan. If solar energy is used to power the elevators and warehouses in the three regions, the total capital cost could range from USD 11 624 (in Khorezm) to USD 1 050 034 in the Kashkadarya region.

The assessment also analysed the potential to use solar PV systems for small scale and large-scale milling. For small scale milling standalone solar mills were assessed while for large-scale milling, the possibility of using solar PV systems to power large scale mills was considered. For large scale milling, the assessment considered the installed processing capacity in the three regions including the private mills and Uzdonmahsulot. Considering this, the energy demand for large scale milling was found to be the highest in Kashkadarya, followed by the Khorezm and the Republic of Karakalpakstan. The assessment included two configuration of PV systems for large scale milling – on-grid PV and stand-alone PV systems including the batteries. The results suggest that for on grid PV system, the capital cost for milling in the three regions can range from USD 32 438 (in the Republic of Karakalpakstan) to USD 2 764 426 in Kashkadarya. For stand-alone PV systems including batteries, the capital investment in the PV system can range from USD 194 054 (in the Republic of Karakalpakstan) to USD 16 537 551 (in Kashkadarya).

For small scale milling, the assessment estimated the total market size of stand-alone PV powered mills that could be deployed across villages in the three regions. These small mills could produce around 20 kg of flour per hour. While it is known that 60 percent of the wheat is produced in large mills, it is unclear whether the share of the remaining 40 percent of the wheat produced is the actual volume of wheat milled by small-scale mills. Due to this lack of information, the analysis estimated the potential to use solar mills by taking three distinct adoption rates of small-scale solar mills. These rates are 15 percent, 25 percent and 50 percent of the total wheat that is not milled by the large scale mills. The results of the analysis suggest that Kashkadarya has the most potential to deploy small-scale solar PV mills. The market size of the solar PV mills can range from USD 7.35 million to USD 24.49 million in Kashkadarya, followed by the Republic of Karakalpakstan (USD 0.91 million to USD 3.04 million) and finally, Khorezm (USD 0.51 million to USD 1.71 million.)

CHAPTER

5

RENEWABLE ENERGY INTERVENTIONS IN THE ALFALFA CHAIN

5.1 ALFALFA CHAIN

Alfalfa is a perennial legume known for its high nutritional value and is a major source of feed for livestock. Due to its high nutritional quality, high yields and high adaptability, alfalfa is one of the most important legume forages in the world. (Feedipedia, 2020) Alfalfa is usually cultivated for hay, but is also used for silage, or is dehydrated to make meal or pellets. In many countries is also used fresh after cutting and drying it. In Uzbekistan, alfalfa is a traditional fodder crop dating back at least 2 500 years and the country is part of its area of domestication (FAO, 2018)[6]. In 2019, the aggregate production of alfalfa across the three study regions was 736 056 tonnes, which is second only to wheat, see **Figure 70**.

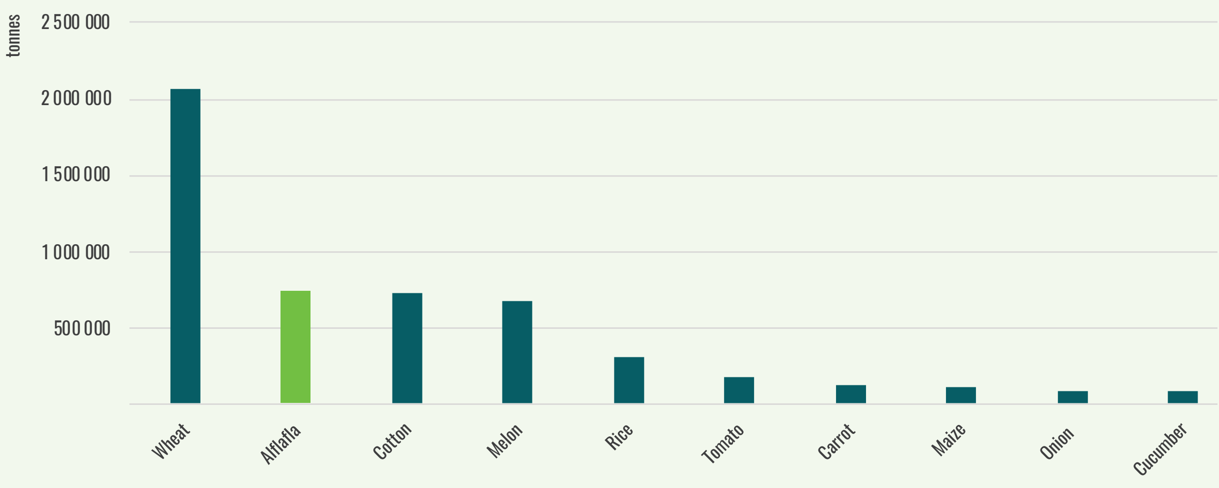
Amongst the three regions, Kashkadariya leads the alfalfa production (504 584 tonnes) followed by the Republic of Karakalpakstan (153 713 tonnes) and Khorezm (77 760 tonnes), see **Figure 71**.

Traditionally, alfalfa was part of the long cycle cotton-alfalfa cropping systems in Uzbekistan. However, to further strengthen national food security the cotton-alfalfa cropping system was replaced by a shorter crop rotation of the cotton-wheat system. As a result, the alfalfa production in the country has reduced significantly. Currently, around 320 000 ha of the irrigated land in Uzbekistan is dedicated to forage crops. Maize is cultivated on around 67 percent of the land and 25 percent of the land is dedicated to alfalfa. The reduction in alfalfa cultivation in Uzbekistan has negatively impacted the health of the soil. Alfalfa can fix atmospheric nitrogen, which positively affects soils health. Alfalfa can be transformed into several final products, all of which however are used as feed for animals. Depending on the final product, the value chain steps along the chain can also vary.

[6] http://www.fao.org/3/i8398en/I8398EN.pdf.

FIGURE 70.

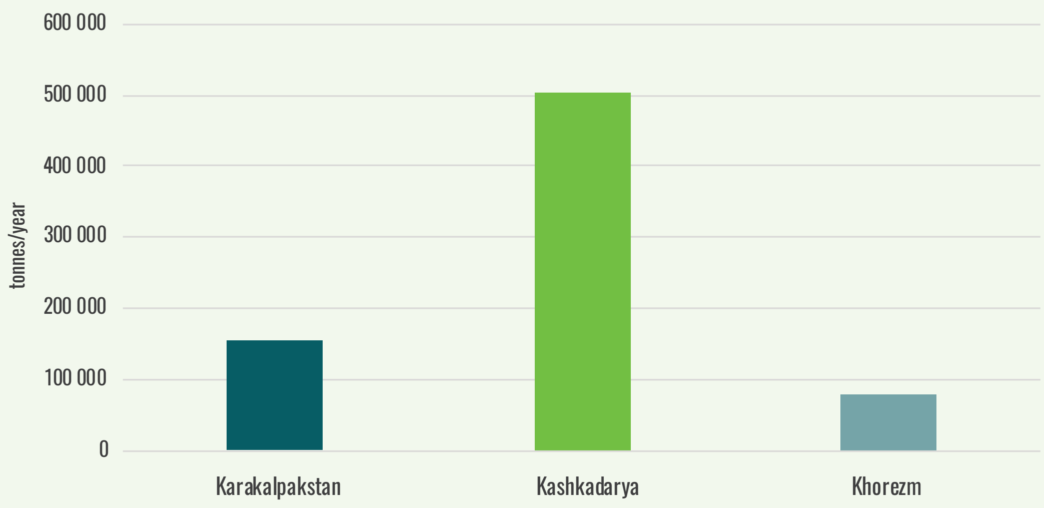
AGGREGATE PRODUCTION OF THE CROP ACROSS THE THREE REGIONS



Source: Republic of Uzbekistan. 2020. Open data portal. [Cited 15 April 2021]. https://data.gov.uz/en

FIGURE 71.

ALFALFA PRODUCTION ACROSS THREE REGIONS



Source: Republic of Uzbekistan. 2020. Open data portal. [Cited 15 April 2021]. https://data.gov.uz/en

The main products that are produced by harvesting alfalfa are:

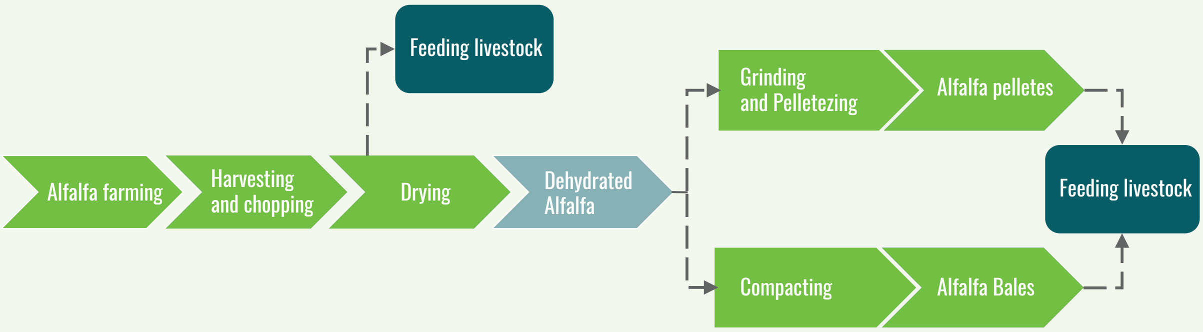
- a. alfalfa hay – this is the simplest and the most used product from alfalfa. To produce hay, alfalfa is harvested when it is at the 25–50 percent flowering stage. The harvested alfalfa is then dried and baled. Harvesting is generally done during a dry period to reduce the labour required to manually dry it. Raking is done at 60 percent DM and baling is done at 82 percent DM;
- b. dehydrated Alfalfa – dehydrated alfalfa includes the additional step of mechanically dehydrating harvested alfalfa to either produce bales or pellets. Dehydration

stabilizes alfalfa while preserving its high protein content, vitamins, and overall nutritional value (Renaud, 2002). Thereafter, alfalfa can be ground to make alfalfa meal or passed through a screw die to make pellets.

Figure 72 depicts the extended value chain of alfalfa including all possible final products. In practice, many countries produce all final products albeit in varying shares.

FIGURE 72.

ALFALFA VALUE CHAIN



Source: Adapted from Feedipedia. 2020. Alfalfa (Medicago sativa). In: *Feedipedia*. [Cited 25 July 2021]. https://www.feedipedia.org/node/275

5.2 POSSIBLE RENEWABLE ENERGY INTERVENTIONS

Energy is consumed in different forms throughout the alfalfa value chain. At the production stage, pumping water and irrigation uses energy either from the grid or from diesel powered pumps. Beyond the farm gates, the energy consumption depends on the final product being produced. Drying, when done mechanically, grinding, and pelletizing of ground alfalfa are the major steps where energy is consumed and where renewable energy can potentially be introduced. However, energy use in grinding can vary substantially depending on the final particle size of ground alfalfa. For instance, Ghorbani ***et al.***, (2010) report that energy use in grinding alfalfa could vary from 5.06 kJ/kg to 30.96 kJ/kg for 18 mm particle size and 12 mm particle size, respectively[7]. Similarly, energy use for pelleting can vary depending on the type and size of pellets produced.

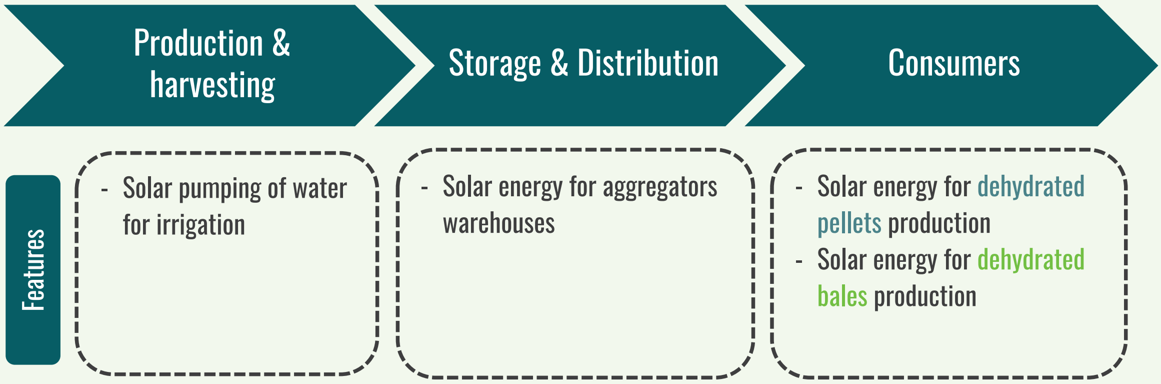
Renewable energy can be used along the alfalfa value chain to irrigate alfalfa fields to increase yields as well as to power the storage and processing infrastructure (see **Figure 73**). As discussed in the previous sections, producing alfalfa bales or pellets can be a way to increase the use of alfalfa as feed for livestock. Pelletizing and baling also facilitates the transport of alfalfa across the country.

©Pixabay/MOHANN (Free for commercial use)

[7] Using a 1.1 kW hammer mill.

FIGURE 73.

ENERGY INTERVENTION ALONG THE ALFALFA VALUE CHAIN



Source: Authors' own elaboration

5.3 ENERGY FOR IRRIGATION

Irrigation is a major activity that impacts the yield of alfalfa. Alfalfa for fodder is grown in irrigated areas for dairy stock. Currently, around 320 000 ha of the irrigated land in Uzbekistan is dedicated to forage crops. Access to electricity in rural areas is erratic and irrigation infrastructures are often outdated and unreliable.

Therefore, at the production stage solar energy can be used to power small water pumps that can provide farmers, especially dehkan farmers, with better access to water and irrigation. While water pumps can be powered by both diesel engines and electricity, using solar power can reduce the potential GHG emissions as compared to the irrigation systems powered by other fossil fuels.

The analysis for increasing irrigation for the alfalfa chain looks at comparing capital costs as well the potential GHG emissions from using pumping systems powered by diesel, electricity and solar PV. (See **Figure 74**).

Energy demand for irrigation is directly dependent on the area that needs to be irrigated and the water demands of the crop. **Table 33** details the alfalfa yield and area under production in each of the districts.

TABLE 33.

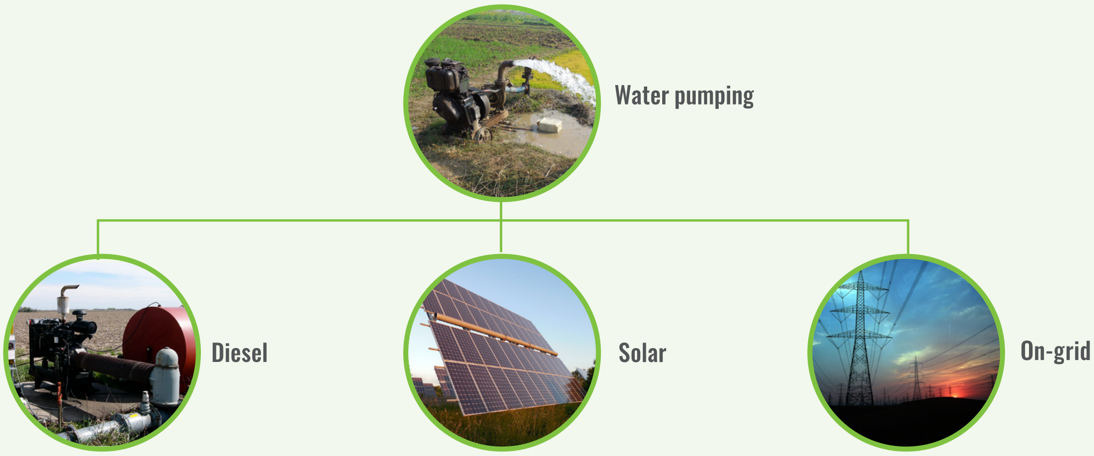
AREA UNDER IRRIGATION

REGION	PRODUCTION (tonnes/year)	AREA (ha)
KARAKALPAKSTAN	153 713	12 297
KASHKADARYA	504 584	39 115
KHOREZM	77 760	6 075
TOTALS	736 056	57 487

Source: Republic of Uzbekistan. 2020. Open data portal. [Cited 15 April 2021]. https://data.gov.uz/en

FIGURE 74.

ANALYSED INTERVENTIONS IN ALFALFA VALUE CHAIN



Source: Authors' own elaboration.

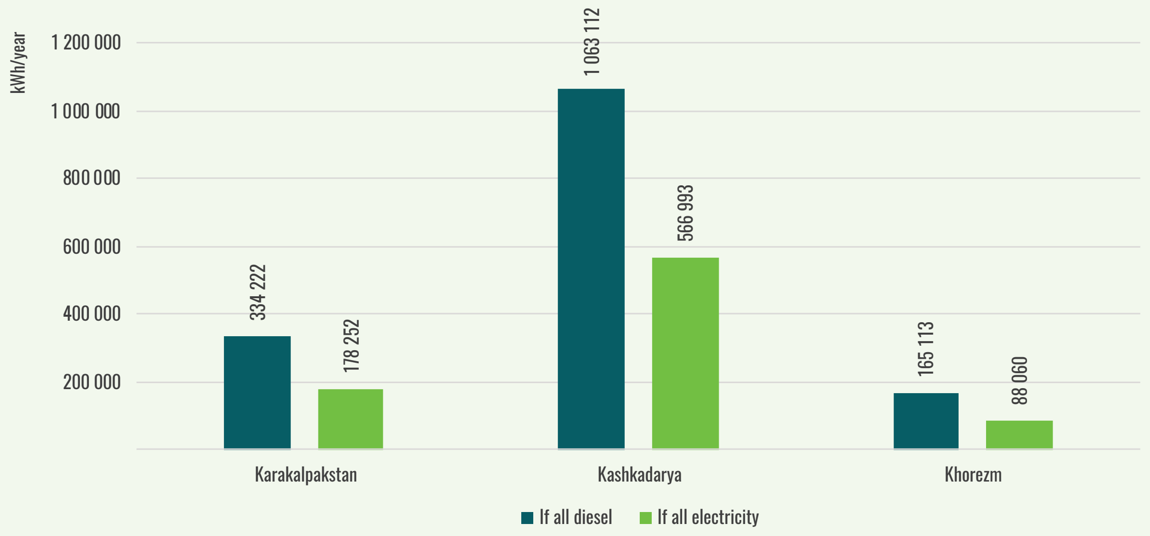
Images source:
Surajmondol. 2014. *Water pump set. In: Wikimedia Commons. Cited 8 June 2022. https://commons.wikimedia.org/wiki/File:Water_pump_set.JPG*
Eliot Phillips. 2007. *Stationary engine. In: Flickr. Cited 8 June 2022. https://www.flickr.com/photos/hackaday/482209112/*
Pxhere. 2017. Solar, energy, solar panel, current, energy revolution, power generation. In: Pxhere. Cited 8 June 2022. https://pxhere.com/en/photo/720578
AshrafChemban. 2019. *Torre de Electricidad. In: Pixabay. Cited 8 June 2022. https://pixabay.com/es/photos/torre-de-electricidad-red-el%C3%A9ctrica-3916954/*

The first stage of analysis estimates the energy required to irrigate alfalfa in each of the three regions if water pumps are powered by diesel or electricity. The comparison shows that diesel pumps would consume more energy than electricity pumps. This is primary due to the fact that electricity pumps are more efficient than diesel pumps.

Based on the energy demand detailed in **Figure 75**, the analysis further estimates the capital cost and GHG reduction potential if solar PV powered pumps are used to replace diesel and electricity pumps. Similar to the wheat analysis, the methodology used to estimate the capital cost is based on a range of adoption rates of the solar pumping systems. It is unlikely that the adoption rate of solar water pumps would be 100 percent meaning that not all the alfalfa production area will use solar pumping for irrigation. Therefore, the estimates of capital costs investment required for the installation of solar pumping systems correspond to the adoption rates between 5 and 75 percent.

FIGURE 75.

ENERGY DEMAND FOR PUMPING WATER (DIESEL VS ELECTRICITY)

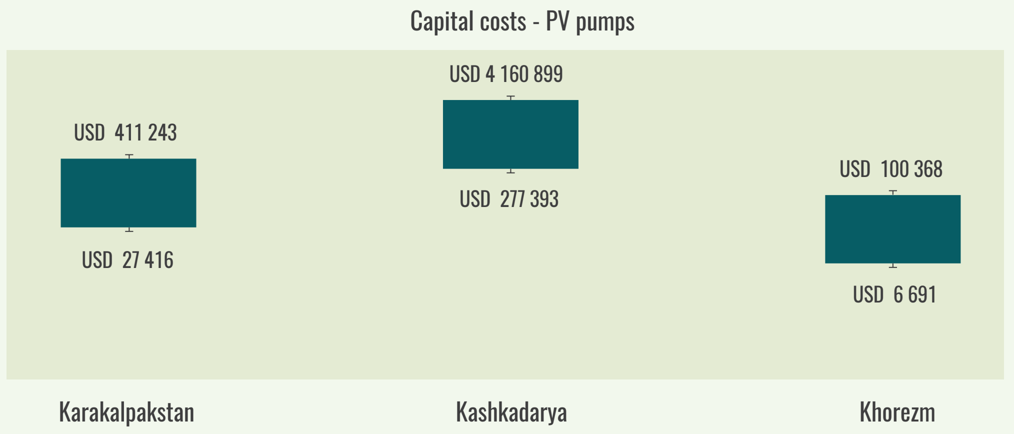


Source: Authors' own elaboration..

Figure 76 presents the estimates of capital cost ranges corresponding to an adoption rate of 5 and 75 percent. Given that the largest area under alfalfa production is in Kashkadarya, the results estimate the largest investment requirement also in that region please delete endpoint. (USD 277 393 to USD 4.1 million) followed by the Republic of Karakalpakstan (USD 27 416 to USD 411 243) and Khorezm (USD 6 691 to USD 100 368).

FIGURE 76.

CAPITAL COSTS FOR SOLAR PV PUMPS (USD)

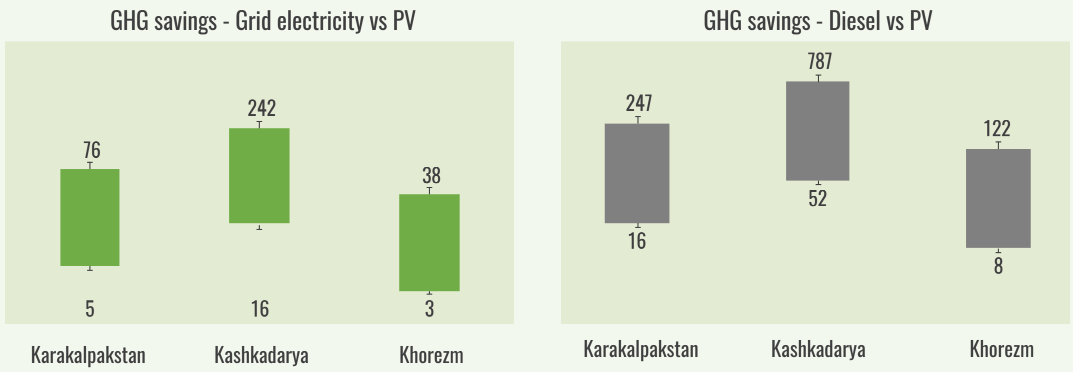


Source: Authors' own elaboration.

It should be noted that solar PV pumping systems are more expensive than diesel and electricity pumps. However, in the long term, the operating cost of PV pumps is lower than both diesel and electricity pumps due to that fact that they do not need fuel to operate. The additional benefits of PV systems are the potential GHG reduction compared to the other two types of pumps. This is exhibited in **Figure 77**. Using PV systems instead of diesel pumps can result in GHG savings between 8 and 787 tonnes CO_2 eq per year. Similarly, using PV pumps instead of grid connected water pumps can save between 3 and 242 tonnes CO_2 eq per year.

FIGURE 77.

POTENTIAL GHG SAVINGS OFFERED BY PV SYSTEMS (tonnes CO_2 eq/year)



Source: Authors' own elaboration.

5.4 ENERGY FOR STORAGE

Once alfalfa has been harvested, it needs to be stored. While alfalfa can be stored on the fields and covered with polyethylene, commercial hay producers prefer enclosed barns or warehouses to minimize storage losses and protect the hay from the elements. Alfalfa bales are stacked tight along open sides and at the top to protect them from rain and snow.

Barns and under-roof storage should be located on a well-drained site and as close to feeding areas as possible. Dry matter losses in enclosed barns are usually less than two percent during the first nine months in storage, while losses in under-roof storage can be as high as five percent[7].

FIGURE 78.

ENERGY OPTIONS TO POWER WAREHOUSES

Source: Authors' own elaboration.

Images source:

S. Mittal/CIMMYT. 2012. *Open grain storage in India. In: Flickr. Cited 14 June 2022. https://www.flickr.com/photos/cimmyt/8622125349*

Repton1x. 2009. *Current. In: Wikimedia Commons. Cited 14 June 2022. https://commons.wikimedia.org/wiki/File:Benkid77_Puddington-Shotwick_footpath_27_110809.JPG*

David Shankbone. 2009. Photovoltaic arrays at the Israeli National Solar Energy Center. In: Wikimedia Commons. Cited 14 June 2022. *https://commons.wikimedia.org/wiki/File:Benkid77_Puddington-Shotwick_footpath_27_110809.JPG*

Losses in forage quality, such as crude protein and fiber, are negligible. Barns and warehouses need access to electricity for lighting and ventilation. They can be powered by both grid electricity or PV systems (see **Figure 78**).

Table 34 presents the crop calendar of alfalfa in the three regions and estimates the total quantity of alfalfa needed to be stored in the three regions.

[7] https://soilcropandmore.info/crops/alfalfa/Oklahoma__Alfalfa/haying-alf-guide.htm

TABLE 34.

ESTIMATION OF STORAGE AREA REQUIRED

ALFALFA STORAGE							
MONTH		KARAKALPAKSTAN		KASHKADARYA		KHOREZM	
		6 405	tonnes/month	21 024	tonnes/month	3 240	tonnes/month
HARVEST MONTH SELECTION	STORAGE MONTH	CUMULATIVE STORAGE (tonnes)	STORAGE DEPLETION (tonnes/ month)	CUMULATIVE STORAGE (tonnes)	STORAGE DEPLETION (tonnes/ month)	CUMULATIVE STORAGE (tonnes)	STORAGE DEPLETION (tonnes/ month)
JANUARY	0	0	8 326	0	27 332	0	4 212
FEBRUARY	0	0	1 921	0	6 307	0	972
MARCH	1	5 124	5 124	16 819	16 819	2 592	2 592
APRIL	2	8 326	8 326	27 332	27 332	4 212	4 212
MAY	3	11 528	11 528	37 844	37 844	5 832	5 832
JUNE	4	14 731	14 731	48 356	48 356	7 452	7 452
JULY	5	15 311	17 933	58 868	58 868	9 072	9 072
AUGUST	6	17 933	21 135	69 380	69 380	10 692	10 692
SEPTEMBER	7	24 338	24 338	79 892	79 892	12 312	12 312
OCTOBER	8	27 540	27 540	90 405	90 405	13 932	13 932
NOVEMBER	0	0	21 135	0	69 380	0	10 692
DECEMBER	0	0	14 731	0	48 356	0	7 452

Source: Authors' own elaboration.

Based on the data in **Table 34**, the maximum quantity of alfalfa needed for storage in the three regions and the minimum safety capacity required are detailed in **Table 35**. The minimum safety capacity is the minimum alfalfa inventory needed to cover or buffer against uncertainties. A 30 percent safety limited was used to estimate the minimum safety capacity.

TABLE 35.

ESTIMATED MAXIMUM STORAGE AREA AND MINIMUM CAPACITY REQUIRED

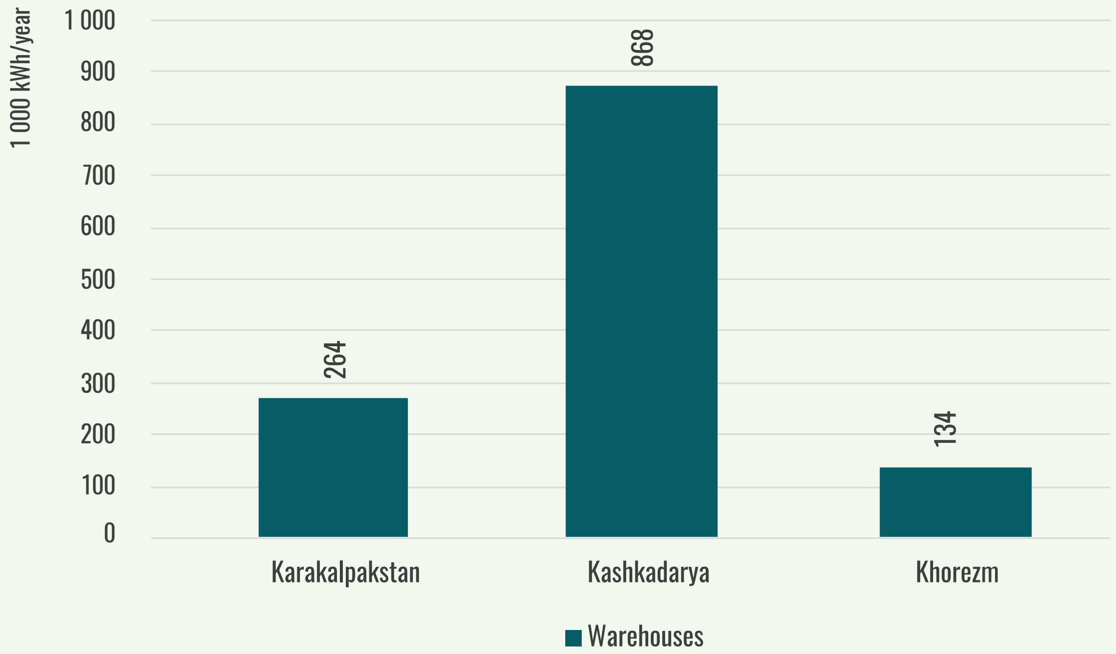
	KARAKALPAKSTAN	KASHKADARYA	KHOREZM
MAX. STORAGE CAPACITY (tonnes)	27 541	90 405	13 932
MIN. SAFETY STORAGE (tonnes)	1 992	6 308	972

Source: Authors' own elaboration.

Consequently, based on the data shows in **Table 34** and **Table 35**, the analysis estimated the energy demand for alfalfa storage warehouse which is shown in **Figure 79**. Given that the largest production of alfalfa is in Kashkadarya, the energy demand for warehouses is also the highest in that region.

FIGURE 79.

ENERGY DEMAND FOR WAREHOUSES



Source: Authors' own elaboration.

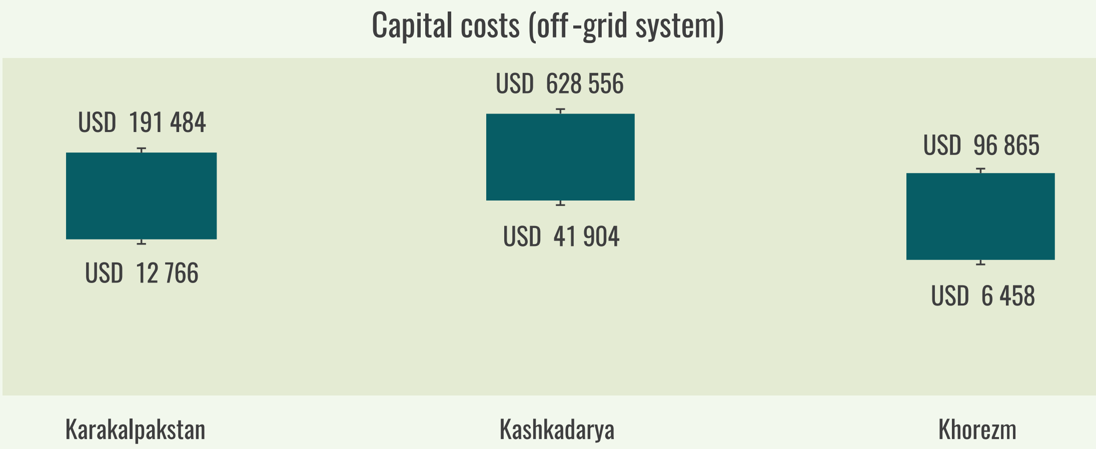
The electricity demand estimated in **Figure 79** can be supplied with either grid electricity or with solar PV. Two distinct configurations of solar PV systems can be installed on the i) On-grid PV and ii) Off grid PV system. The main difference between the two is that in the first configuration, the PV system is connected to the grid and therefore does not require batteries to store energy, while in the second configuration, batteries are required to store energy.

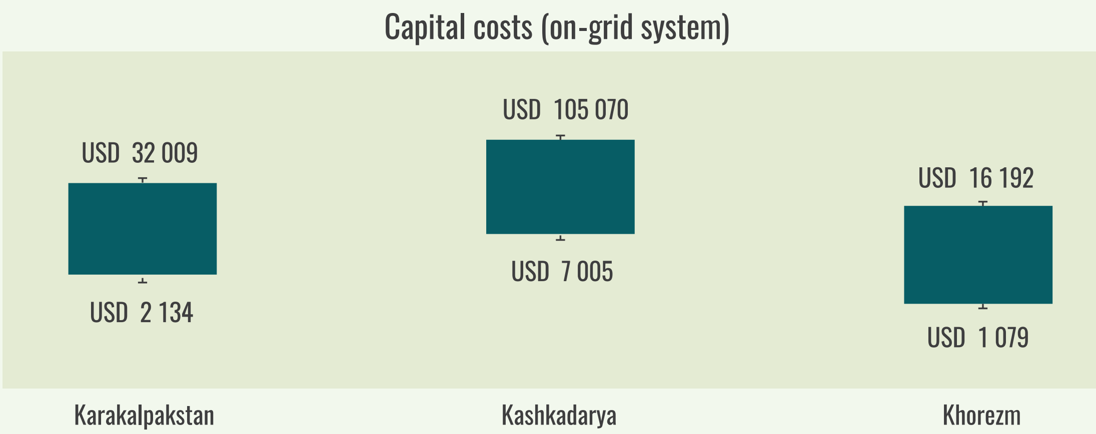
Based on this information, the analysis estimated the capital costs to install both on-grid and off-grid PV systems at the storage stage of the value chain. **Figure 80** shows the estimates for capital costs for these systems. The results suggest that based on the adoption rate, the capital cost for off-grid PV systems can range from USD 6 458 (in Khorezm at 5 percent adoption rate) to USD 628 556 (in Kashkadarya at 75 percent adoptions rate).

For on-grid systems, the costs are lower as compared to off-grid systems mainly due to fact that batteries are not needed in on-grid systems. The capital costs under this scenario can range from USD 1 079 (in Khorezm at 5 percent adoption rate) to USD 105 070 (in Kashkadarya at a 75 percent adoption rate). In terms of GHG savings, using solar PV system instead of grid electricity can result in annual GHG reduction ranging from 4 tonnes CO_2 eq (in Khorezm at a 5 percent adoption rate) to 370 tonnes CO_2 eq (in Kashkadarya at a 75 percent adoption rate).

FIGURE 80.

CAPITAL COST FOR INSTALLING ON-GRID AND OFF-GRID PV SYSTEMS (USD)

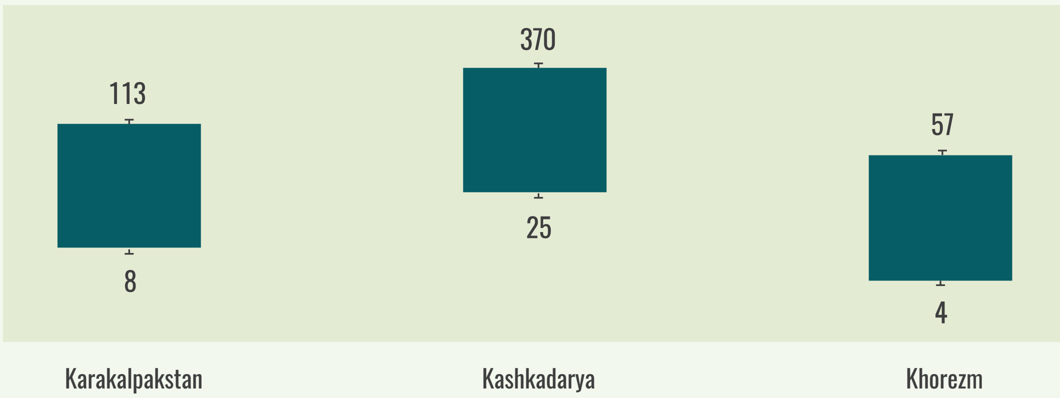




Source: Authors' own elaboration.

FIGURE 81.

GHG SAVINGS - GRID ELECTRICITY VS PV (tonnes CO2 eq/year)



Source: Authors' own elaboration.

5.5 ENERGY FOR PELLETING AND BALING ALFALFA

In order to facilitate easier transport and to allow for the fortification of alfalfa as feed, the harvested alfalfa hay can be either baled or compressed into pellets. This could be beneficial to the country in that it would make it easier to distribute alfalfa internally in the country, as well as to the farmers because it will allow them to produce a value-added product that can be sold at higher prices. **Table 36** provides an example that illustrates how much extra income farmers can produce for every 10 000 tonnes of alfalfa produced. **Table 36** shows the cost of alfalfa hay, alfalfa bales and alfalfa pellets and the potential increase in income that farmers can expect from producing bales and pellets from alfalfa. The estimates show that on average, farmers' income can increase by 23 percent if they produce alfalfa bales and by 104 percent if they produce alfalfa pellets instead of selling alfalfa hay.

TABLE 36.

INCREASE IN INCOME FROM BALES AND PELLETS

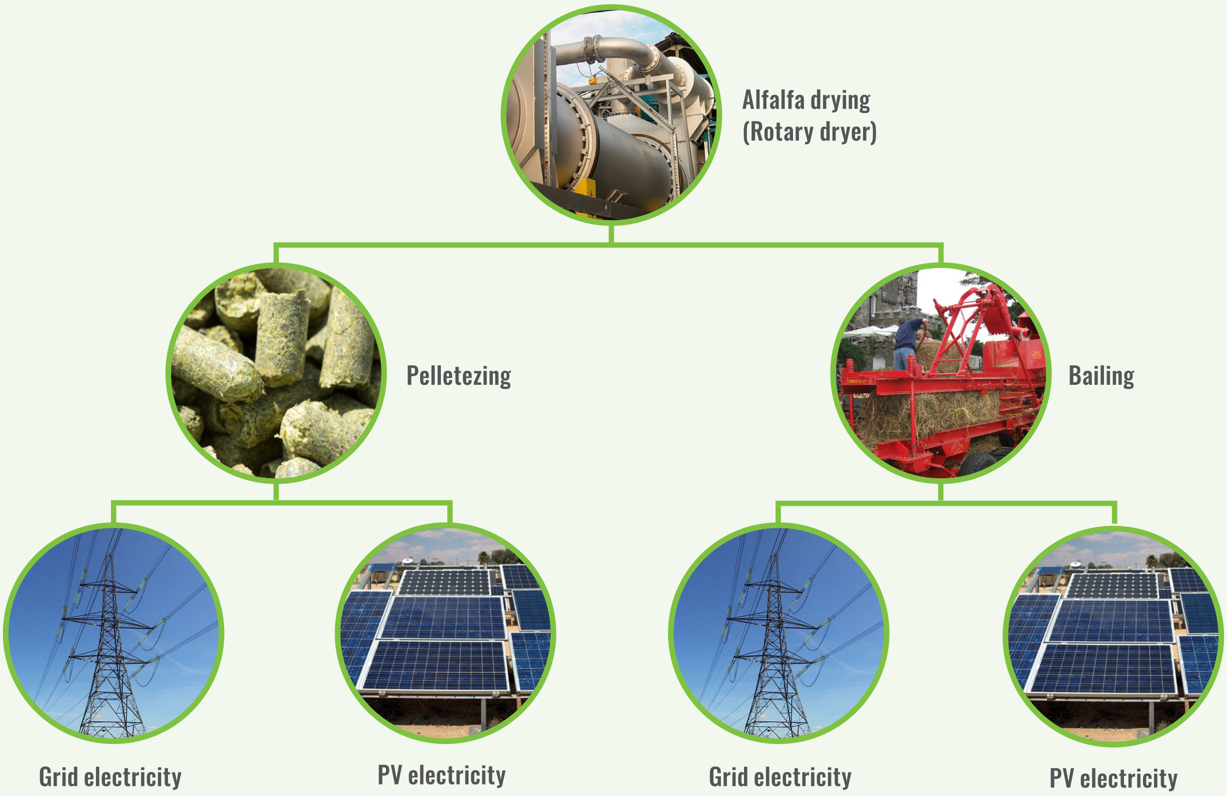
ITEM	QUANTITY (tonnes)	SELLING PRICE (USD/tonne)	TOTAL INCOME (USD)	INCREASE IN INCOME (%)
ALFALFA HAY	10 000	110	1 100 000	
ALFALFA BALES	6 456	210	1 355 724	23%
ALFALFA PELLETS	6 814	330	2 248 781	104%

Source: Authors' own elaboration.

Making alfalfa bales and pellets requires specific machinery. For bales, both a tractor and baler are required while for pellets a pelleting machine. In both cases additional energy is needed to perform the operations. Both baling machines and pelleting need access to electricity in order to run. Additionally, before harvested alfalfa can be baled or pelletized it needs to be dehydrated. Therefore, at the processing stage there are three main interventions that were analysed: drying alfalfa, producing alfalfa pellets and baling alfalfa (See **Figure 82**).

FIGURE 82.

ENERGY INTERVENTION FOR BALING AND PELLETING ALFALFA



Source: Authors' own elaboration.

Images source:

Brookoffice. *2013. Rotary Dryer - Allgaier. In: Wikimedia Commons. Cited 14 June 2022. https://commons.wikimedia.org/wiki/File:Rotary_Dryer_-_Allgaier.jpg*

Feed- pellet-mill. 2022. *Solutions to feed pelletezing problems. In: Feed-pellet-mill. Cited 14 June 2022. https://www.feed-pellet-mill.com/news/pellet-mill-operation.html*

Richard Hoare. 2008. Jones Baling Machine. In: Geograph - Wikimedia Commons. Cited 14 June 2022. *https://commons.wikimedia.org/wiki/File:Jones_Baling_Machine_-_geograph.org.uk_-_1406072.jpg*

Repton1x. 2009. *Current. In: Wikimedia Commons. Cited 14 June 2022. https://commons.wikimedia.org/wiki/File:Benkid77_Puddington-Shotwick_footpath_27_110809.JPG*

David Shankbone. 2009. Photovoltaic arrays at the Israeli National Solar Energy Center. In: Wikimedia Commons. Cited 14 June 2022. *https://commons.wikimedia.org/wiki/File:Benkid77_Puddington-Shotwick_footpath_27_110809.JPG*

The conversion factors used to estimate the quantity of bales and pellets that can be produced are detailed in **Table 37**.

The analysis estimated the total quantity of alfalfa pelletizing and baling that can be produced in the three regions. These are shown in **Table 38**.

Having estimated the quantity of pellets and bales that can be produced, the analysis further estimated the total electricity needed to produce the quantity of pellets and bales estimated in **Figure 83**. The results suggest that Kashkadarya has the highest energy demand for alfalfa pellets and bales followed by Khorezm and the Republic of Karakalpakstan.

TABLE 37.

CONVERSION FACTORS USED

OPERATION	CONVERSION FACTOR
DEHYDRATION	0.72
BALING	0.90
PELLETING	0.95

Source: Authors' own elaboration.

TABLE 38.

POTENTIAL TO PRODUCE PELLETS AND BALES

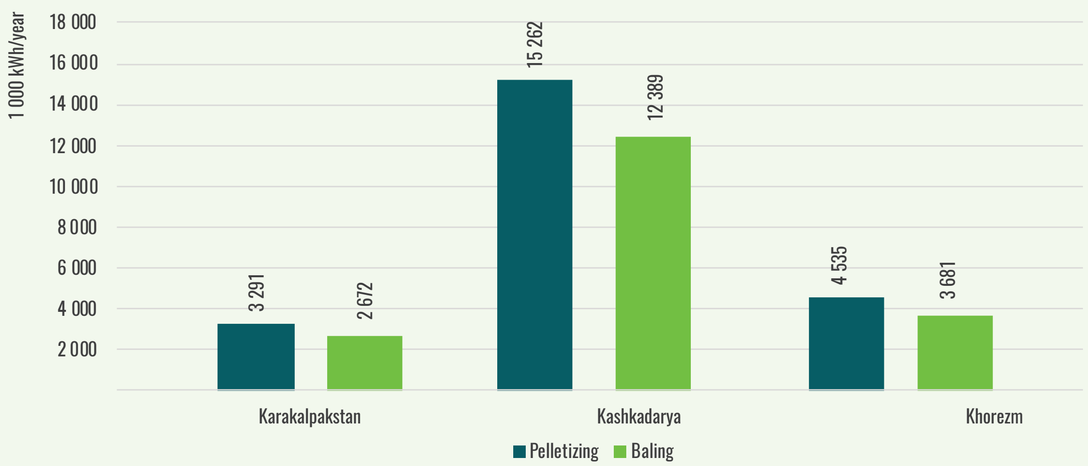
REGION	AMOUNT AVAILABLE (tonnes/year)	PELLETS (tonnes/year)	BALING (tonnes/year)
KARAKALPAKSTAN	135 000	91 996	126 749
KASHKADARYA	626 000	426 587	404 135
KHOREZM	186 000	126 749	120 078

Source: Authors' own elaboration.

Both pelletizing and baling need electricity to operate. The electricity can be provided by both on-grid and off-grid PV systems. The analysis further estimated the capital cost to power baling and pelleting operations with PV systems. The results suggest that Kashkadarya has the most potential for using solar PV systems to power pelleting operations (see **Figure 84**). For off-grid systems this can range from USD 99 853 (5 percent adoption rate) to USD 9 719 173 (at 75 percent adoption rate). For on-grid systems, the investment needed to power pelleting operations is lower than off-grid systems because these systems do not require batteries. In Kashkadarya, this can range from USD 16 692 (at 5 percent adoption rate) and USD 1 642 664 (at 75 percent adoption rate).

FIGURE 83.

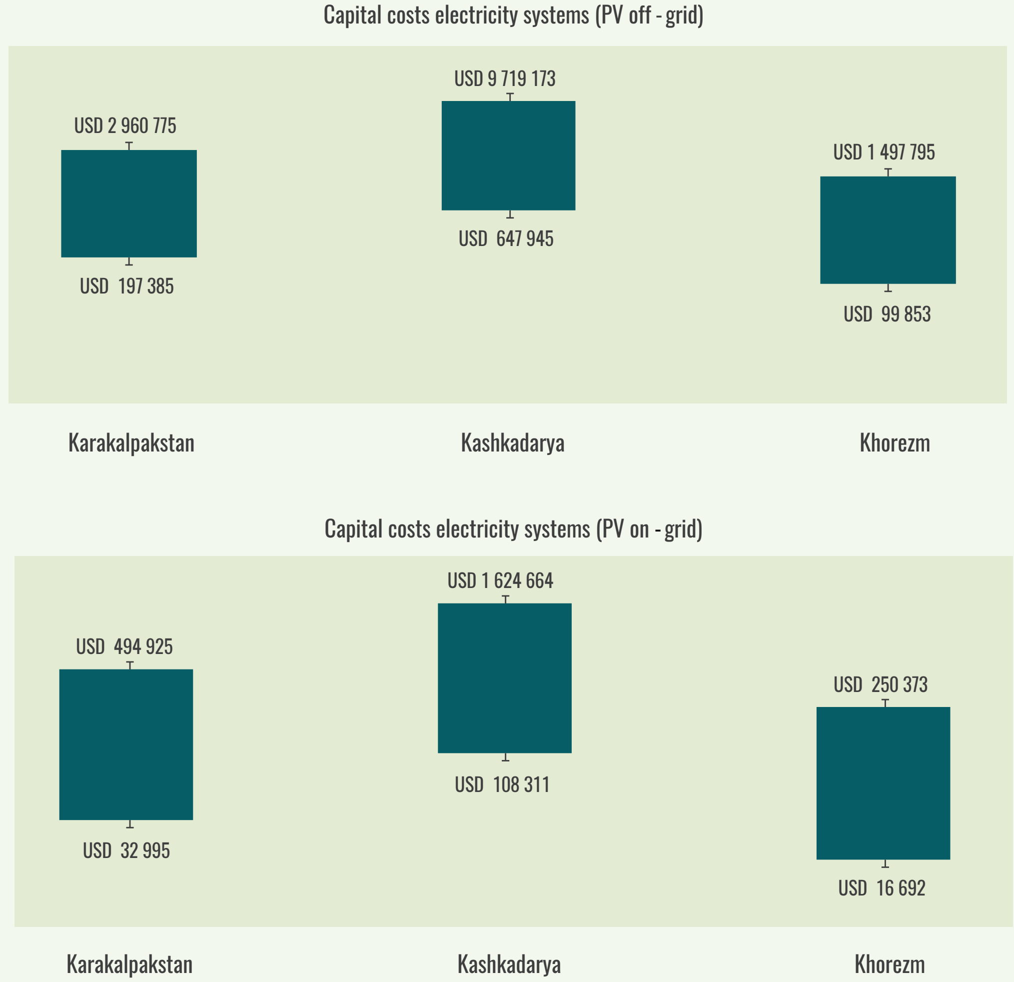
ENERGY DEMAND FOR PELLETIZING AND BALING ALFALFA



Source: Authors' own elaboration.

FIGURE 84.

CAPITAL COST FOR ON-GRID AND OFF-GRID PV SYSTEMS TO POWER PELLETING OPERATION (USD)

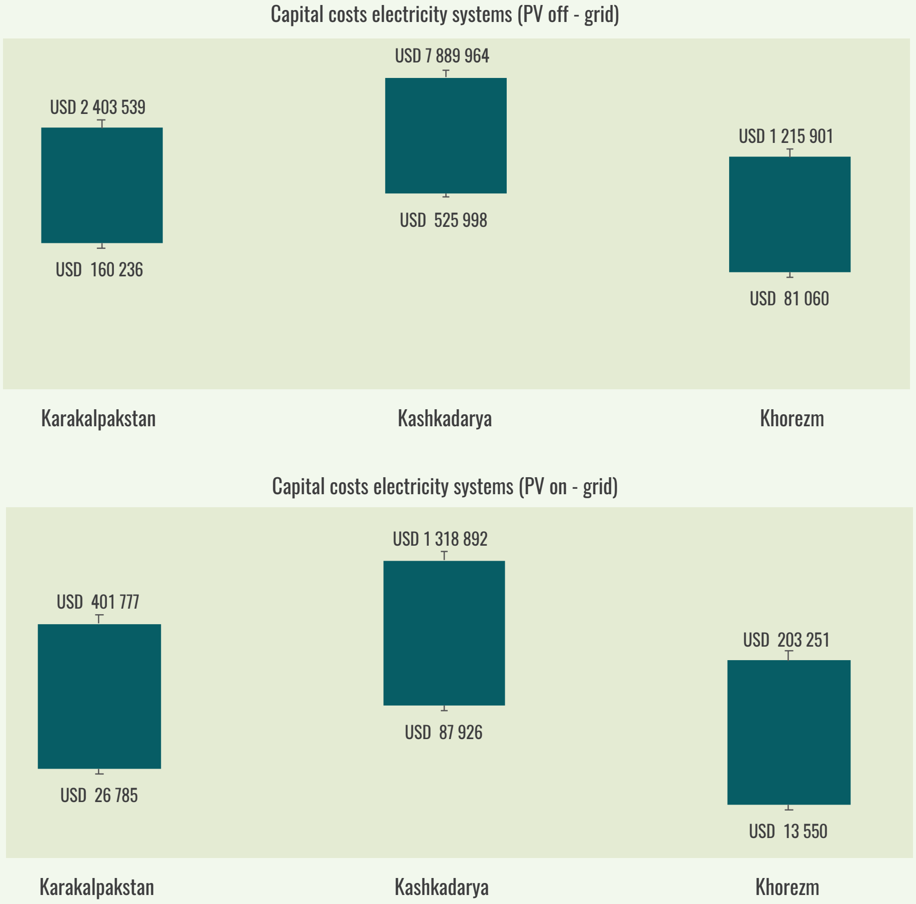


Source: Authors' own elaboration.

The results suggest that for baling, Kashkadarya has the most potential for producing alfalfa and hence the highest capital costs. This is also the case with pelleting in that the investments required for off-grid PV systems are higher than for on-grid systems, since on-grid systems do not require batteries. For baling systems, **Figure 85** show the investment in off-grid PV systems can range from USD 81 060 (at 5 percent adoption rate in the Republic of Karakalpakstan) to USD 7 889 964 (at 75 percent adoption rate in Kashkadarya). For on-grid systems, the investment in baling systems ranges from USD 13 550 (at a 5 percent adoption rate in the Republic of Karakalpakstan) to USD 1 318 892 (at a 75 percent adoption rate in Kashkadarya).

FIGURE 85.

CAPITAL INVESTMENT REQUIRED FOR ON-GRID AND OFF-GRID PV SYSTEMS TO POWER BALING OPERATION (USD)



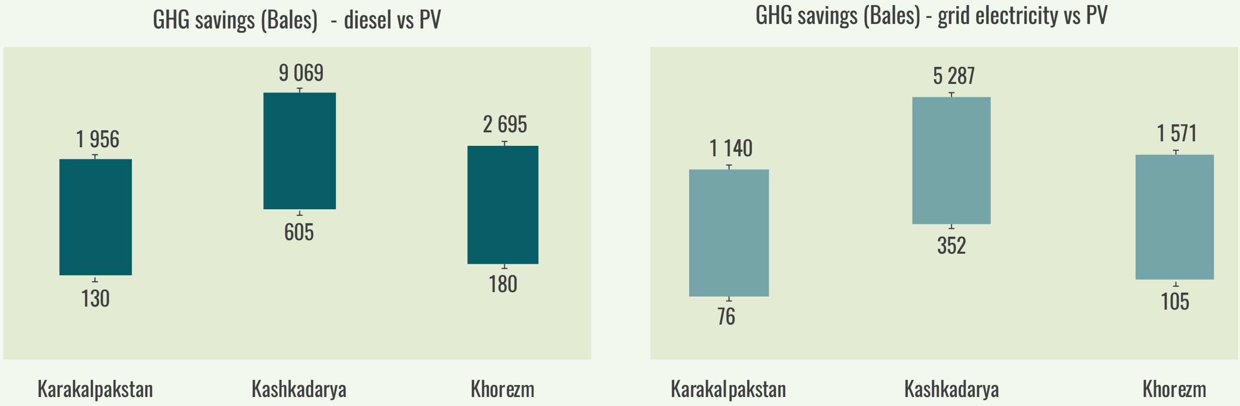
Source: Authors' own elaboration.

Solar PV systems are not the only option for power baling and pelleting operations for alfalfa. Grid electricity as well as diesel generators can also be used to power these operations. However, one of the major benefits of using solar PV systems is the potential reducing in GHG emissions. **Figure 86** estimates the potential GHG emissions savings by using solar PV systems to power baling operations, as opposed to using diesel generators and grid electricity.

Similarly, **Figure 87** estimates the potential GHG savings from using solar PV systems to power pelletizing operation as opposed to using diesel generators or grid electricity.

FIGURE 86.

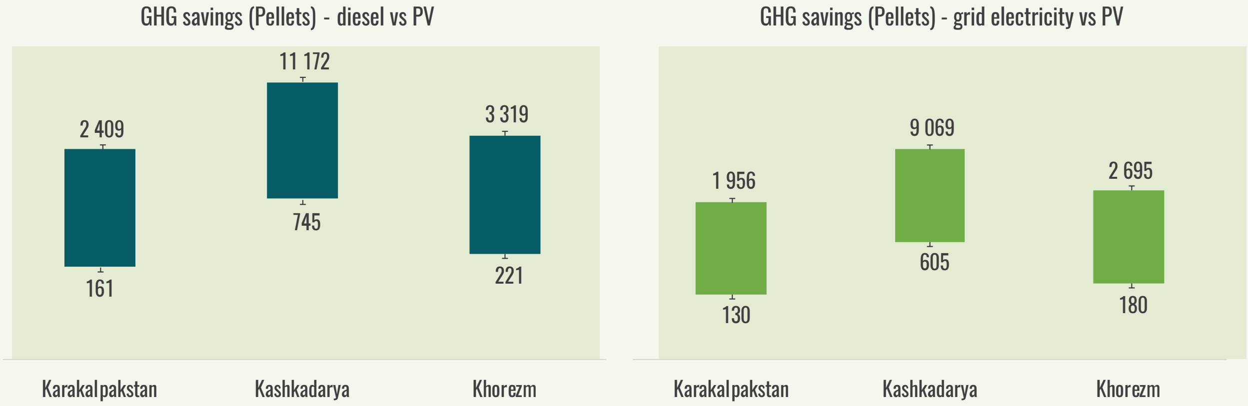
POTENTIAL GHG EMISSION REDUCTION OF USING SOLAR PV SYSTEMS COMPARED TO DIESEL GENERATORS AND GRID ELECTRICITY FOR BALING OPERATIONS (tonnes CO_2 eq/year)



Source: Authors' own elaboration.

FIGURE 87.

GHG SAVINGS FROM USING SOLAR PV OPPOSED TO DIESEL GENERATORS AND GRID ELECTRICITY TO POWER PELLETING OPERATION (tonnes CO_2 eq/year)



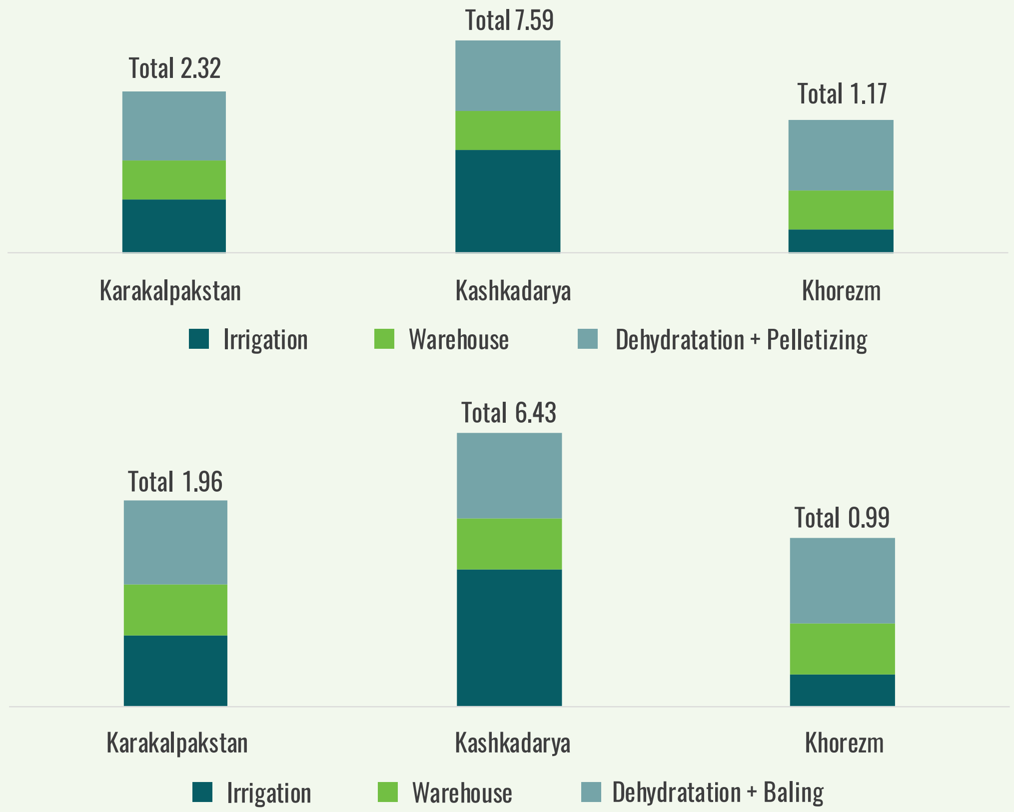
Source: Authors' own elaboration.

5.6 SUMMARY

By combining the results of all energy interventions along the alfalfa value chain, the aggregate results can provide the potential use od renewable energy along the whole change. The two graphs in **Figure 88** show the total energy demand in two scenarios based on an analysis that assumes that the available alfalfa is either baled or pelletized.

FIGURE 88.

AGGREGATE ELECTRICITY DEMAND FOR ALL THE INTERVENTIONS ALONG THE ALFALFA VALUE CHAIN (MILLION kWh/year)

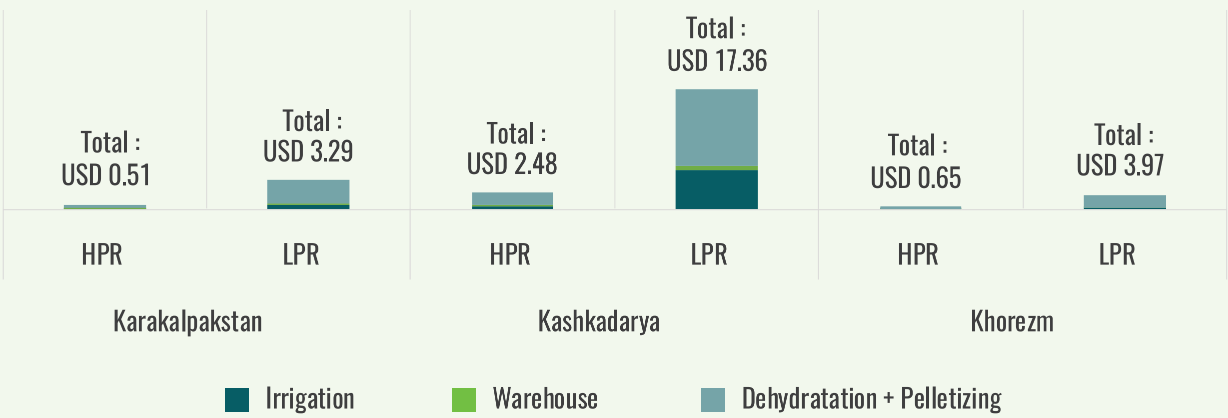


Source: Authors' own elaboration.

Furthermore, **Figure 89** shows the minimum and maximum investments required for irrigation, warehouse and pelleting interventions. The minimum and maximum investments correspond to the low and high adoption rates of these technologies. **Figure 90** shows the minimum and maximum investment required for irrigation, warehouse, and baling interventions.

FIGURE 89.

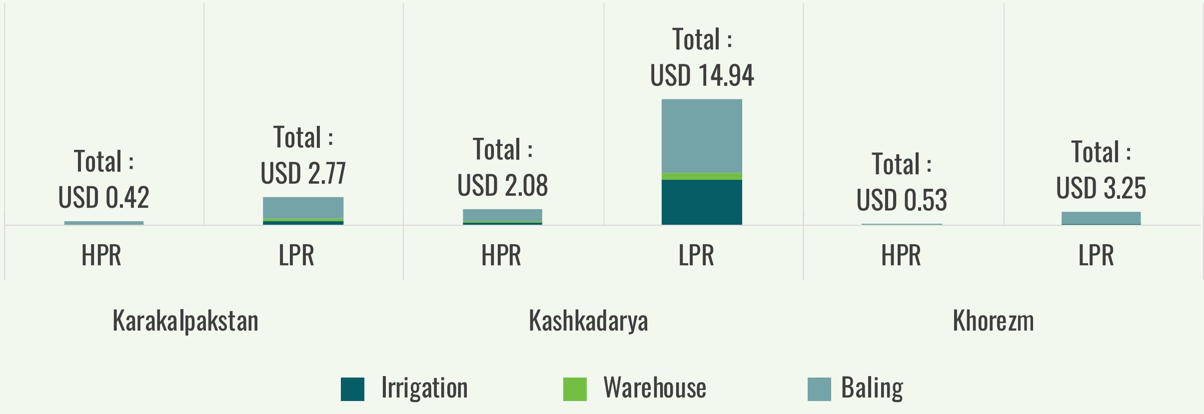
CAPITAL INVESTMENT REQUIREMENTS FOR IRRIGATION, WAREHOUSING AND PELLETING OPERATIONS (MILLION USD)



Source: Authors' own elaboration.

FIGURE 90.

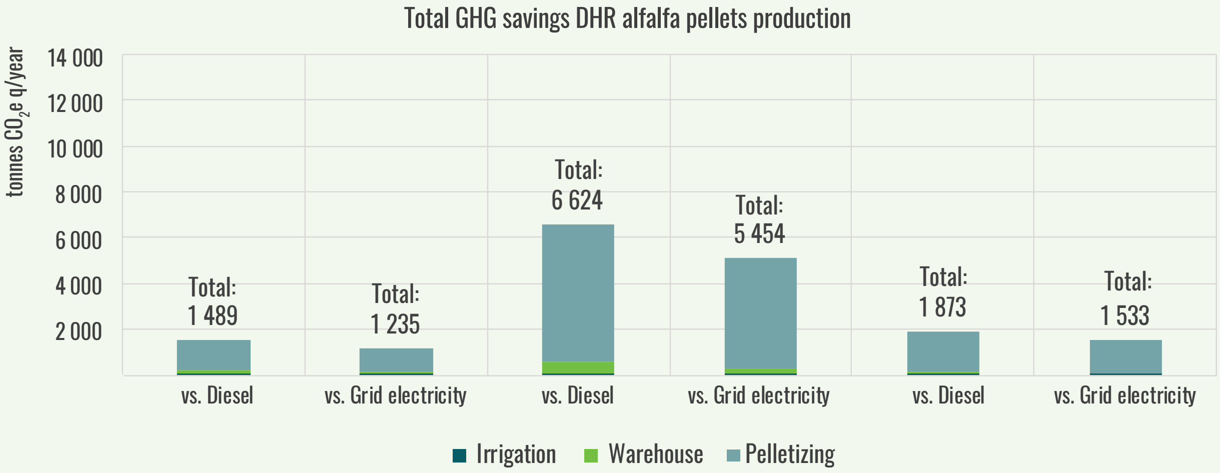
CAPITAL INVESTMENT REQUIREMENTS FOR IRRIGATION, WAREHOUSING AND BALING OPERATIONS (MILLION USD)

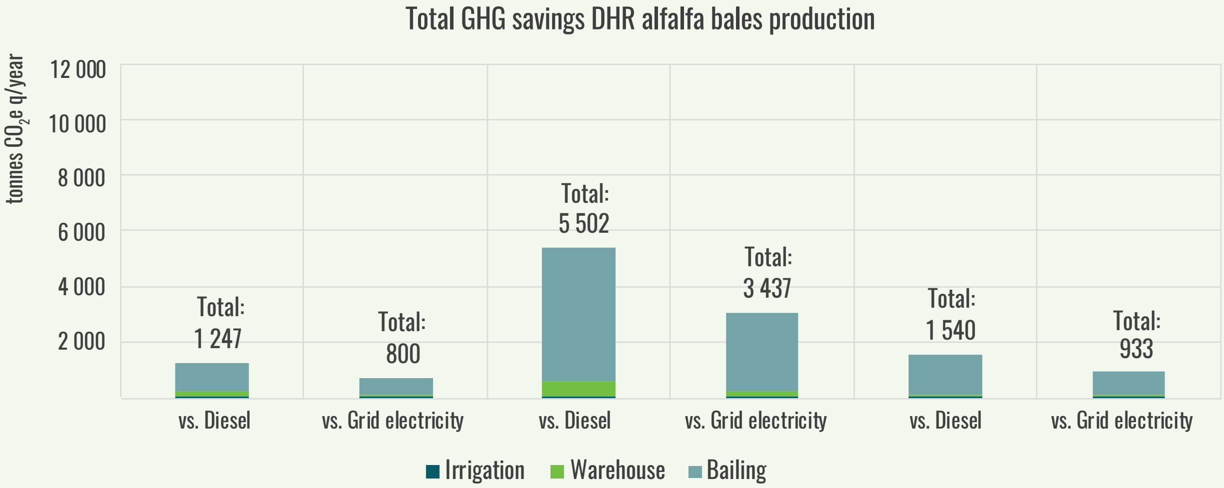


Source: Authors' own elaboration.

FIGURE 91.

GHG SAVINGS FROM ENERGY INTERVENTIONS ALONG THE ALFALFA CHAIN (tonnes CO2 eq/year)





Source: Authors' own elaboration.

The aggregate result suggests that the investments in conservation technologies add value to alfalfa; if this is converted to DHR bales (23 percent) or DHR pellets (104 percent). Furthermore, the total investments for the three provinces would range USD 500 thousand–USD 17 million for pelleting operations and USD 400 thousand–USD 15 million for baling operations (see **Figure 89** and **Figure 90**). The associated GHG emission savings will range 1 200–6 600 tonnes CO_2 eq/year for PV vs equivalent diesel-fuelled options and 800–5 400 tonnes CO_2 eq/year PV vs grid electricity options (see **Figure 91**).

CHAPTER

6

RENEWABLE ENERGY INTERVENTIONS IN THE HORTICULTURE CHAIN

6.1 HORTICULTURE CHAIN

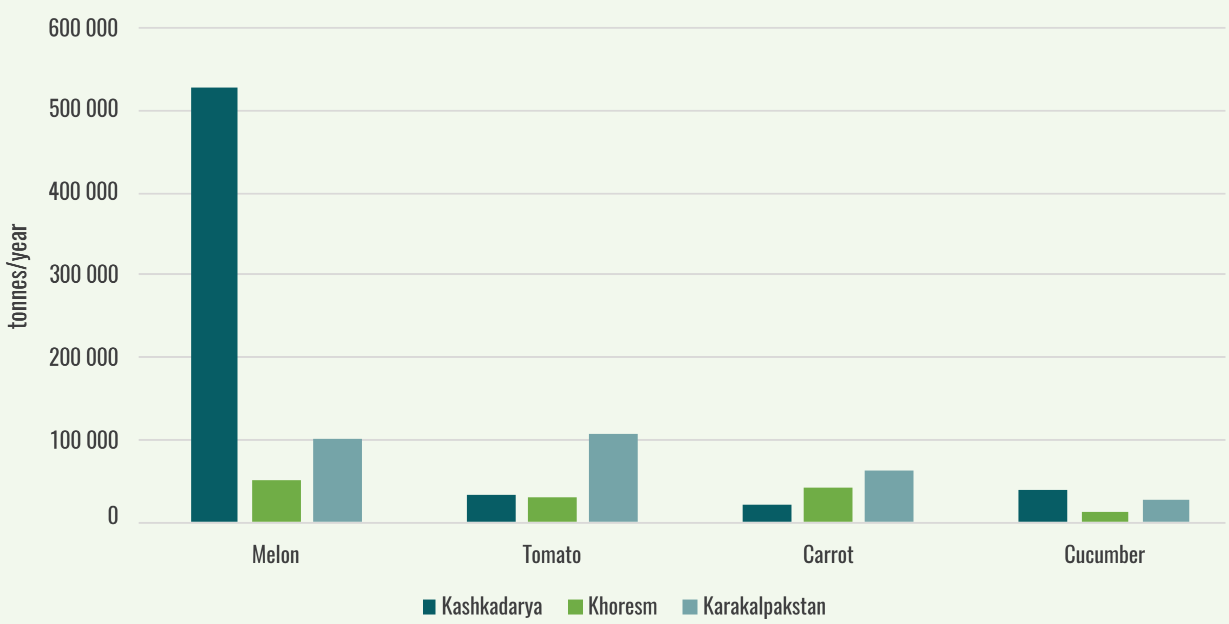
Horticulture is an important agriculture sub sector in Uzbekistan and accounts for 50 percent of the value of crop output and over 35 percent of agriculture export value. Production of the main horticulture products grew steadily between 2012 and 2016 with the following average rates: 10.3 percent for vegetables, 9.8 percent for potatoes, 9.5 percent for grapes, and 9.6 percent for melons. Uzbekistan's horticulture subsector is an important source of income for the 4.7 million dehkan households. Horticultural products are grown on an additional 21 thousand larger private farms. Horticultural export earnings have also surged in recent years, growing from USD 373 million in 2006 to USD 1.16 billion in 2010. (ADB, 2018)

The horticulture sector provides an important source of all-season jobs in rural areas and is a significant employer of women. Horticulture production is also beneficial for rural employment as it requires more hired labour than for cotton and wheat production. Currently, the horticulture subsector is mainly composed of small-scale farmers. The processing infrastructure currently consists of around 149 large processing firms, and numerous small processing enterprises exist nationally. Main processed horticultural products include canned and dried fruit and vegetables, tomato paste and juices, and grape wines and liquors. A little over 15 percent of total horticultural crops produced are processed. The total capacity of the cold storage in Uzbekistan is estimated at about 1 million tonnes, though the official data indicates that total capacity is 588 million tonnes. (ADB, 2018)

Storage of horticulture products presents a challenge for the country. Horticulture crops like fruits and fresh vegetables are susceptible to heat and biological rotting if not stored in cold conditions. Access to cold storage is still limited in the country, and most of the cold storage facilities are concentrated in export-oriented provinces and horticultural production areas like Samarkand, Tashkent, and Fergana Valley. The ADB, World Bank and EBRD are supporting the country to build cold storages. Nevertheless, the current capacity of the cold storage is still not sufficient to meet the demand for cold storage of fresh produce. In the three regions of Kashkadarya, Karakalpakstan and Khorezm, the main horticulture crops produced are melons and tomatoes, as shown in **Figure 92**. Both melons and tomatoes need to be stored cold in order to reduce possibility of biological decay.

FIGURE 92.

MAIN HORTICULTURE CROPS PRODUCED IN THE THREE REGIONS

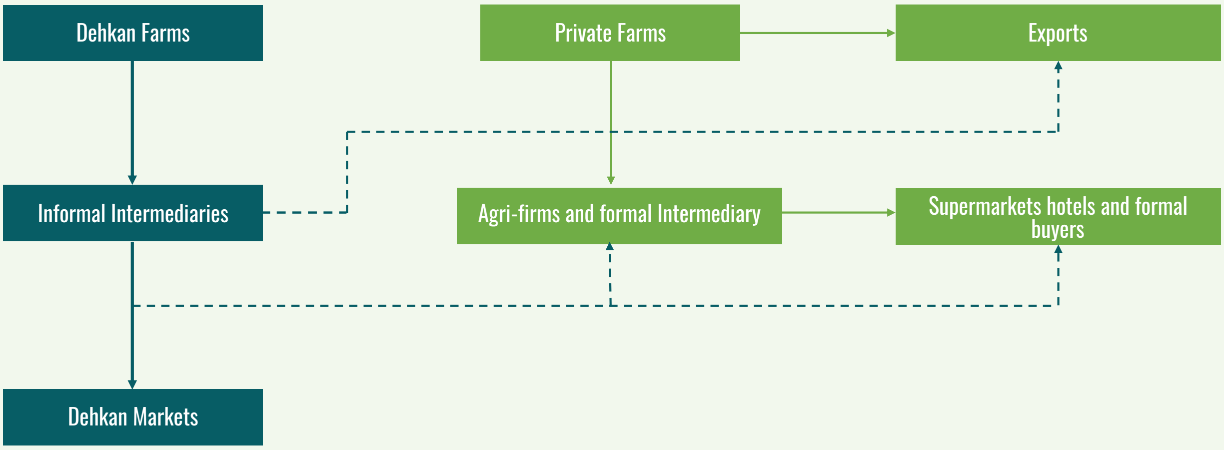


Source: Republic of Uzbekistan. 2020. Open data portal. [Cited 15 April 2021]. https://data.gov.uz/en

The horticulture value chain in the three regions is dominated by dehkan farmers who produce 90 percent of the total production. Additionally, around 45 percent of the land under melon production is managed by dehkan farmers. Melons are an important export crop for Uzbekistan. While most of the melons produced by small holders is consumed locally, there are several large private firms who export ons to other countries (see **Figure 93**).

FIGURE 93.

HORTICULTURE VALUE CHAIN



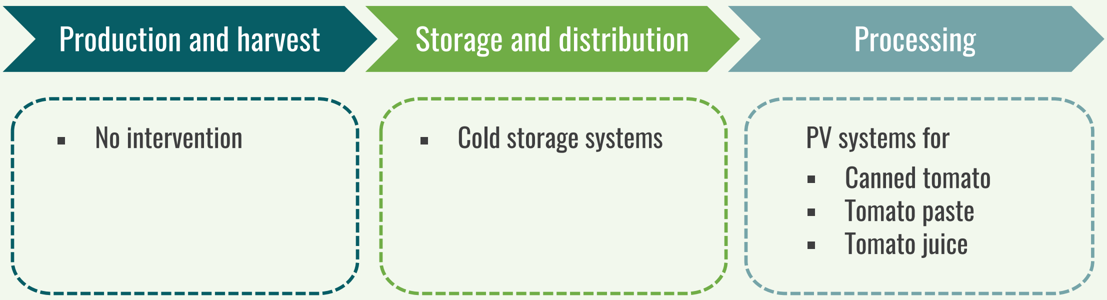
Source: Based on consultations with country experts and World Bank. 2012. Uzbekistan Strengthening the Horticulture Value Chain. *Background paper series. Washington.* Cited 24 July 2021. *https://openknowledge.worldbank.org/handle/10986/21495*

6.2 ENERGY INTERVENTIONS

Given that lack of access to cold storages and processing infrastructure in the horticulture value chain, the analysis focusses on the expanding cold storage and processing capacity. **Figure 94** shows the main interventions that are analysed for the horticulture value chain.

FIGURE 94.

INTERVENTIONS ANALYSED IN HORTICULTURE CHAIN



Source: Authors' own elaboration.

Traditional cold storages require access to reliable electricity to operate optimally. In areas where access to electricity is unreliable or absent, deploying cold storages is challenging. Additionally, even where grids are present, deploying traditional cold storages connected to the grid adds to the overall GHG emissions. An alternative could be to use solar cold storages that can be deployed with or without access to the grid.

The first step of the assessment analysed the use of solar cold storages to store horticulture products in the three regions. To estimate the quantity of cold storage capacity needed in the three regions, it was necessary to estimate the annual production of melons and tomatoes produced in each region. **Table 39** details the annual production of melons and tomatoes for the year 2019 in each region.

TABLE 39.

PRODUCTION OF MELONS AND TOMATO IN THE THREE REGIONS

REGION	MELONS (tonnes/year)	TOMATOES (tonnes/year)
KARAKALPAKSTAN	102 000	108 234
KASHKADARYA	526 750	34 091
KHOREZM	4 520	31 794

Source: Republic of Uzbekistan. 2020. Open data portal. [Cited 15 April 2021]. https://data.gov.uz/en

Dehkan farmers produce 90 percent of the total horticulture production in the country. Therefore, this analysis focused on the quantity of melons and tomatoes that are produced by dehkan farmers. The remaining 10 percent is produced by large private farms, and it is assumed that they already have access to modern cold storage facilities. Based on this **Table 40** estimates the quantity of melons and tomatoes needed to be stored in cold storages in the three regions.

TABLE 40.

QUANTITY NEEDED TO BE STORED IN COLD STORAGE

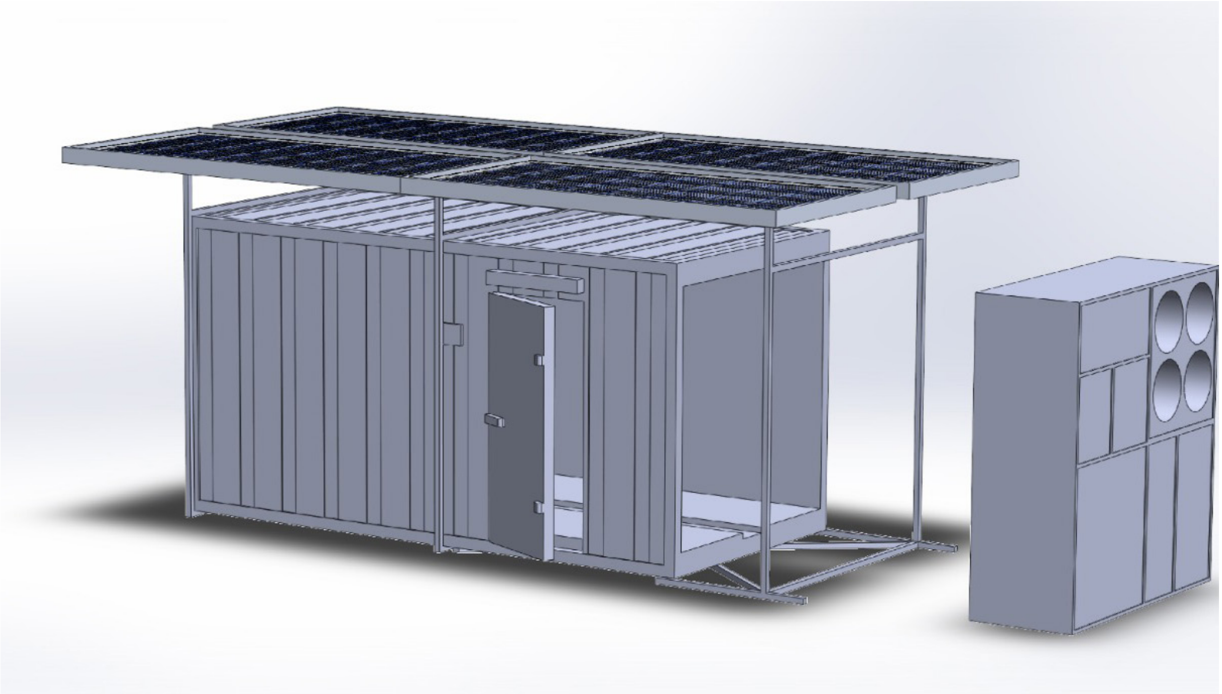
REGION	MELONS (tonnes/year)	TOMATOES (tonnes/year)
KARAKALPAKSTAN	91 800	97 411
KASHKADARYA	474 075	30 682
KHOREZM	4 068	28 561

Source: Based on estimate from Republic of Uzbekistan. 2020. Open data portal. [Cited 15 April 2021]. https://data.gov.uz/en and consultation with national experts.

Solar powered cold storages – decentralized storage units that are powered by solar power – are small (see **Figure 95**). On average the capacity of these cold storage is 164 tonnes/year. Assuming that the cold storage will work all year-round and on a 24-hour basis, horticulture products would need to be stored a total of 8 760 hours.

FIGURE 95.

AN EXAMPLE OF SOLAR COLD STORAGE



Source: Gallego Ríos, Jhuliana. 2022. FAO

6.3 DECENTRALIZED SOLAR POWERED COLD STORAGE

Based on the technical capacity of cold storage and the data shown in **Table 40**, **Table 41** estimates the number of cold storages needed to store 100 percent of the available of horticulture products as well as the total energy demand.

TABLE 41.

ESTIMATED ENERGY DEMAND FOR COLD STORAGES AND THE NUMBER OF COLD STORAGES NEEDED

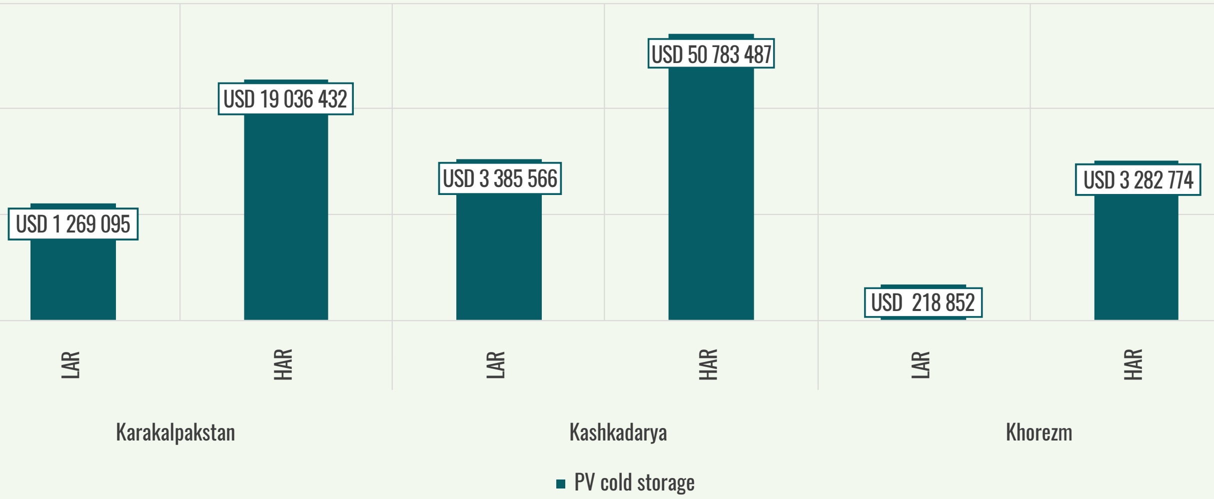
REGION	NUMBER OF COLD STORAGE UNITS (tonnes)	ANNUAL ELECTRICITY CONSUMPTION (kWh/year)	ELECTRICITY CAPACITY NEEDED (kW)
KARAKALPAKSTAN	1 154	316 928	36
KASHKADARYA	3 078	845 468	79
KHOREZM	199	54 653	6

Source: Authors' own elaboration.

However, not all the horticulture produce available in the three regions will be stored in solar cold storages. Some produce will be sold fresh while other produce will be stored in traditional grid connected cold storages, or processed into value added products. To account for this, the analysis further estimates the capital cost of installing solar cold storages at 5 percent and a 75 percent adoption rate. A 5 percent adoption rate implies that only 5 percent of the needed cold storages are powered by solar PV while a 75 percent adoption rate implies that 75 percent of the cold storages needed are solar cold storages. **Figure 96** details the capital cost of installing solar cold storages at 5 percent and 75 percent adoption rates in the three regions.

FIGURE 96.

ESTIMATED INVESTMENT COSTS OF INSTALLING SOLAR COLD STORAGES AT LAR (5 PERCENT) AND HAR (75 PERCENT) (USD)



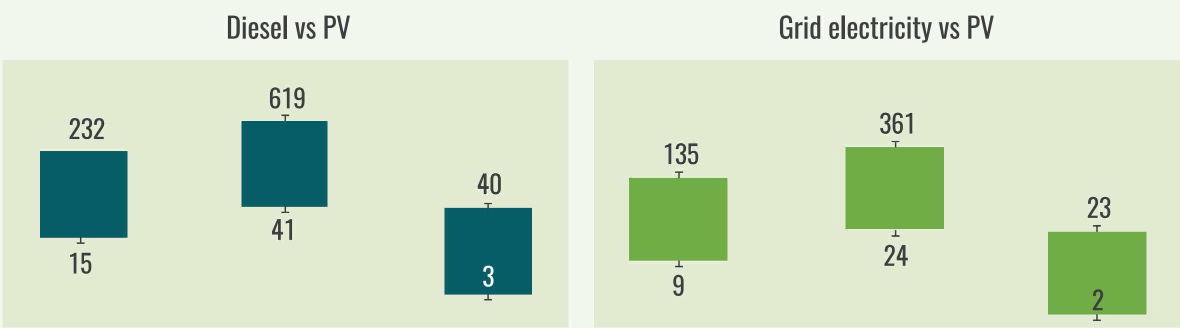
Source: Authors' own elaboration.

The results suggest that Kashkadarya has the largest potential to install solar cold storages, followed by the Republic of Karakalpakstan and Khorezm respectively. In Kashkadarya, the investment requirement in solar cold storages can range from USD 3.39 million to USD 50.78 million.

In terms of the GHG emissions reduction potential for using solar cold storage as opposed to diesel powered cold storage can result in a GHG reduction of between 3 tonnes CO_2 eq/year (in Khorezm at a 5 percent adoption rate) to 619 tonnes CO_2 eq/year (in Kashkadarya at a 75 percent adoption rate). Additionally, using solar cold storage as opposed to grid electricity powered cold storage can result in a GHG reduction of between 2 tonnes CO_2 eq/year (in Khorezm at a 5 percent adoption rate) to 361 tonnes CO_2 eq/year (in Kashkadarya at a 75 percent adoption rate). See **Figure 97**.

FIGURE 97.

GHG REDUCTION POTENTIAL OF USING SOLAR PV COLD STORAGE AS OPPOSED TO DIESEL AND GRID CONNECTED COLD STORAGES (tonnes CO_2 eq/year)



Source: Authors' own elaboration.

6.4 RENEWABLE ENERGY-BASED PROCESSING

Once the horticulture produce is harvested and is stored it can then be exported, sold on the domestic market or can be processed into higher value products. In the case of melons and tomatoes, while melons are mainly exported raw and there is no value addition, tomatoes can be processed into several high value products including juice, and canned tomato. The processing capacity of horticulture products is currently limited in Uzbekistan. There are 277 processing companies that process 17.6 percent of all horticultural products produced in the country (ADB, 2019a). However, in the future the government expects the share of the food processing to reach 24.8 percent. Currently, 50 percent of the processing companies are concentrated in Fergana, Samarkand, and Tashkent provinces (ADB, 2019).

Limited data is available on what share of tomatoes are currently processed into higher value products. Nevertheless, given that there are limited processing infrastructures in the three regions, it might be productive to increase processing capacity in the three regions. Furthermore, due to the lack of official targets for tomato processing and given that on a national scale scarcely over 15 percent of the agricultural products are processed, the analysis assessed the energy demand at 15 percent of the tomatoes produced to be processed into tomato juice, paste and canned tomato. Based on this assumption, **Table 42** details the target tomato processing capacity for each of the three districts.

TABLE 42.

TARGETED TOMATO PROCESSING QUANTITY (15 PERCENT OF PRODUCED)

REGION	TARGETED TOMATOES PROCESSED (tonnes/year)
KARAKALPAKSTAN	14 612
KASHKADARYA	4 602
KHOREZM	4 284

Source: Authors' own elaboration.

Furthermore, to estimate the total quantity of the canned tomato, tomato paste and tomato juice that could be produced, the standard conversion factors were used which are detailed in **Table 43**.

TABLE 43.

CONVERSION FACTORS USED FOR THE ANALYSIS

CONVERSION	CONVERSION FACTOR
kg TOMATO PASTE/kg FRESH TOMATO	0.14
kg TOMATO JUICE/kg FRESH TOMATO	0.55
kg CANNED TOMATO/kg FRESH TOMATO	0.87

Source: Adapted from: Aqua-calc. 2021. Density of TOMATO PASTE, UPC: 822356000868 (food) [online]. [Cited 8 April 2021]. *https://www.aqua-calc.com/page/density-table/substance/tomato-blank-paste-coma-and-blank-upc-column--blank-822356000868*

FineCooking. *2021. Substituting canned tomatoes for fresh [online].* [Cited 12 April 2021]. *https://www.finecooking.com/article/substituting-canned-tomatoes-for-fresh*

Table 44 defines the target quantity of the three processed products that can be made from tomato in the three regions by combining the data in **Table 42** and **Table 43**.

TABLE 44.

TARGET QUANTITY FOR TOMATO PASTE, JUICE, AND CANNED TOMATOES IN THE THREE REGIONS

REGION	TOMATO PASTE/year (tonnes)	TOMATO JUICE/year (tonnes)	CANNED TOMATO/year (tonnes)
KARAKALPAKSTAN	2 008	8 030	12 775
KASHKADARYA	632	2 529	4 024
KHOREZM	589	2 354	3 746

Source: Authors' own elaboration.

In addition to estimating the target quantity of final processed products, the analysis also uses the energy required to process raw tomatoes per unit into the final product. The energy requirement is detailed in **Table 45**.

TABLE 45.

ENERGY REQUIREMENT TO PROCESS RAW TOMATO INTO RESPECTIVE PROCESSED PRODUCTS

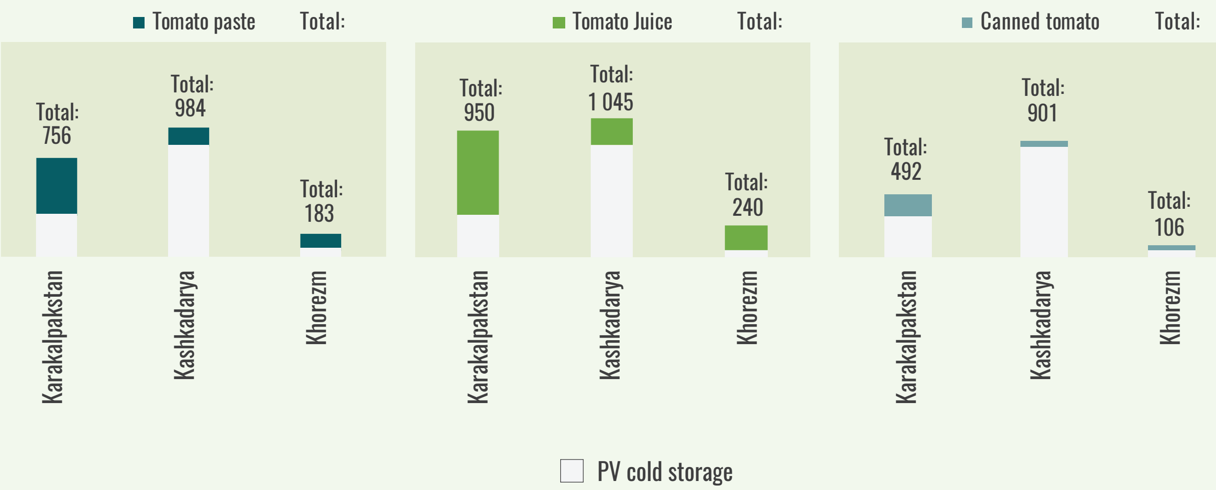
PARAMETER	TOMATO PASTE	TOMATO JUICE	CANNED TOMATO	UNIT
ELECTRICITY DEMAND	30	43	12	kWh/tonne FRESH TOMATO
OPERATING HOURS/day	11	11	11	hours/day
OPERATING HOURS/year	2 882	2 882	2 882	hours/year

Source: Adapted from Sustainable Agriculture Research & Education Program. 2021. Environmental Impacts of California Tomato Cultivation and Processing [online]. [Cited 12 April 2021]. *https://sarep.ucdavis.edu/are/energy/tomatoes*

Subsequently, **Figure 98** exhibits the total final energy demand to produce the three processed products in the three regions based on the data detailed in **Table 43**, **Table 44**, and **Table 45**.

FIGURE 98.

TOTAL ELECTRICITY DEMAND TO PRODUCE THE THREE PROCESSED TOMATO PRODUCTS (1 000 kWh/year)

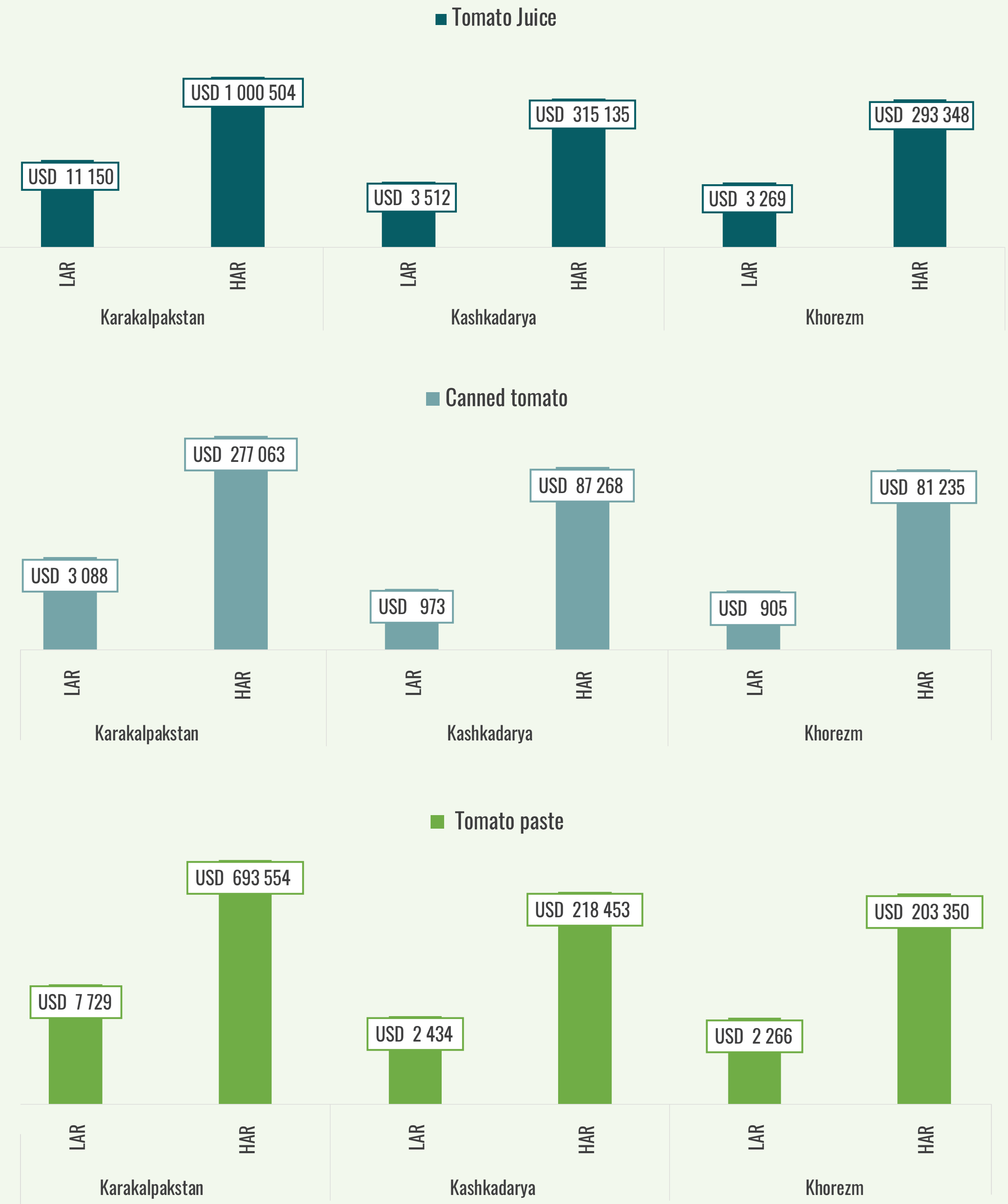


Source: Authors’ own elaboration.

Furthermore, not all of the processing facilities are destined to be powered by solar PV systems; some facilities will be powered by grid electricity. To account for this fact, the analysis used a range of adoption rates to estimate the capital cost of using solar PV systems to power processing machinery. A range of 5 to 75 percent was used in the analysis. A 5 percent adoption (LAR) rate in this case means that 5 percent of the factories producing the processed products are powered by solar PV systems, while an adoption rate of 75 percent (HAR) signifies that 75 percent of the factories producing the processed products are powered by solar PV systems. Based on these scenarios, **Figure 99** estimates the total investment required to use PV systems to process tomatoes into the three products under both high a low adoption rate.

FIGURE 99.

CAPITAL COSTS ESTIMATES TO USE SOLAR PV SYSTEMS TO POWER PROCESSING OPERATIONS (USD)

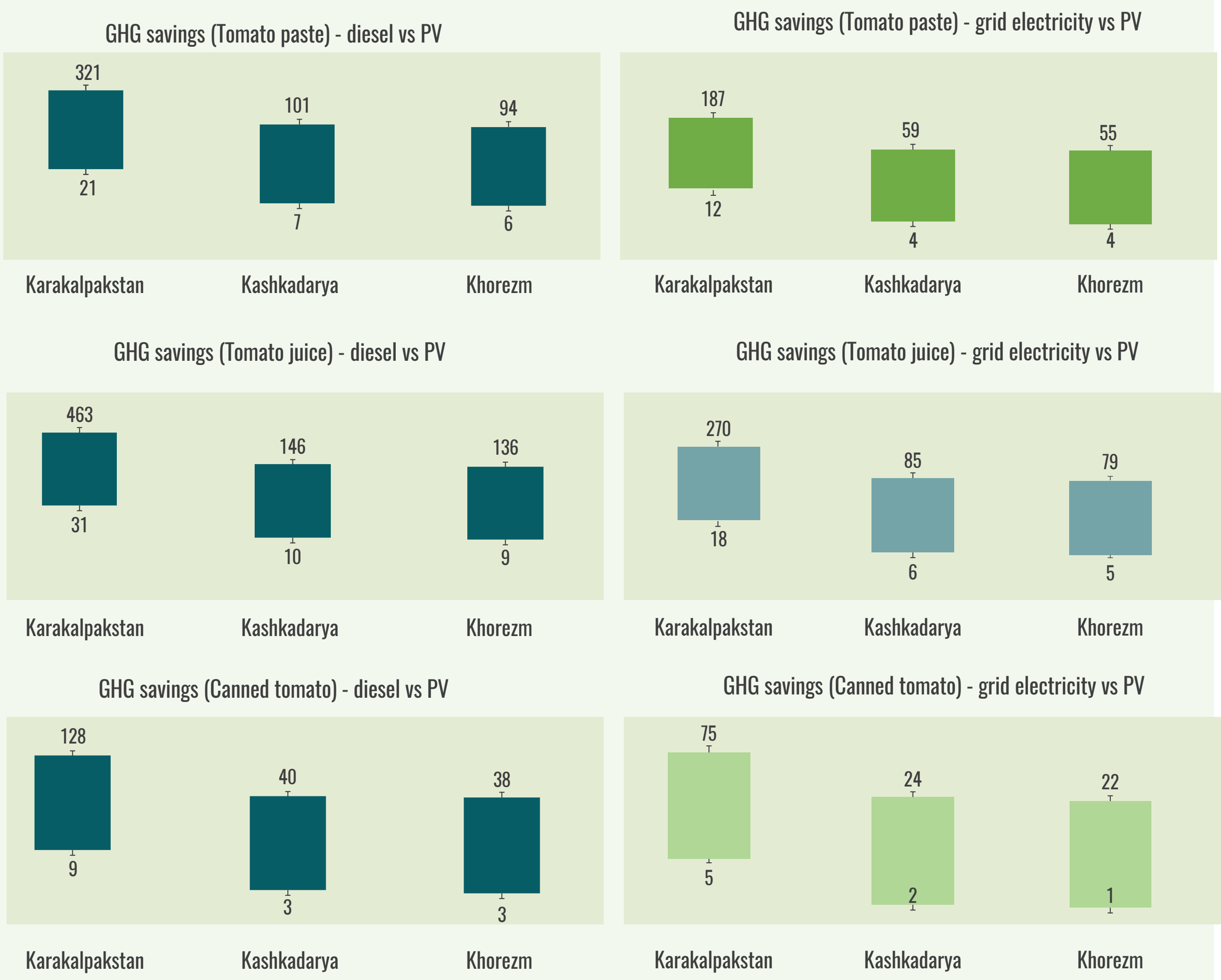


Source: Authors' own elaboration.

While the processing facilities can be powered with different energy sources, the use of solar PV has the additional benefit of minimizing GHG emissions. Generally, the GHG emission reduction potential is higher when PV systems are used to replace diesel powered facilities. However, substantial GHG savings can also be achieved by replacing grid connected systems with solar PV as shown in **Figure 100**.

FIGURE 100.

GHG REDUCTION POTENTIAL OF USING SOLAR PV AS OPPOSED TO DIESEL GENERATORS AND GRID ELECTRICITY (tonnes CO_2 eq/year)



Source: Authors' own elaboration.

6.5 SUMMARY

By combining the results of all energy interventions along the horticulture value chain, the aggregate results provide the potential to use renewable energy along the whole chain.

The main interventions assessed along the horticulture chain were:

- **a.** Energy for cold storage
- **b.** Energy for processing of horticulture products (canned tomato, to produce tomato paste and tomato juice).

Dehkan farmers account for 90 percent of the total horticulture production in the country. Therefore, this analysis focused on the quantity of melons and tomatoes that are produced by dehkan farmers. The remaining 10 percent is produced by large private farms, and it is assumed that they already have access to modern cold storage facilities. Solar powered cold storages – decentralized storage units that are powered by solar power – are small. On average the capacity of these cold storage is 164 tonnes/year. Assuming that the cold storage will work all year-round and on a 24-hour basis, horticulture products would need to be stored a total of 8 760 hours.

Not all the horticulture produce available in the three regions will be stored in solar cold storages. Some produce will be sold fresh while other produce will be stored in traditional grid connected cold storages or processed into value added products. To account for this, the analysis estimates the capital cost of installing solar cold storages at a 5 percent and a 75 percent adoption rate. A 5 percent adoption rate implies that only 5 percent of the needed cold storages are powered by solar PV while a 75 percent adoption rate implies that 75 percent of the cold storages needed are solar cold storages.

The results of the assessment show that the potential to use solar cold storage can range from USD 218 852 (low adoption rate in Khorezm) to USD 50 783 487 (high adoption rate in Kashkadarya). Kashkadarya has the largest potential to install solar cold storages, followed by the Republic of Karakalpakstan and Khorezm respectively. Furthermore, using solar cold storages instead of diesel powered or grid connected cold storages can result in GHG savings. Based on the estimated potential to use cold storages, the GHG emissions reduction potential for using solar cold storage as opposed to diesel powered cold storage can result in GHG savings between 3 tonnes CO_2 eq/year (in Khorezm at a 5 percent adoption rate) to 619 tonnes CO_2 eq/year (in Kashkadarya at a 75 percent adoption rate). Using solar cold storage as opposed to grid electricity powered cold storage can result in a GHG reduction of between 2 tonnes CO_2 eq/year (in Khorezm at a 5 percent adoption rate) to 361 tonnes CO_2 eq/year (in Kashkadarya at a 75 percent adoption rate).

In addition to cold storages, the assessment of horticulture chain also included the possibility of using renewable energy at the processing stage of the chain. Tomato is a major horticulture product in the regions and given that there are limited processing infrastructures in the three regions, it might be productive to increase processing capacity. However, due to the lack of official targets for tomato processing and given that on a national scale scarcely over 15 percent of the agricultural products are processed, the analysis assessed the energy demand at 15 percent of the tomatoes produced to be processed into tomato juice, paste and canned tomato. The assessment first estimated the energy demand for processing these products and then the total capital investment required to use PV as the energy source of power for the processing operations. Furthermore, not all of the processing facilities are destined to be powered by solar PV systems; some facilities will be powered by grid electricity. To account for this fact, the analysis used a range of adoption rates to estimate the capital cost of using solar PV systems to power processing machinery. A range of 5 to 75 percent was used in the analysis. A 5 percent adoption (low adoption rate, LAR) rate in this case means that 5 percent of the factories producing the processed products are powered by solar PV systems, while an adoption rate of 75 percent (high adoption rate, HAR) signifies that 75 percent of the factories producing the processed products are powered by solar PV systems.

The results suggest that for tomato juice production, the capital investment needs to use solar energy to power the processing operation can range from USD 3 269 (at 5 percent adoption rate in Khorezm) to USD 1 000 504 (at 75 percent adoption rate in the Republic of Karakalpakstan).

For canned tomato, the results suggest that the capital investment needed to use solar energy to power the processing operation can range from USD 905 (at 5 percent adoption rate in Khorezm) to USD 277 063 (at 75 percent adoption rate in the Republic of Karakalpakstan). Similarly, to produce tomato paste, the capital investment needed to use solar energy can range from USD 2 266 (at 5 percent adoption rate in Khorezm) to USD 693 554 (at 75 percent adoption rate in the Republic of Karakalpakstan).

CHAPTER

7

RENEWABLE ENERGY INTERVENTIONS IN THE DAIRY CHAIN

7.1 DAIRY CHAIN

Livestock is an important agriculture subsector in Uzbekistan, and contributes 40 percent of the gross agricultural output. Most production comes from 4.7 million small dehkan farms who own 95 percent of the cattle. Any intervention that can improve the livestock sector will have a big impact on dehkan farmers, as they are responsible for 95 percent of meat and 96 percent of the milk production. Dehkans produce most of the milk and are also the main marketers of milk, selling 85 percent of the milk in the country (IFAD, 2015). This is of significant importance and implies that the value chain of milk is not composed of modern aggregators but is controlled and managed by small dehkan farmers. Average cow milk yields within dehkan farms rarely exceed 8 kg per day with lactation periods of merely 7 months. Similar to the national pattern, in the three study regions most of cattle are owned by dehkan farmers (IFAD, 2015). Khorezm has the most cattle of the three regions followed by Kashkadarya and the Republic of Karakalpakstan. **Table 46** details the distribution of cattle heads in the three regions by type of farms.

TABLE 46.

NUMBER OF CATTLE IN EACH REGION

REGION	NUMBER OF HEADS IN COMMERCIAL FARMS	NUMBER OF HEADS IN DEHKAN FARMS
KARAKALPAKSTAN	22 858	298 046
KASHKADARYA	31 951	498 330
KHOREZM	41 492	994 281
TOTAL IN ALL PROVINCES	96 301	1 790 657

Source: Republic of Uzbekistan. 2020. Open data portal. Cited 15 April 2021. https://data.gov.uz/en

Based on the cattle heads in the three regions detailed in **Table 46**, the analysis further estimated the total milk produced in the three regions by both small dehkan farmers and by commercial farms. On average, a cow produces around 8 kg of milk every day and the lactating period is around 7 months in a year. The results are depicted in **Table 47**.

TABLE 47.

MILK PRODUCED BY CATTLE IN THE THREE REGIONS BY DEHKAN FARMERS

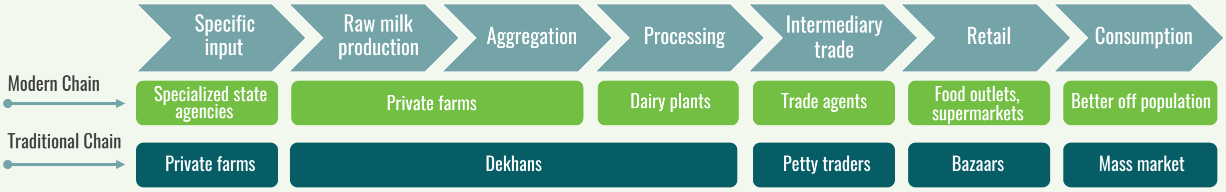
REGION	DAILY PRODUCTION (kg milk/day)	ANNUAL PRODUCTION (tonnes/year)
KARAKALPAKSTAN	22 858	298 046
KASHKADARYA	31 951	498 330
KHOREZM	41 492	994 281

Source: Authors' own elaboration based on consultations with national experts and data from IFAD. 2015. Dairy value chain development program- Design completion report. Rome. https://webapps.ifad.org/members/eb/115/docs/EB-2015-115-R-14-Project-design-report.pdf

Once the milk is produced it passes through several steps before reaching the final consumers. In Uzbekistan, two parallel chains exist: the first is the small scale traditional dehkan value chain where most of the milk is produced and traded. In this chain the dehkan farmers produce most of the milk, which is sold to petty traders who then sell the milk in small bazaars. This value chain controls around 85 percent of the milk produced in the country. The second chain is a more modern chain where large private farms produce milk, which is then either sold to the urban markets directly or is subsequently processed into higher value products such as UTH milk.

FIGURE 101.

DAIRY VALUE CHAINS IN UZBEKISTAN



Source: IFAD. 2015. Dairy value chain development programme. Design completion report. Rome. https://webapps.ifad.org/members/eb/115/docs/EB-2015-115-R-14-Project-design-report.pdf

7.2 ENERGY INTERVENTIONS IN THE DAIRY CHAIN

Based on distinct characteristics of the dairy chain depicted in **Figure 101**, the analysis identified two main energy interventions in the dairy value chains. Milk is a highly perishable commodity that needs to be cooled to around four degrees (4°C) as soon as it has been extracted to ensure quality. Therefore, given that the traditional dairy chain controls the majority of the milk produced, which is sold in small bazaars, the analysis identified the potential to use small scale solar milk chillers that can keep the milk cold and fit for consumption. Furthermore, milk chillers come in different sizes that are suitable to be deployed at the village level as well as the markets. At the village level, small 20 litre milk chillers can be used for milk cooling and farmers can keep it cool before transport to the market. At the bazaars where larger quantities of milk need to be cooled, a mid-sized chiller of 165 litre can be used (see **Table 48**).

TABLE 48.

TECHNICAL DETAILS OF THE 2 INTERVENTIONS ANALYSED

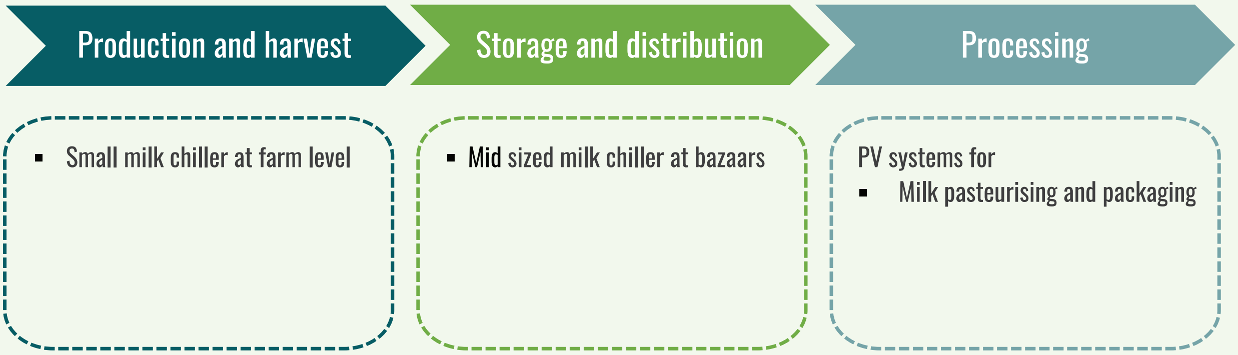
INTERVENTION	CAPACITY (liters)	COST (USD)
FARM LEVEL MILK CHILLER	20	515
MILK CHILLER AT BAZAARS	165	1 619

Source: SunDanzer. 2021. Solar refrigerators and freezers [online]. [Cited 12 March 2021]. https://sundanzer.com/product-category/household/#

In addition to this, for the modern milk chain where milk is produced by private farms and is then either sold or processed, solar energy can be used to pasteurize milk (see **Figure 102**). This intervention requires that solar PV systems be installed in pasteurization factories to produce electricity that can then power the pasteurization process.

FIGURE 102.

INTERVENTIONS ANALYSIS FOR DAIRY VALUE CHAIN



Source: Authors' own elaboration.

7.3 FARM LEVEL CHILLERS

The small farm level milk chiller will need to store 500 717 tonnes in the Republic of Karakalpakstan and 837 194 tonnes in Kashkadarya and 1 670 392 tonnes in Khorezm. Given the quantity to be stored in milk chillers and based on the technical data detailed in **Table 49**, **Figure 103** details the total electricity demand for farm level milk chillers in the three regions.

TABLE 49.

TECHNICAL DATA USED TO ANALYSE FARM LEVEL CHILLER

PARAMETER	VALUE	UNIT
STANDARD CAPACITY	5	tonnes/year
MILK DENSITY	1.03	kg/L
ELECTRICITY CONSUMPTION	21.77	kWh/tonne
STORED HOURS PER YEAR	5 040	h/year

Sources: Mukhiddinov, Q.A., Alimova, D.K., Safarov, J.E., Sultanova, S.A. & Aït-Kaddour, A. 2021. Determination of Protein content in Cheese Products. IOP Conference Series: Earth and Environmental Science, 868(1): 12046. https://doi.org/10.1088/1755-1315/868/1/012046

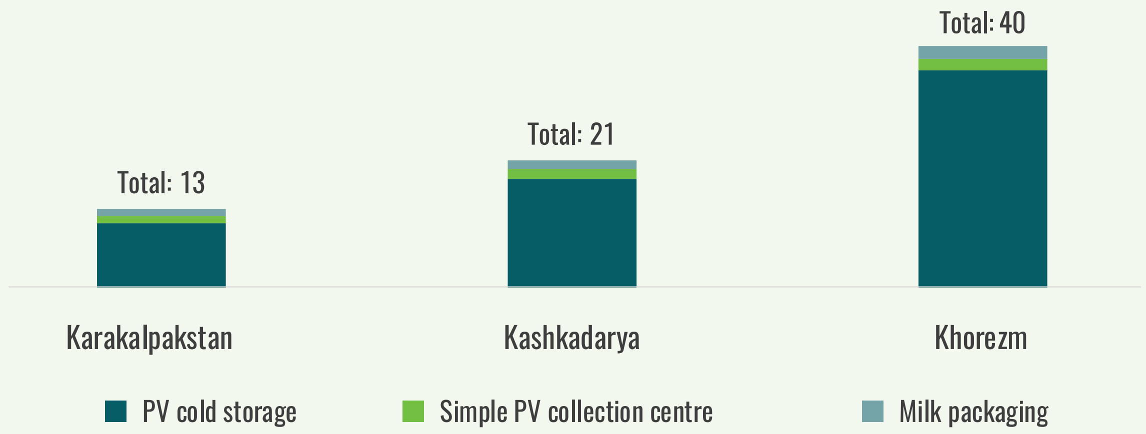
SunDanzer. *2021. Solar refrigerators and freezers [online].* [Cited 12 March 2021]. *https://sundanzer.com/product-category/household/#*

WHO. 2016. E003: Refrigerators and Freezers. Performance Quality Safety, p. 2016 pp.

It is unlikely that all the milk available at the farm level will be stored in the solar milk chillers. Some milk will be sold directly, while some will be stored in a cooling facility powered by other energy sources. To account for this variation, the analysis uses an adoption rate of 5 to 75 percent. An adoption rate of 5 percent would mean that this percentage of chillers needed for cooling the milk at the farm level are powered by solar PV systems; an adoption rate of 75 percent would mean that this percentage of the milk chillers needed for storing milk at the farm level are powered by solar PV systems (see **Figure 104**).

FIGURE 103.

AGGREGATE ELECTRICITY DEMAND FOR FARM LEVEL MILK CHILLERS (MILLION kWh/year)

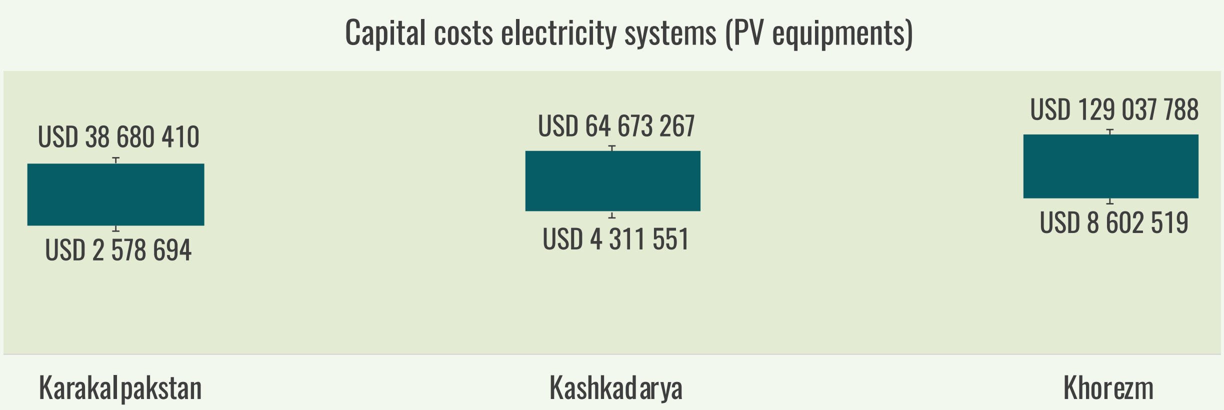


Source: Source: Authors' own elaboration.

Using solar PV systems instead of grid or diesel-powered cooling systems can reduce the GHG emissions caused from chilling of milk (see **Figure 105**). Depending on the adoption rate of the solar milk chillers, the possible GHG reduction when using solar chillers instead of gird connected chillers could range from 310 tonnes CO_2 eq (in the Republic of Karakalpakstan at a 5 percent adoption rate) to 15 516 tonnes CO_2 eq (in Khorezm at a 75 percent adoption rate).

FIGURE 104.

CAPITAL COST OF DEPLOYED SMALLS SCALE SOLAR MILK CHILLERS AT THE FARM LEVEL AT ADOPTION RATES BETWEEN 5 AND 75 PERCENT (USD)

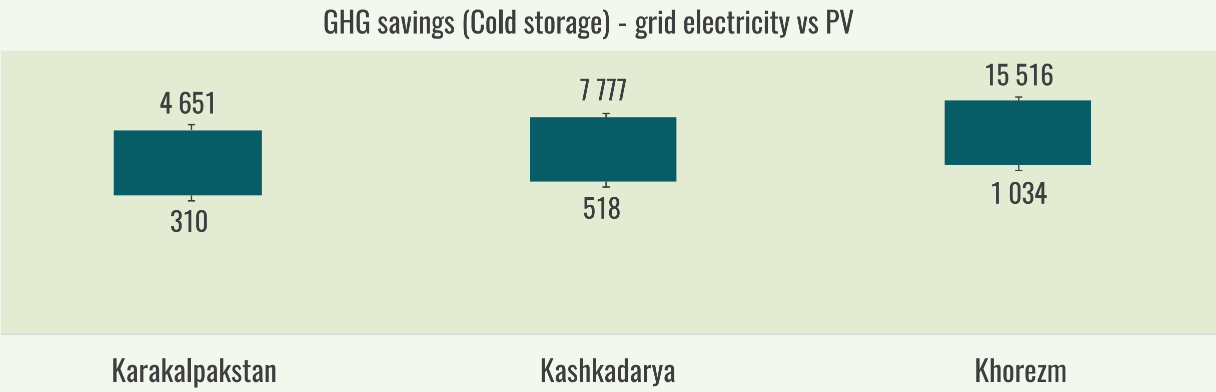


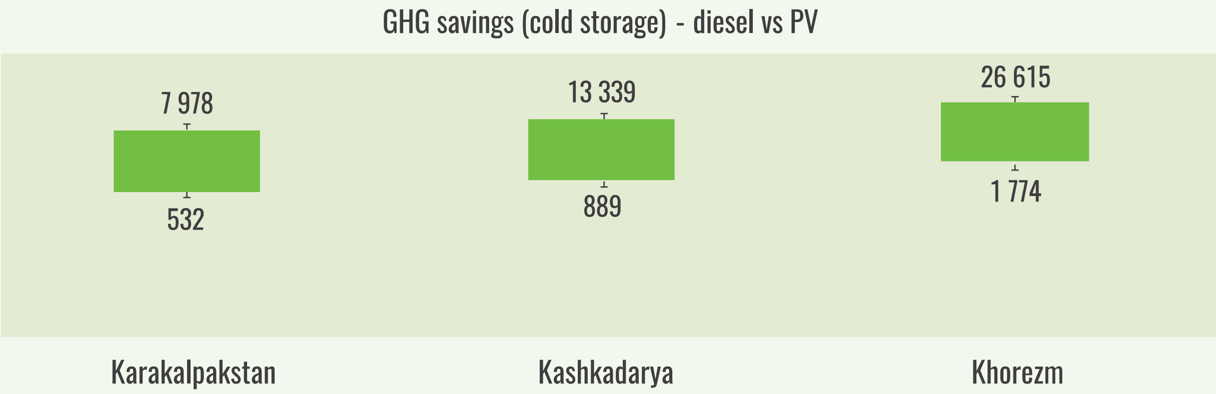
Source: Authors' own elaboration.

The GHG reduction potential is higher when chillers are powered by solar PV instead of diesel power chillers. In this case, the GHG reduction potential can range from 532 tonnes CO_2 eq (in Karakalpakstan at a 5 percent adoption rate) to 26 615 tonnes CO_2 eqv (in Khorezm at a 75 percent adoption rate).

FIGURE 105.

GHG EMISSION REDUCTION POTENTIAL OF USING SOLAR PV CHILLERS INSTEAD OF GRID CONNECTED CHILLERS AND DIESEL-POWERED CHILLERS (tonnes CO_2 eq/year)





Source: Authors' own elaboration.

7.4 MID-SIZED CHILLERS AT BAZAARS

In the traditional value chain, after the milk has been produced in the dehkan farms, it is then transported to the bazaars for sale. Keeping milk cold at the bazaar is also key to reducing milk losses and ensuring the milk is fit for consumption. Given that the milk would be aggregated from the small-scale farmers at the bazaars, the use of a higher capacity milk chiller is envisaged at this stage. From the information received during the technical consultations, it is estimated that 10 percent of the milk produced reaches the bazaars through petty traders, while the remaining is consumed by the dehkan farmers or sold among them.

Based on the total milk produced in the region, **Table 50** estimates the quantity of milk that reaches the bazaars.

TABLE 50.

QUANTITY OF MILK NEEDED TO BE CHILLED IN THE BAZAARS

REGION	tonnes/year
KARAKALPAKSTAN	50 072
KASHKADARYA	83 719
KHOREZM	167 039

Source: Author's estimates based on consultation with national experts.

Once the milk reaches the bazaars, the milk is aggregated and stored before sale to consumers. A solar milk chiller of 165 tonnes/year capacity was used for this analysis. The technical data on which the assessment is based on is shown in **Table 51**

TABLE 51.

TECHNICAL DATA USED FOR ANALYSIS

PARAMETER	VALUE	UNIT
STANDARD CAPACITY	165	tonnes/year
MILK DENSITY	1.03	kg/L
ELECTRICITY CONSUMPTION	21.77	kWh/tonne
STORED HOURS PER YEAR	5 040	h/year

Sources: Mukhiddinov, Q.A., Alimova, D.K., Safarov, J.E., Sultanova, S.A. & Aït-Kaddour, A. 2021. *Determination of Protein content in Cheese Products.* IOP Conference Series: Earth and Environmental Science, 868(1): 12046. *https://doi.org/10.1088/1755-1315/868/1/012046*

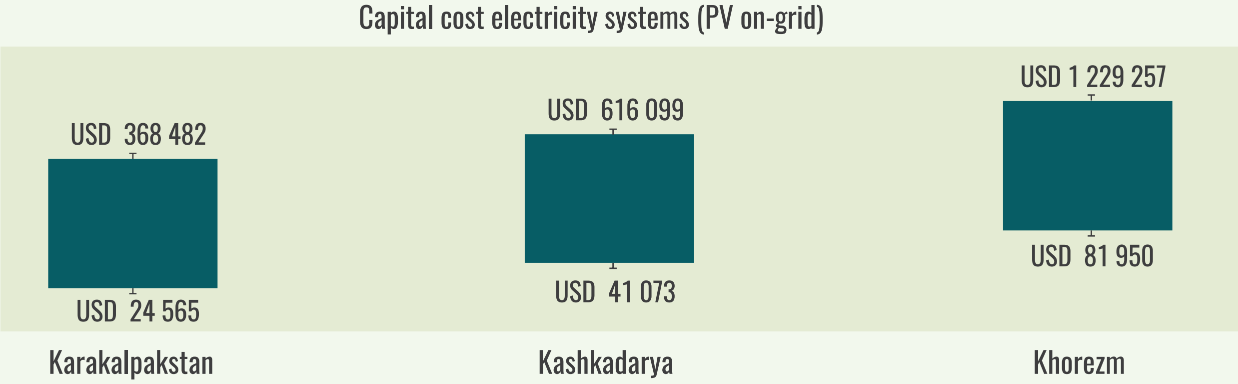
SunDanzer. 2021. Solar refrigerators and freezers [online]. [Cited 12 March 2021]. *https://sundanzer.com/product-category/household/#*

WHO. 2016. E003: Refrigerators and Freezers. Performance Quality Safety, p. 2016 pp.

Figure 106 is based on the data in **Table 50** and **Table 51** and estimates the investment needed to install mid-sized solar milk chillers at the bazaars in the three regions, using adoption rates of 5 and 75 percent. The results suggest that the investment needed could range from USD 24 565 (5 percent adoption rate in the Republic of Karakalpakstan) to USD 1.2 million (75 percent adoption rate in Khorezm).

FIGURE 106.

CAPITAL COST OF DEPLOYED SMALLS SCALE SOLAR MILK CHILLERS IN BAZAARS AT ADOPTION RATES OF 5 AND 75 PERCENT (USD)

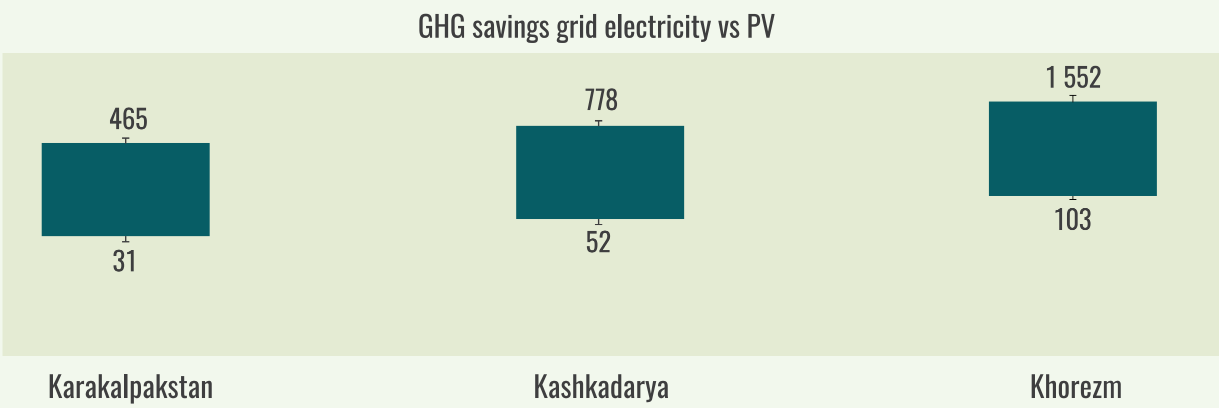


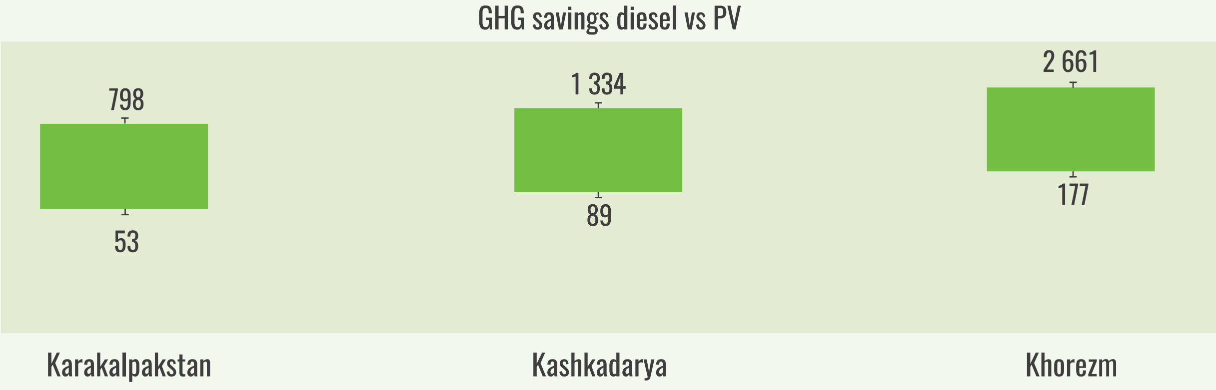
Source: Authors' own elaboration.

As was the case in farm level PV milk chillers, using PV milk chillers at bazaars instead of diesel or grid powered chillers can also reduce GHG emissions. **Figure 107** details the potential reduction in GHG emission from using solar PV milk chillers instead of diesel powered or grid powered chillers. The results suggest that depending on the adoption rate of the solar milk chillers, the possible GHG reduction by using solar chillers instead of gird connected chillers could range from 31 tonnes CO_2 eq (in the Republic of Karakalpakstan at a 5 percent adoption rate) to 1 552 tonnes CO_2 eq (in Khorezm at a 75 percent adoption rate). The GHG reduction potential is higher when chillers are powered by solar PV instead of diesel power chillers. In this case, the GHG reduction potential can range from 53 tonnes CO_2 eq (in the Republic of Karakalpakstan at a 5 percent adoption rate) to 2 661 tonnes CO_2 eq (in Khorezm at a 75 percent adoption rate).

FIGURE 107.

GHG EMISSION REDUCTION POTENTIAL OF USING SOLAR PV CHILLERS AT BAZAARS INSTEAD OF GRID CONNECTED CHILLERS AND DIESEL-POWERED CHILLERS (tonnes CO_2 eq/year)





Source: Authors' own elaboration.

7.5 ELECTRICITY FOR MILK PASTEURIZATION

In addition to milk chilling, processing of milk could be a value-added activity that could be used to further modernize the dairy value chain in the three regions. Pasteurization and packaging of milk is a way to increase the shelf life of milk as well as make it safe for consumption. However, pasteurising milk is an energy intensive process and when powered by fossil fuel can increase GHG emissions from the dairy value chain.

Solar PV systems can be used to power the milk processing factories in the three regions, which can have the dual benefit of value addition in raw milk, as well as reduction in GHG emissions (when compared to grid or diesel-powered processing facilities). However, total energy demands for milk processing and packaging in the regions depend on the installed processing capacity and the share of milk that is processed. **Table 52** presents the share of total milk processes and the corresponding processed milk quantity in each region.

TABLE 52.

SHARE OF MILK PROCESSED IN THE THREE REGIONS

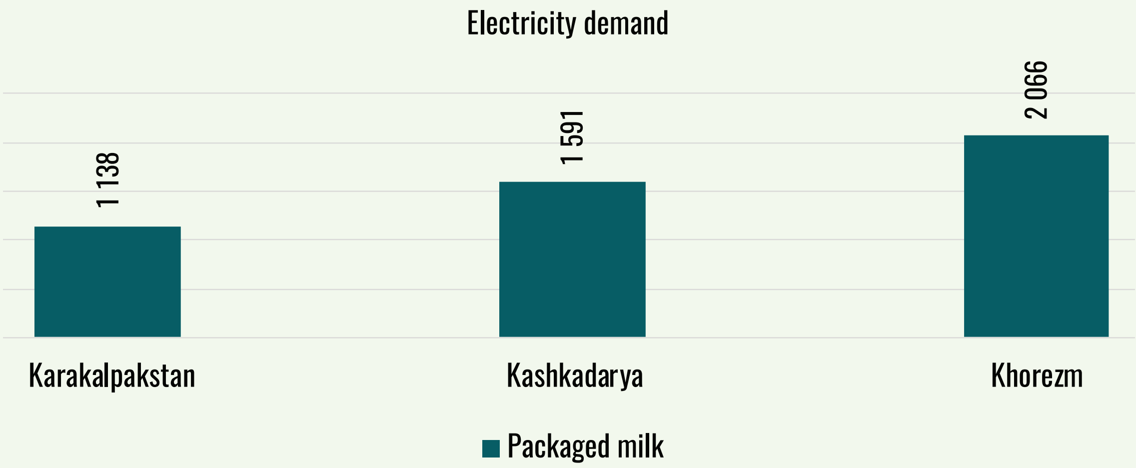
REGION	SHARE OF PROCESSING CAPACITY (%)	SHARE OF PROCESSING CAPACITY (tonnes raw milk/year)
KARAKALPAKSTAN	24%	298 046
KASHKADARYA	33%	31 816
KHOREZM	43%	41 316

Source: Authors' own elaboration based on consultations with national experts and data from IFAD. 2015. Dairy value chain development program- Design completion report. Rome. https://webapps.ifad.org/members/eb/115/docs/EB-2015-115-R-14-Project-design-report.pdf

Based on the data in **Table 52**, the analysis estimated the total electricity demand from processing and packaging milk in each region, as shown in **Figure 108** . Given the large volume of milk produced and processed in Khorezm, it also has the highest electricity demand for milk processing.

FIGURE 108.

ELECTRICITY DEMAND FOR MILK PROCESSING IN THE THREE REGIONS (1 000 kWh/year)



Source: Authors' own elaboration.

The total electricity needed to process and package milk in the three regions can be supplied by various energy sources including solar PV, grid or diesel generators. The analyses focus on the use of solar PV systems to power milk processing factories, in order to estimate the capital cost requirements and potential GHG benefits. Two types of PV systems are analysed. The first is the on-grid systems where PV systems are connected to the grid and therefore no batteries are required for storing the energy on site, while the second is the off- grid system where the processing factories are powered solely by the PV systems and therefore need batteries to store electricity.

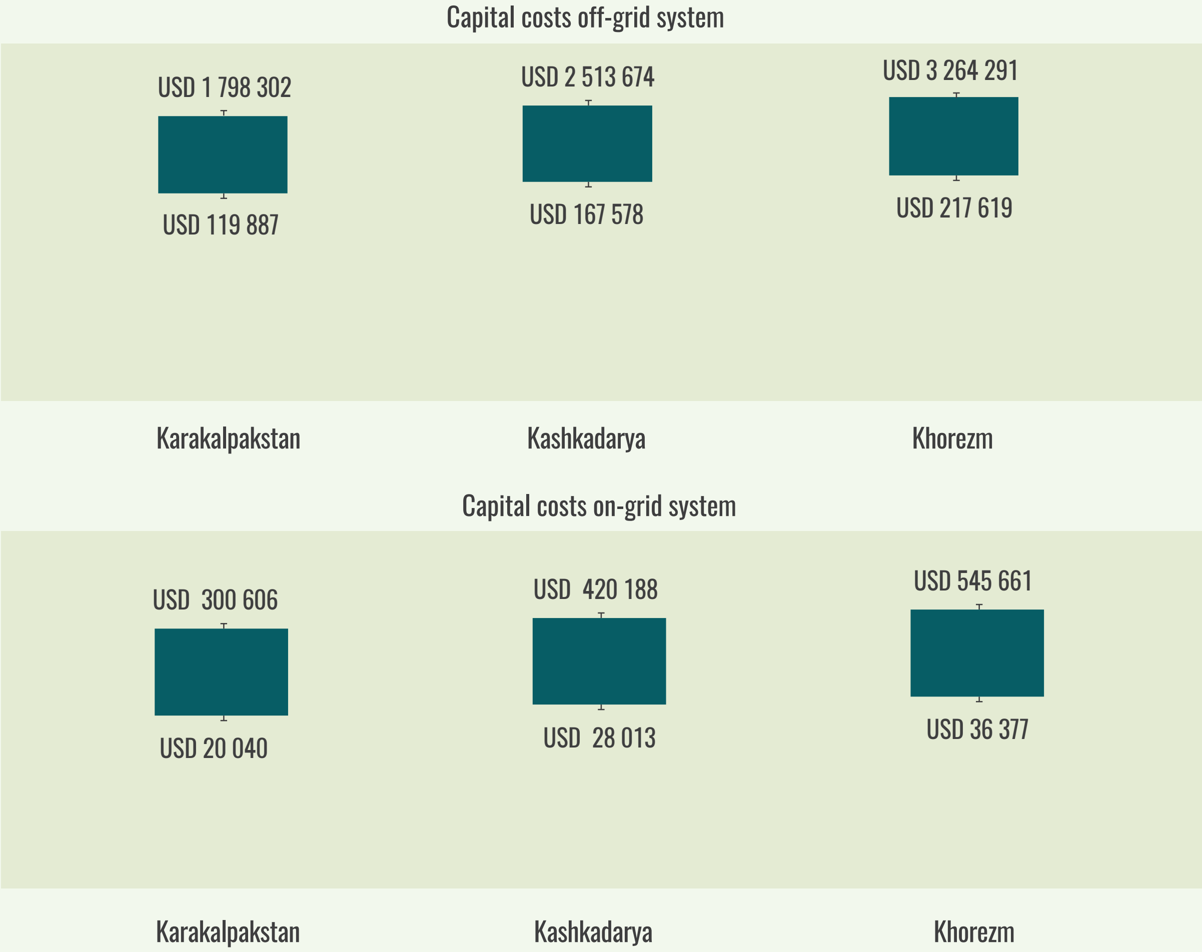
Additionally, it is unlikely that all the milk processing factories will run on PV systems. Given that grid electricity is accessible in most parts of the country, some factories will continue to be powered by the grid. To account for this fact, the analysis uses adoption rate ranging from 5 to 75 percent to estimate the corresponding capital costs of using the PV systems. A 5 percent adoption rate signifies that 5 percent of all processing facilities in the region are powered by solar PV systems, while an adoption rate of 75 percent means that 75 percent of the processing factories are powered by PV systems.

The results presented in **Figure 109** suggest that for off-grid systems the capital costs can range from USD 119 887 (5 percent adoption rate in the Republic of Karakalpakstan) to USD 3 264 291 (75 percent adoption rate in Khorezm). For on-grid systems the investment required is significantly less than off-grid systems since no batteries are needed in on-grid systems. The results for on-grid systems suggest that the investment needed could range from USD 20 020 (5 percent adoption rate in the Republic of Karakalpakstan) to USD 545 661 (75 percent adoption rate in Khorezm). Furthermore, using PV systems as opposed to grid or diesel-powered systems can also help reduce GHG emission from milk processing.

Figure 110 estimates the potential reduction in GHG emissions from using solar PV systems instead of diesel or grid electricity systems. The results indicate that compared to a diesel-powered milk processing facility, a PV powered processing facility can result in a reduction of GHG emission between 55.54 tonnes CO_2 eq per year (at a 5 percent adoption rate in the Republic of Karakalpakstann) and 1 512 tonnes CO_2 eq per year (at a 75 percent adoption rate in Khorezm). When compared to grid powered processing facilities solar PV systems can result in a reduction in GHG emission between 32.38 tonnes CO_2 eq per year (at a 5 percent adoption rate in the Republic of Karakalpakstan) and 881.58 tonnes CO_2 eq per year (at a 75 percent adoption rate in Khorezm).

FIGURE 109.

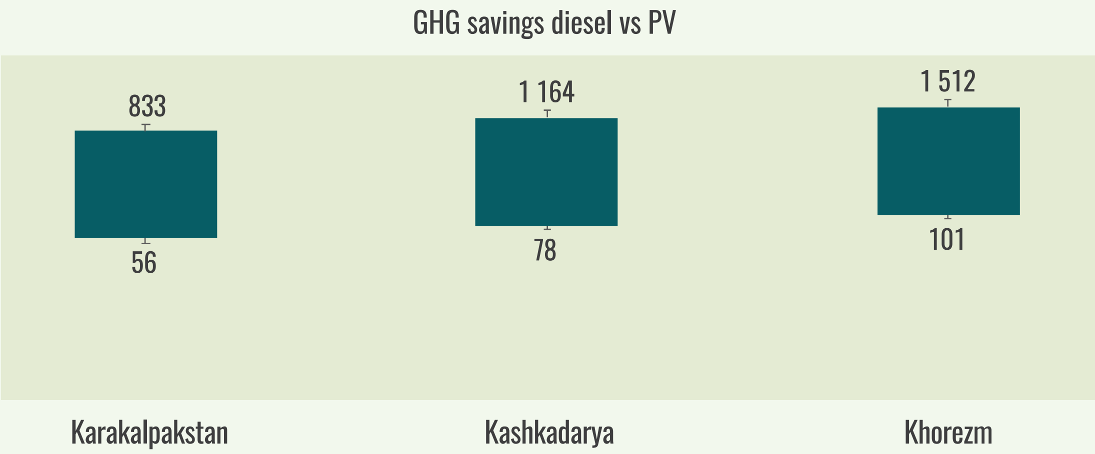
CAPITAL COST OF USING OFF-GRID AND ON-GRID PV SYSTEMS TO POWER MILK PROCESSING FACILITIES BASED ON THE ADOPTION RATES OF 5 AND 75 PERCENT (USD)

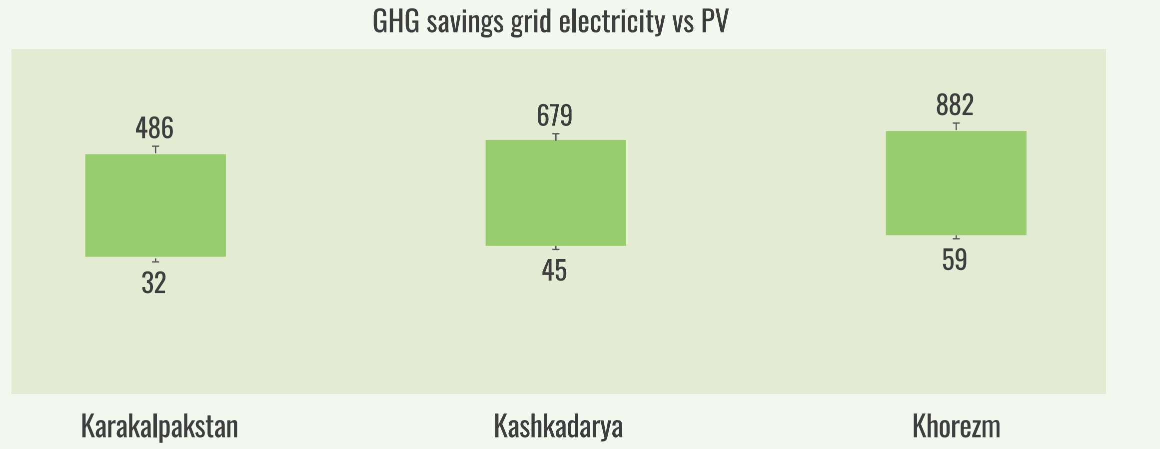


Source: Authors' own elaboration.

FIGURE 110.

GHG EMISSION REDUCTION POTENTIAL (tonnes CO_2 eq/year)





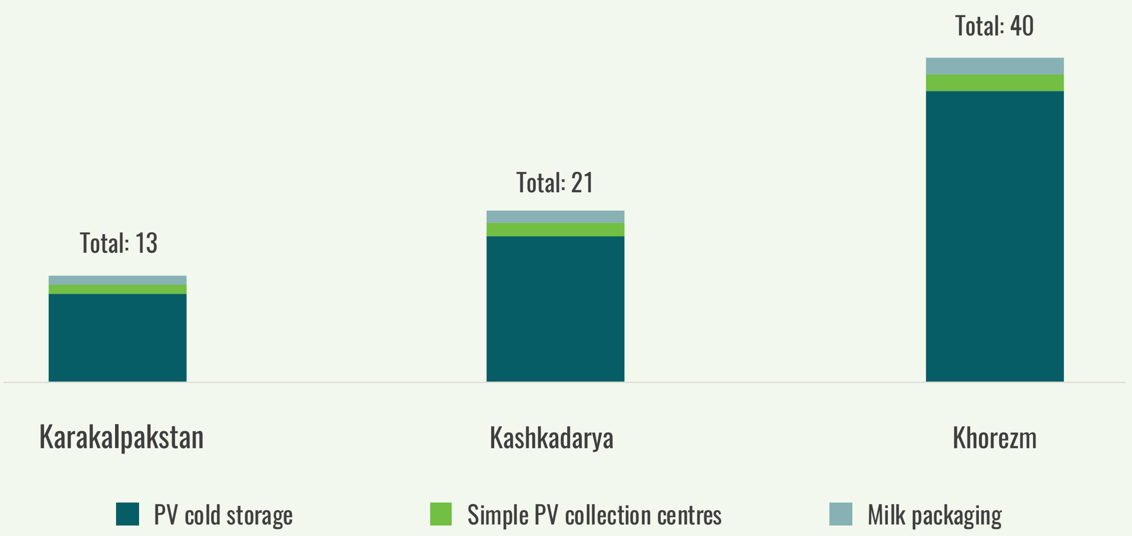
Source: Authors' own elaboration.

7.6 SUMMARY

The dairy value chain is energy intensive and access to dependable and affordable energy can reduce milk losses, support production of higher value products while also offering an opportunity to use sustainable energy. The results for analysis of milk value chain suggest that Khorezm has the highest aggregate energy demand for cooking and processing milk, followed by Kashkadarya and the Republic of Karakalpakstan. See **Figure 111**.

FIGURE 111.

TOTAL ELECTRICITY DEMAND (MILLION kWh/year)

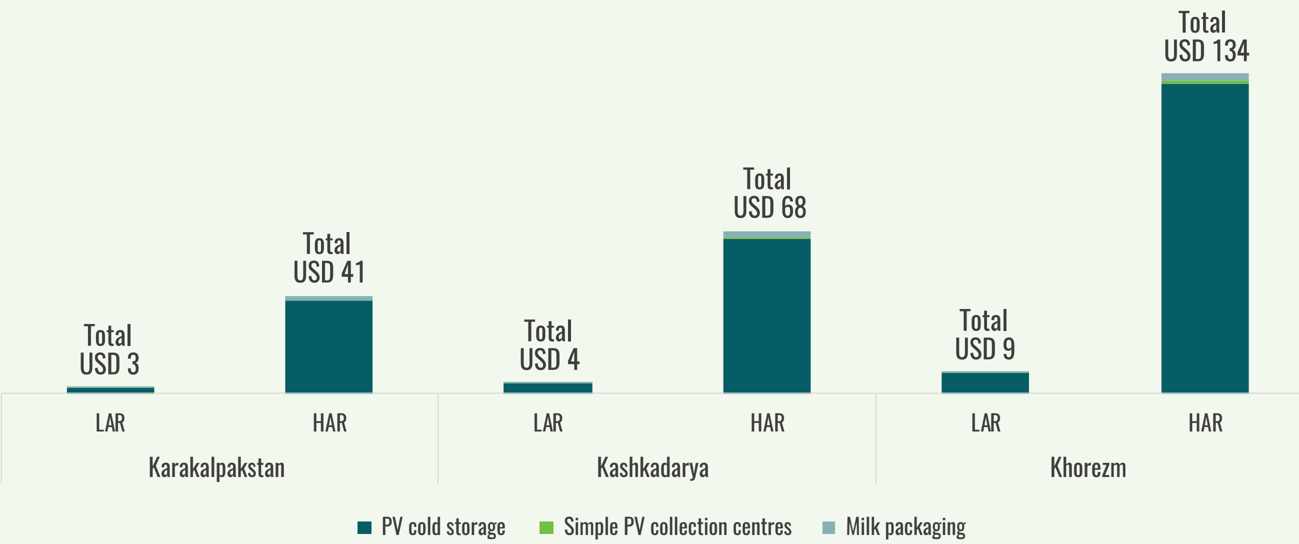


Source: Authors' own elaboration.

Because of the higher energy demand in Khorezm, the highest market potential to deploy solar PV intervention is also the highest in Khorezm. As show in **Figure 112**, depending on the adoption rate of the analysed technologies, the total market size of all three interventions analysed in Khorezm can range from USD 8.72 million (5 percent adoption rate) to USD 134 million (at 75 percent adoption rate).

FIGURE 112.

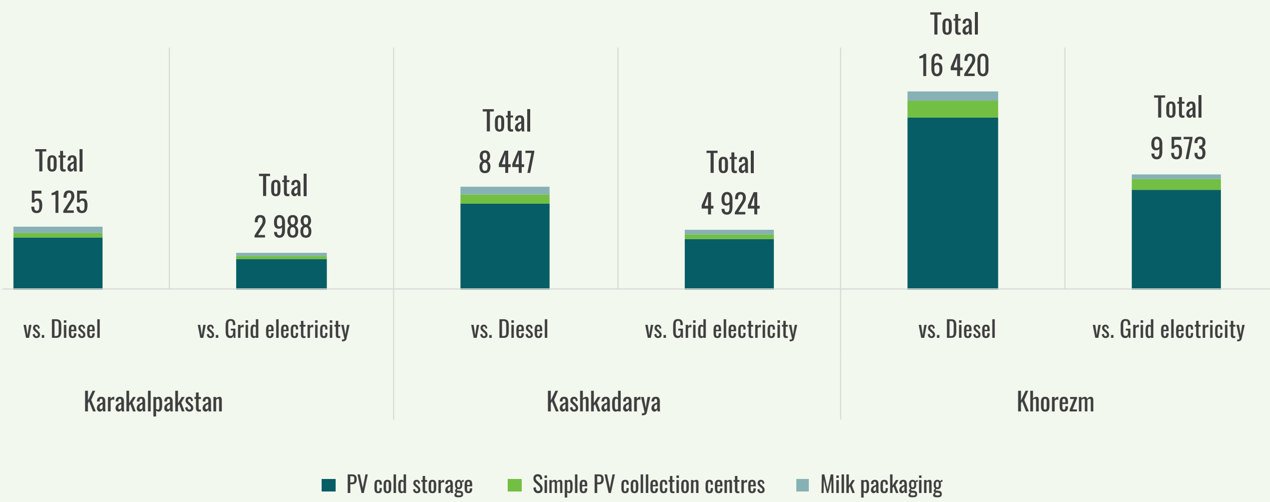
TOTAL MARKET SIZE FOR PV INTERVENTIONS IN MILK VALUE CHAIN (MILLION USD)



Source: Authors' own elaboration.

FIGURE 113.

EMISSION SAVINGS COMPARISON FOR DIESEL AND GRID ELECTRICITY OPTIONS FOR PV INTERVENTIONS IN MILK VALUE CHAIN (tonnes CO_2 eq/year)



Source: Authors' own elaboration.

In **Figure 113**, the analysis suggest that the GHG reduction potential is highest in Khorezm and can range from 9 573 tonnes CO_2 eq/year (when replacing grid electricity) to 16 420 tonnes CO_2 eq/year (when replacing diesel).

CHAPTER

8

CONCLUSIONS

RENEWABLE ENERGY POTENTIAL ASSESSMENT

The analysis of wind and solar potential for electricity generation is based on the publicly available data on wind speed and solar irradiation in Uzbekistan. The utility-level PV solar power plants and wind power plants require relatively large surface areas, and their operation can negatively impact the environment. Land use and biodiversity protection were taken into consideration when assessing sustainable technical potential. Furthermore, since connection to the electricity grid has a direct effect on investment costs of large-scale systems, areas closer to electricity transmission lines were considered preferable for wind and solar power plants. The assessment showed that up to 13 GW of wind power plants could be established within 10 kilometers of existing and/or planned transmission lines, outside of agricultural zones and areas of sensitive biodiversity, in the three study regions.

With the capacity factor ranging between 38 percent and 49 percent (depending on the province), annual electricity production could reach almost 60 TWh. Among the three regions, the Republic of Karakalpakstan has the highest wind potential, and Kashkadarya the lowest. Under the same assumption regarding the siting of solar power plants, and assuming the use of a typical PV solar technology (monofacial crystalline silicon PV modules fixed at optimal tilt angle), the overall sustainable technical potential for installation of solar PV plants in the three regions is higher than 110 GW, with potential annual electricity production of almost 180 TWh.

Of the three study regions, the Republic of Karakalpakstan has the highest sustainable technical potential for PV energy, despite having the lowest level of solar irradiation — this is due to the large land area suitable for solar power plant use. The Kashkadarya region follows, with the highest level of solar irradiation but somewhat limited space suitable for solar power plants. Overall, the analysis showed that the sustainable technical potential of wind energy in the three regions is sufficient to supply 49 percent of the projected national electricity demand in 2030, while solar potential is much stronger, at 148 percent of the projected demand.

In addition to solar and wind, bioenergy potential of unused agricultural residues was assessed. The assessment was based on the national agricultural statistics and technical consultation with experts active in the field of crop production, soil and livestock production. The results showed that the most abundant residue type is cotton stalk. Overall, more than 2.3 million tonnes of cotton stalk are available for energy production. Cotton stalk can be used in production of modern solid biofuels, such as briquettes and pellets, as well as a feedstock for electricity generation. The largest amounts are generated in Kashkadarya, although the amounts in the other two provinces are relatively similar. All three provinces have a significant bioenergy potential from available crop residues, amounting to around 99 thousand TJ per year. Finally, the assessment of the available livestock manure (cattle and poultry) that is easily collected, shows that overall biogas production potential is higher than 25 thousand TJ/year.

RENEWABLE ENERGY IN THE SELECTED AGRI-FOOD CHAINS

The assessment also analysed the potential for renewable energy interventions in the three regions across four agri-food chains: wheat, alfalfa, dairy and horticulture. Renewable energy has the potential to reduce losses, increase efficiency, add value and raise income for farmers.

Two specific types of renewable energy interventions are analysed. Type 1 interventions are stand-alone, decentralized energy systems used to power specific processes within food value chains. Type 2 interventions use local renewable energy systems which can be on- or off-grid

Several interventions were analysed and those with the most promise for scaling up were identified. **Figure 114** details all the interventions (Type 1 and 2) were analysed for each value chain in the three regions.

FIGURE 114.

ALL INTERVENTIONS ASSESSED FOR EACH CHAIN

Wheat

Type 1
- PV irrigation
- Solar mills

Type 2
- PV for grain storage
- PV for flour mills

Alfalfa

Type 1
- PV irrigation

Type 2
- PV for alfalfa storage
- PV for DHR alfalfa pellets
- PV for FHR alfalfa bales

Horticulture

Type 1
- Solar powered cold storages

Type 2
- PV for tomato processing

Dairy

Type 1
- Solar powered milk cold storages
- Simple TV collection centres

Type 2
- PV for packaged milk

Source: Authors' own elaboration.

Images source:

Paul. 2009. *Wheat. In: Flickr. Cited 15 June 2022. https://www.flickr.com/photos/w9ned/3623814756*

Kevin Casper. *n.d. Alfalfa Crop Farm. In: Public Domain Pictures. Cited 15 June 2022. https://www.publicdomainpictures.net/es/view-image.php?image=91564&picture=alfalfa-crop-farm*

Tomia. *2006. Melon-slice. In: Wikimedia Commons. Cited 15 June 2022. https://commons.wikimedia.org/wiki/File:Melon-slice.jpg*

Alabama Farmers Federation. *2011. Dairy. In: Flickr. Cited 15 June 2022. https://flic.kr/p/feRk7C*

The possible renewable energy interventions for the selected value chains technologies differ by complexity of installation, maintenance and management of the systems, investment needed and immediate benefits. **Figure 115** summarizes the actual interventions that combine ease of implementation (low complexity, easy to source, etc.) with those best suited to the current context.

FIGURE 115.

SELECTED INTERVENTIONS ALONG EACH VALUE CHAIN

Wheat

Type 1

- PV irrigation
- Solar mills

Alfalfa

Type 2

- PV for DHR alfalfa pellets

Horticulture

Type 1

- Solar powered cold storages

Dairy

Type 1

- Solar powered milk cold storages

Source: Authors' own elaboration.

Images source:

Shree Krishna Dhital. 2013. Wheat Plants. In: Wikimedia Commons. Cited 14 June 2022. https://commons.wikimedia.org/wiki/*File:Wheat_Plants.JPG*

Andreas Rühle. 2008. Pellets for Rabbits. In: Wikimedia Commons. Cited 14 June 2022. https://commons.wikimedia.org/wiki/*File:Pellets_for_Rabbits.jpg*

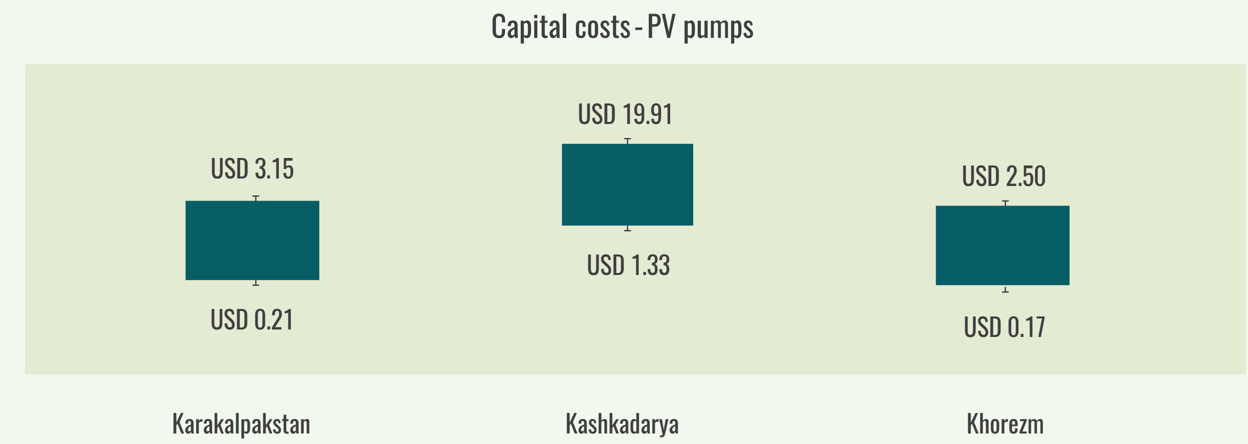
Ministry of environment-Rwanda. *2019. Visit to InspiraFarms Cold Rooms Facility - Kigali Amendment Celebration. In: Flickr. Cited 27 July 2022. https://www.flickr.com/photos/98168367@N06/46921403871*

Berrakmakine. 2012. Milk cooling tank. In: Wikimedia Commons. Cited 27 July 2022. https://commons.wikimedia.org/wiki/*File:BERRAK_500_lt_S%C3%BCt_So%C4%9Futma_Tank%C4%B1.JPG*

Under the wheat value chain, solar irrigation and mills can bring several benefits. Solar PV water pumps can increase irrigation and reduce strain on aging infrastructure. As show in **Figure 116**. The capital cost of installing PV pumps is highest in the Kashkadarya region, ranging from USD 1.33 million (5 percent adoption rate) to USD 19.91 million (75 percent adoption rate). This is followed by the Republic of Karakalpakstan (USD 0.21 million–USD 3.15 million) and Khorezm (USD 0.17 million–USD 2.5 million).

FIGURE 116.

INVESTMENT RANGE FOR PV PUMPS IN WHEAT VALUE CHAIN (MILLION USD)



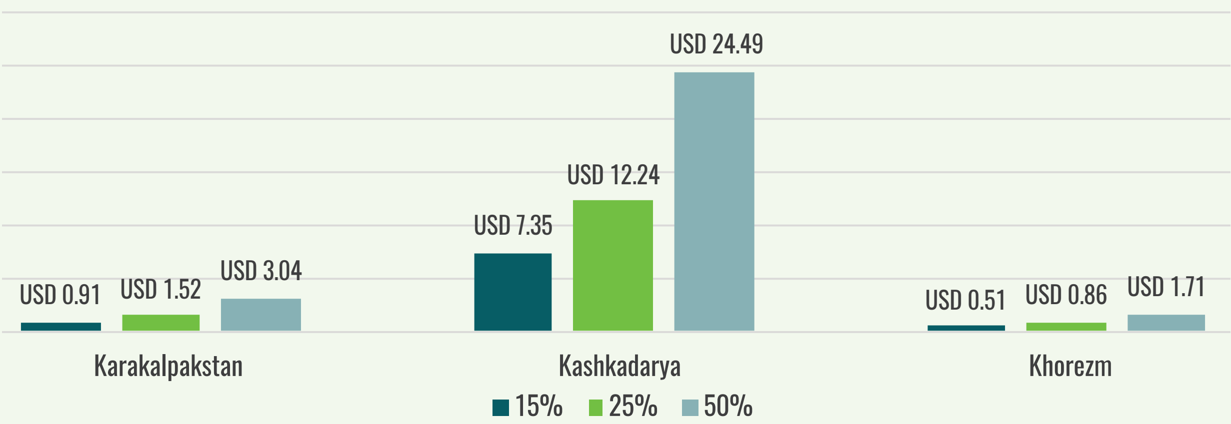
Source: Authors' own elaboration.

The replacement of old and inefficient diesel and electric powered pumps also brings a potential reduction in GHG emissions.

Solar PV mills also have GHG reduction potential, and provide the opportunity to process wheat closer to where the crop is grown. As presented in **Figure 117**, Kashkadarya has the most potential to deploy small-scale solar PV mills. The need for investment is highest in Kashkadarya, ranging from USD 7.35 million to USD 24.49 million, followed b ythe Republic of Karakalpakstan (USD 0.91 million to USD 3.04 million) and Khorezm (USD 0.51 million to USD 1.71 million).

FIGURE 117.

INVESTMENT RANGES FOR INSTALLING SOLAR PV MILLS IN THE THREE REGIONS (MILLION USD)

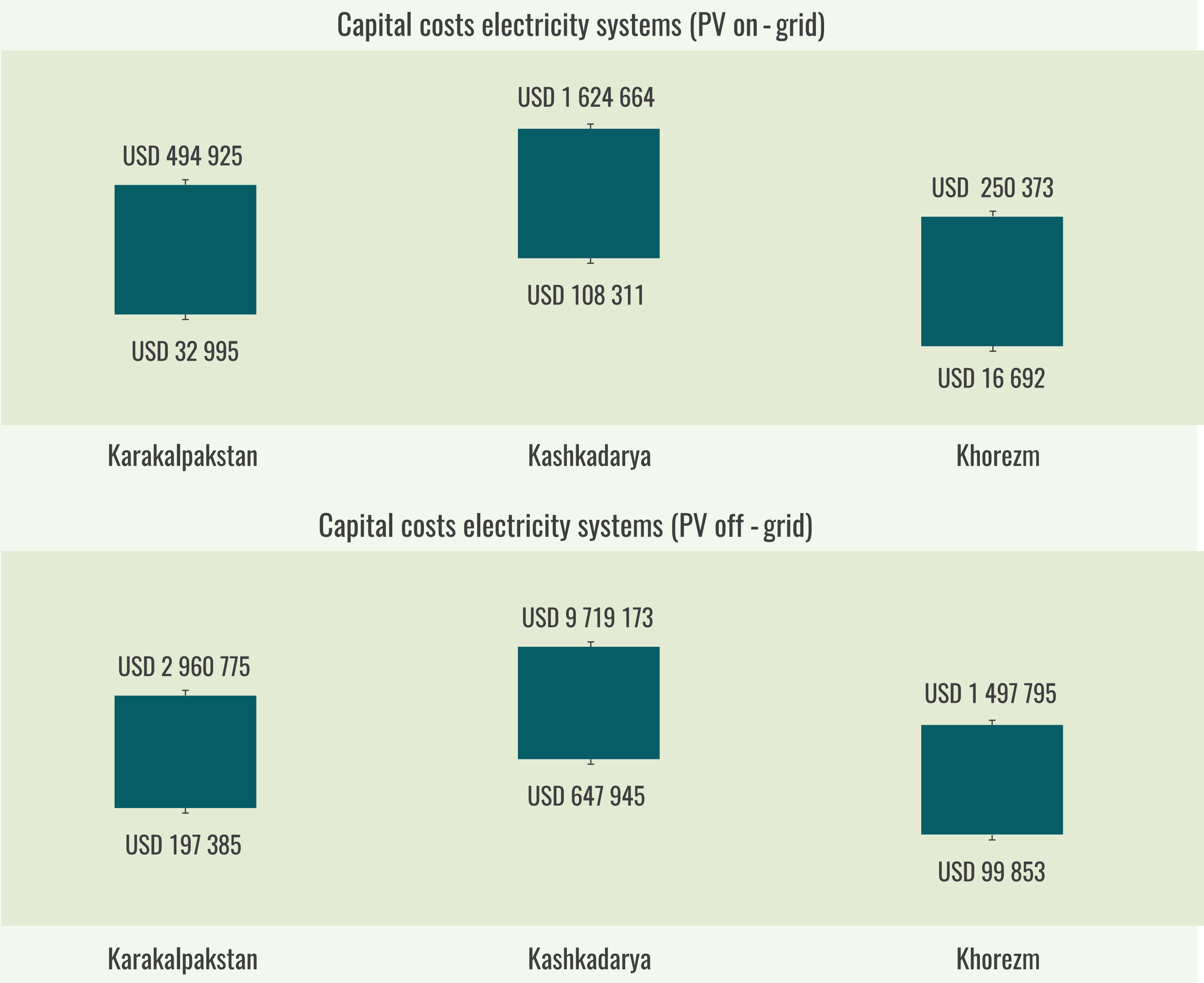


Source: Authors' own elaboration.

Alfalfa is a perennial legume known for its high nutritional value and is a major source of feed for livestock (which is in short supply in Uzbekistan). However, transport is expensive because of its bulky nature. Dehydrating and pelletizing alfalfa can reduce transport costs. Additionally, pelletizing can allow the addition of nutrients, creating a value-added product. The pelletizing process can be either grid connected or decentralized solar PV. **Figure 118** details the investment needs in both cases.

FIGURE 118.

ESTIMATED INVESTMENT COST FOR PELLETIZING ALFALFA IN THE THREE REGIONS (USD)

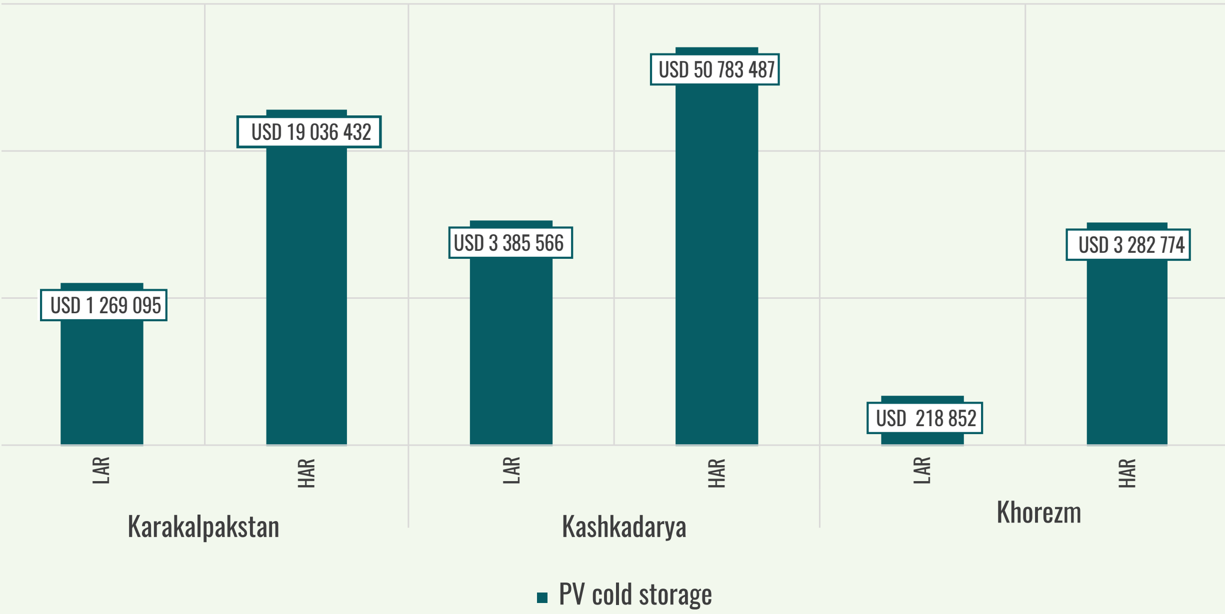


Source: Authors' own elaboration.

Horticulture is a growing sector in Uzbekistan. Melons and tomatoes are the major horticulture crops produced in the three regions. This sector provides jobs in rural areas and is a significant employer of women. However, without proper temperature-controlled storage, still limited in the country, products undergo biological spoilage and losses. In areas where access to electricity is unreliable or absent, deploying cold storages is challenging. Even where grids are present, traditional cold storages add to the overall GHG emissions. Solar cold storages can be deployed close to where crops are produced to help reduce losses. The analysis suggests that there is a significant potential for solar powered cold storages in the three regions (see **Figure 119**).

FIGURE 119.

ESTIMATED INVESTMENT COSTS OF INSTALLING SOLAR COLD STORAGES AT LOW MARKET PENETRATION (LOW ADOPTION RATE (LAR): 5 PERCENT) AND HIGH PENETRATION (HIGH ADOPTION RATE (HAR): 75 PERCENT) (USD)



Source: Authors' own elaboration.

Access to cooling is also paramount in the dairy value chain. Milk cooling is needed both at farm level and at bazaars where milk is sold. At the farm level small 20-litre PV powered chillers could be used while at the bazaars a mid-sized PV powered chiller with a 165-litre capacity seems viable.

As estimated in **Figure 120**, depending on the adoption rate of PV chillers, the investment can range from USD 2.5 million (5 percent adoption rate in the Republic of Karakalpakstan) to USD 129 million (75 percent adoption rate in Khorezm).

It should be noted that the results presented here are technical and focus mainly on the technology side of the intervention, on the investment required and on the ease of sourcing the technology. In addition to the required investment needs, the successful deployment of these technologies would require the development of local capacity to install and maintain this equipment. Additionally, much of the equipment identified in this assessment might need to be imported. Therefore, for long-term sustainability of these technologies adequate policies will be necessary for long term deployment and maintenance.

FIGURE 120.

INVESTMENT NEEDS FOR INSTALLING SOLAR MILK CHILLERS AT LOW AND HIGH ADOPTION RATES (USD)

Source: Authors' own elaboration.

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APPENDIX A. WIND ENERGY ASSESSMENT

A1. THEORETICAL BACKGROUND

Wind speed is the most important parameter to consider when determining the wind energy potential of a certain location. Generally, higher wind speeds are indicative of a higher wind energy potential for a region. Apart from wind speed, another important parameter is the wind power density (W/m²), which is the mean annual power available per square meter of swept area of a wind turbine (Engineering ToolBox, 2009). It can be calculated using the following equation:

$$P_w = \frac{1}{2} * \rho * v_w^3$$

where ρ is the air density and v_w is the wind speed. It should be noted that the wind power density is determined for different heights, as both air density and wind speed change with the altitude.

Moreover, using the logarithmic velocity profile it is possible to calculate the wind speed at any height, in order to find the wind speed at hub height for a wind turbine (KatabaticPower, 2021). The equation that can be used is:

$$\frac{v(h)}{v_{ref}} = \frac{\log\left({}^{h}/_{z_0}\right)}{\log\left({}^{h_{ref}}/_{z_0}\right)}$$

where h is the hub height, h_{ref} and v_{ref} the reference height and wind speed respectively. The parameter z_0 is called roughness length and is dependent on the terrain roughness, which includes protrusions from and/or depressions into the surface; typical values are within the range of 0.0002 m–1 m.

A2. WIND ENERGY POTENTIAL ASSESSMENT IN 5 LOCATIONS

The wind energy potential of five locations within the provinces of interest was examined. The approach and methodology are described below.

WEIBULL DISTRIBUTION

In order to conduct a more detailed analysis of the wind energy potential of a location, it is important to obtain wind speed measurements throughout the year. Typically, wind speed is recorded every 10 minutes for the duration of one year and is categorized into wind classes with a range of 1 m/s. After gathering all the data, the frequency of each wind speed interval can be determined. When experimental data is not available, the Weibull distribution can be utilized. The two-parameter Weibull distribution function is commonly used for representing the wind speed frequency distribution and is defined as follows (Allouhi ***et al.***, 2017; Bahrami ***et al.***, 2019):

$$f_w(v) = \frac{k}{A} * \left(\frac{v}{A}\right)^{k-1} * exp\left(-\left(\frac{v}{A}\right)^k\right)$$

where $f_w(v)$ is the wind speed probability, v is the wind speed, A is the scale factor (m/s) and k is the shape factor, which is dimensionless.

The respective Weibull distribution parameters of the five locations are depicted in **Table 53**, as presented by Bahrami ***et al.***, 2019, who conducted a technical and economic analysis of the wind energy potential in Uzbekistan, focusing on 17 different locations. Five of those sites are located inside the provinces of interest and are thus chosen for this analysis.

TABLE 53.

WEIBULL DISTRIBUTION PARAMETERS

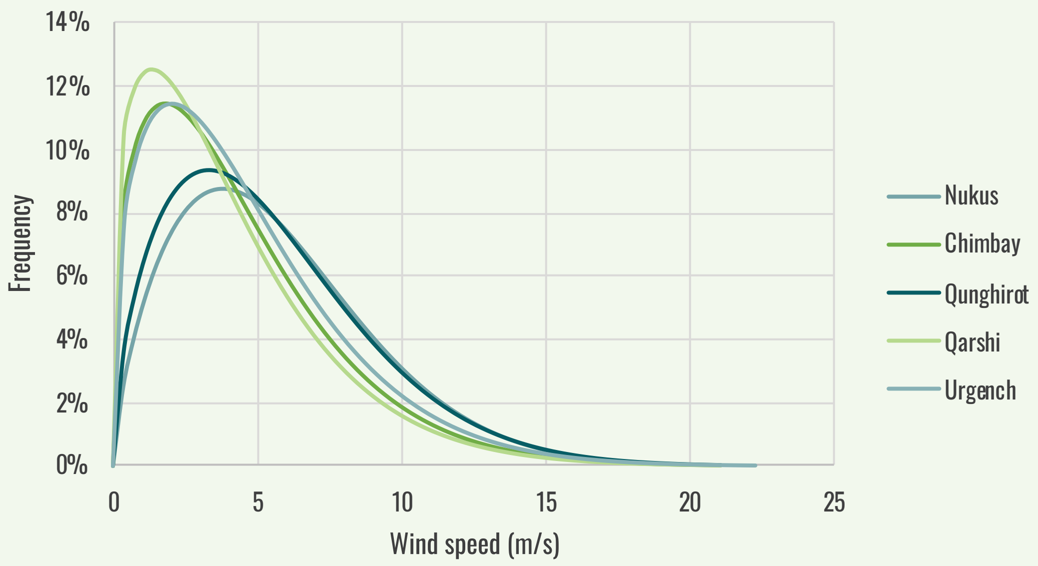
REGION	LOCATION	SHAPE FACTOR K	SCALE FACTOR A (m/s)
KARAKALPAKSTAN	CHIMBAY	1.36	3.21
	QUNGHIROT	1.60	4.08
	NUKUS	1.70	4.46
KASHKADARYA	QARSHI	1.28	2.94
KHOREZM	URGENCH	1.39	3.22

Source: Bahrami, A., Teimourian, A., Okoye, C.O. & Shiri, H. 2019. Technical and economic analysis of wind energy potential in Uzbekistan. Journal of Cleaner Production, 223: 801–814.

Based on the data of **Table 53**, it is possible to create the wind speed frequency distribution. Generally, from the shape of the Weibull distribution for each location an initial assessment of the wind energy potential can be made. Higher frequencies for high wind speeds mean a wider distribution and indicate an important prospect for energy production at a given location. On the contrary, having a narrow Weibull distribution curve shows a lower potential for wind energy utilization.

FIGURE 121.

WEIBULL DISTRIBUTION FOR THE FIVE LOCATIONS



Source: Authors' own elaboration.

In **Figure 121** it can be seen that in Qarshi, lower wind speeds display much higher frequencies, which in turn indicates the limited potential of the region. At a height of 100m, a wind speed of approximately 1.5 m/s appears to be the most common, with a frequency of 12.5 percent. It should be noted that for most wind turbines, a speed of 2.5 m/s or higher is required for energy generation. Similarly, both Urgench and Chimbay show comparable behaviour, albeit slightly improved. In both cases, a wind speed of approximately 2.5 m/s displays a maximum frequency of 11.5 percent. In the province of Karakalpakstan, Qunghirot and Nukus display the most promising results. In both cases, higher wind speeds appear more often, with a speed of around 3 m/s being the most common one.

WIND TURBINE SELECTION

The energy output of a wind turbine is determined based on its power curve and wind speed. Within the scope of this study, seven different turbines from different manufacturers were chosen. The choice of turbines was done aiming to include a wide range of values for important parameters, which are rated power, hub height, swept area and wind speed range that allows energy generation. All these characteristics, which are presented in **Table 54**, affect the final energy production of the system.

TABLE 54.

WIND TURBINE CHARACTERISTICS

WIND TURBINE	RATED POWER (MW)	HUB HEIGHT (m)	SWEPT AREA (m^2)	CUT-IN SPEED (m/s)	CUT-OUT SPEED (m/s)
VESTAS V105/3450	3.45	72.5	8 659	3.5	25
ENOENERGY 126/3.5	3.5	137	12 468	3	25
LAGERWEY LW72/2000	2.0	80	3 984	2	25
GE 3.2/130	3.2	134	13 273	2	25
MULTIBIRD M500	5.0	102	10 568	3.5	25
NORDEX N131/3600 DELTA	3.6	134	13 478	3	20
AERODYN SCD 8/168	8.0	150	22 167	3.5	25

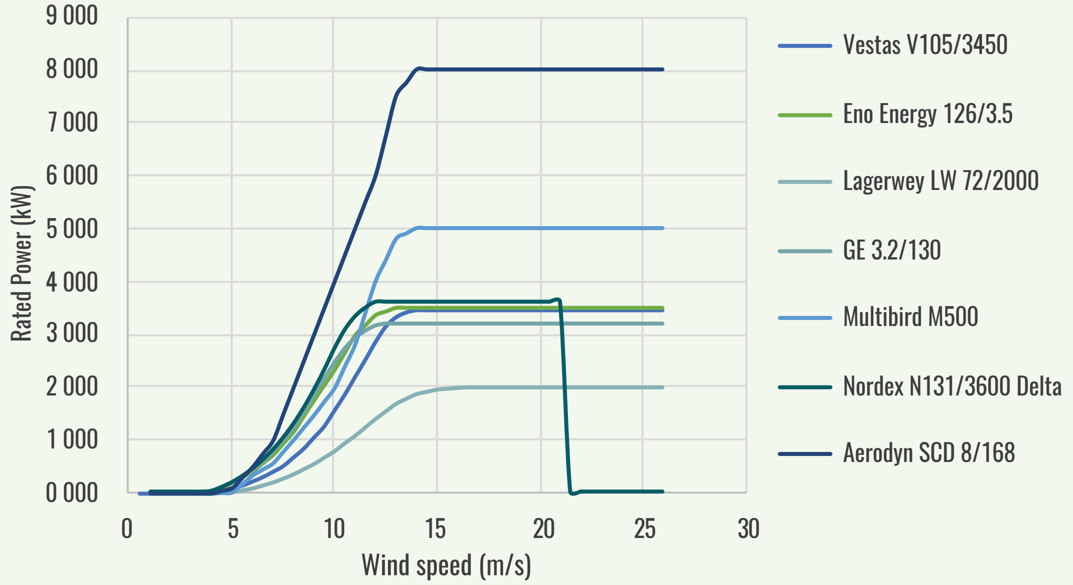
Source: Bauer, L. and Matysik, S. 2021. Wind turbines database. [Cited 10 June 2021]. https://en.wind-turbine-models.com/turbines

The power curve of a wind turbine is a graph which shows the electrical output of the system at different wind speeds. Using the power curves (shown in **Figure 122**) and combining them with the Weibull distribution, it is possible to proceed with the calculation of the annual energy production (AEP) and assess the efficiency of the wind turbine performance using the capacity factor (CF). CF can be calculated using the following equation and a higher value indicates a better performance for the turbine (CSS, 2020).

$$C_F = \frac{Annual\ Energy\ Production}{Nominal\ Power * 8760}$$

FIGURE 122.

POWER CURVES OF THE WIND TURBINES



Source: Bauer, L. and Matysik, S. 2021. Wind turbines database. [Cited 10 June 2021]. https://en.wind-turbine-models.com/turbines

APPENDIX B. BIOMASS AVAILABILITY ASSESSMENT

B1. LIVESTOCK AND CROP RESIDUES DATA

TABLE 55.

LIVESTOCK RESIDUES CHARACTERISTICS

TYPE OF RESIDUE	DENSITY (kg/m^3)	REALISTIC METHANE POTENTIAL RMP (m^3 biogas/m^3 feed day)			BIOGAS HEATING VALUE (MJ/m^3)
		KARAKALPAKSTAN	KHOREZM	KASHKADARYA	
CATTLE MANURE	500	61	57	83	20
CHICKEN MANURE	450	105	97	154	

Source: Authors' own elaboration; El-Haggar, S.M. 2007. Sustainability of Agricultural and Rural Waste Management. Sustainable Industrial Design and Waste Management: 223–260; FAO & Ministry of Energy of Zambia. 2020. Sustainable bioenergy potential in Zambia- An integrated bioenergy and food security assessment. Environmental and Natural Resources Management Working Papers No. 84. Rome, FAO

Table 55 presents the parameters of the livestock residues that are used for determining the theoretical bioenergy potential from biogas production. The required parameters are the density of the residues, the realistic methane potential (RMP) and the calorific value of biogas. RMP is sensitive to the ambient temperature, so it varies between the three provinces based on their respective average annual temperature.

Additionally, in **Table 56** the Lower Heating Value (LHV) of the available crop residues is presented and is used to determine the theoretical bioenergy potential from crop residues in Uzbekistan.

TABLE 56.

LHV OF SELECTED CROP RESIDUE TYPES

CROP RESIDUE TYPE	LOWER HEATING VALUE (MJ/kg)	REFERENCE
SUNFLOWER STALK	15.7	FAO & Ministry of Energy of Zambia, 2020
COTTON STALK	19.1	
COTTON HUSK	17.2	
RICE HUSK	13.8	
CORN COB	17.5	Awulu et al., 2018; Maj et al., 2019; Posom & Nakawajana, 2018; Sihombing et al., 2020
SESAME STALK	15.8	Clini et al., 2008; Ghosh, 2020
WHEAT HUSK	16.2	Santos et al., 2019; U.S. Environmental Protection Agency, 2007

B2. LIVESTOCK RESIDUES AVAILABILITY AND THEORETICAL POTENTIAL

TABLE 57.

LIVESTOCK RESIDUES AVAILABILITY AND THEORETICAL POTENTIAL ON DISTRICT LEVEL

REGION	DISTRICT	COMMERCIAL CATTLE	DEHKAN CATTLE	COMMERCIAL CHICKEN	DEHKAN CHICKEN	BIOGAS POTENTIAL
		(tonnes/year)				(TJ)
REPUBLIC OF KARAKALPAKSTAN	AMUDARYA	15 810	691 952	3 902	16 739	1 823
	BIRUNI	24 117	672 208	9 913	7 977	1 783
	KARAUZYAK	5 218	166 944	404	4 517	443
	KEGEYLI	16 767	342 603	233	1 545	885
	KUNGRAD	17 003	277 513	1 538	4 073	745
	KANLIKOL	5 524	145 420	1 592	1 051	381
	MUYNAK	16 252	104 085	54	1 107	299
	NUKUS	14 628	196 166	77	3 301	530
	TAKHTAKUPIR	8 643	187 225	23	4 382	498
	TURTKUL	27 575	551 958	4 263	4 572	1 455
	KHODJEYLI	18 225	335 088	1 202	4 676	890
	CHIMBAY	20 281	326 069	387	5 019	870
	SHUMANAY	3 418	275 489	1 232	1 693	694
	ELLIKKALA	23 350	534 666	5 812	8 359	1 428
	TOTAL	**216 811**	**4 807 386**	**30 632**	**69 011**	**12 724**
KHOREZM	BAGAT	18 604	353 663	8 352	8 568	922
	GURLEN	20 773	386 941	2 973	8 501	979
	KOSHKUPIR	21 583	373 011	10 469	5 810	970
	URGENCH	31 438	501 351	27 168	8 875	1 370
	KHAZARASP	20 198	443 987	5 318	5 478	1 105
	KHANKA	33 992	492 231	18 489	9 256	1 319
	KHIVA	22 849	351 511	5 644	6 239	905
	SHAVAT	23 084	388 284	5 203	6 970	990
	YANGIARYK	11 974	310 989	5 735	4 877	782
	YANGIBAZAR	21 410	333 588	7 020	4 628	860
	TOTAL	**225 905**	**3 935 556**	**96 371**	**69 202**	**10 202**

KASHKADARYA	GUZAR	25 665	346 493	2 626	6 556	1 298
	DEKHKANABAD	23 735	343 486	1 145	2 500	1 244
	KARSHI	24 048	500 500	13 967	8 427	1 895
	KASAN	30 890	668 184	2 402	7 304	2 387
	KAMASHI	35 314	738 655	2 270	8 259	2 642
	KITAB	34 052	549 751	10 745	4 955	2 046
	MIRISHKOR	26 898	374 060	2 801	7 965	1 405
	MUBAREK	12 688	470 041	1 136	3 420	1 634
	NISHAN	14 698	536 952	627	5 031	1 870
	KASBI	18 494	598 537	1 834	2 657	2 079
	CHIRAKCHI	25 164	890 863	9 937	9 803	3 176
	SHAKHRISABZ	23 941	479 749	20 388	6 069	1 853
	YAKKABAG	17 883	421 337	11 500	3 595	1 562
	TOTAL	**313 470**	**6 918 608**	**81 378**	**76 541**	**25 091**

Source: Authors' own elaboration.

B3. CROP RESIDUES AVAILABILITY AND THEORETICAL POTENTIAL

TABLE 58.

CROP RESIDUES AVAILABILITY AND THEORETICAL POTENTIAL ON DISTRICT LEVEL

REGION	DISTRICT	WHEAT HUSK	COTTON STALK (BASE)	COTTON STALK (50%)	COTTON HUSK	RICE HUSK	CORN COB	SESAME STALK	SUNFLOWER STALK	THEOR. POTENTIAL
		(tonnes/year)								(TJ)
REPUBLIC OF KARAKALPAKSTAN	AMUDARYA	3 550	195 203	108 446	10 253	144	477	2 228	513	4 016
	BIRUNI	3 433	129 438	71 910	6 799	123	98	1 008	179	2 667
	KARAUZYAK	5 030	36 046	20 026	1 893	158	27	923	67	821
	KEGEYLI	4 735	41 164	22 869	2 162	117	30	1 022	94	920
	KUNGRAD	4 827	58 559	32 533	3 076	54	74	941	111	1 268
	KANLIKOL	4 708	29 948	16 638	1 573	139	110	1 112	132	699
	MUYNAK	948	1 322	734	69	15	15	50	7	43
	NUKUS	44 687	244 273	135 707	12 830	368	177	2 588	357	5 665
	TAKHTAKUPIR	3 592	99 163	55 091	5 209	74	88	1 071	146	2 064
	TURTKUL	4 667	91 882	51 046	4 826	133	226	3 056	111	1 969
	KHODJEYLI	6 865	118 171	65 651	6 207	154	121	1 359	225	2 504
	CHIMBAY	10 674	77 765	43 203	4 085	221	205	3 011	321	1 788
	SHUMANAY	4 016	59 093	32 829	3 104	95	43	1 125	100	1 269
	ELLIKKALA	3 422	127 329	70 738	6 688	44	132	572	84	2 616
	TOTAL	**105 154**	**1 309 356**	**654 678**	**68 774**	**1 839**	**1 823**	**20 066**	**2 447**	**28 308**
KHOREZM	BAGAT	7 347	106 470	59 150	5 592	177	39	0	0	2 252
	GURLEN	7 185	179 507	99 726	9 429	606	51	0	0	3 716
	KOSHKUPIR	6 259	138 090	76 717	7 253	111	86	0	0	2 867
	URGENCH	7 633	130 541	72 523	6 857	169	106	0	0	2 739
	KHAZARASP	7 266	162 840	90 467	8 553	575	81	0	0	3 384
	KHANKA	8 438	161 756	89 864	8 496	167	70	0	0	3 376
	KHIVA	6 247	98 381	54 656	5 168	49	38	0	0	2 070
	SHAVAT	6 539	129 923	72 179	6 824	128	87	0	0	2 708
	YANGIARYK	3 531	73 295	40 719	3 850	105	119	0	0	1 527
	YANGIBAZAR	6 653	129 903	72 168	6 823	119	79	0	0	2 709
	TOTAL	**67 098**	**1 310 706**	**655 353**	**68 845**	**2 206**	**756**	**0**	**0**	**27 349**

KASHKADARYA	GUZAR	15 510	85 269	47 372	4 479	0	25	0	135	1 959
	DEKHKANABAD	672	0	0	0	0	0	0	0	0
	KARSHI	25 188	233 437	129 687	12 261	0	54	0	205	5 082
	KASAN	31 967	327 051	181 695	17 178	0	54	0	579	7 070
	KAMASHI	18 479	119 305	66 281	6 267	0	32	0	133	2 689
	KITAB	7 687	0	0	0	0	41	0	306	130
	MIRISHKOR	35 018	257 712	143 173	13 536	0	22	0	189	5 726
	MUBAREK	15 165	116 800	64 889	6 13 5	0	16	0	115	2 584
	NISHAN	30 272	239 511	133 062	12 580	0	29	0	109	5 284
	KASBI	26 397	312 454	173 586	16 412	0	72	0	131	6 681
	CHIRAKCHI	19 016	106 717	59 287	5 605	0	32	0	334	2 449
	SHAKHRISABZ	12 036	78 542	43 634	4 125	0	49	0	332	1 772
	YAKKABAG	16 543	104 148	57 860	5 470	0	61	0	874	2 366
	TOTAL	**253 950**	**1 980 946**	**990 473**	**104 048**	0	**487**	0	**3 442**	**43 802**

Source: Authors' own elaboration.

Energy, climate change and agriculture are closely interlinked, and the introduction of renewable energy interventions in the agriculture sector can catalyse poverty reduction and climate change mitigation. The agricultural is an important sector of the economy for Uzbekistan as it employ over 26 percent of the total working population. Uzbekistan has universal access to energy in addition to significant fossil fuel resources, which are supported by a well-extended energy distribution network. However, the energy sector faces several challenges due to inefficient and outdated infrastructure, resulting in high losses as well as power outages, especially in rural areas. Access to stable energy is essential to rural farmers, especially for irrigation, as the impact of climate change is expected to intensify in the near future.

This report is part of the technical analysis that informs the GEFs project preparation grant application (PPG) under the GEFs food system, land use and restoration (FOLUR) impact programme. The focus of the analysis is on three regions of Uzbekistan: the Republic of Karakalpakstan, Kashkadarya and Khorezm. Firstly, the report provides an overview of solar energy, wind energy and specific elements of bioenergy potential. Building on this, the report identifies specific renewable energy interventions that can enhance the agriculture production of wheat landscapes in the selected regions in Uzbekistan. In addition to the wheat value chain, the alfalfa, dairy and horticulture chains were identified as important chains for the country and the specific regions being considered. Furthermore, the assessment provides details on the specific types of renewable energy interventions that could be implemented for the specific value chains under evaluation, as well as the related costs and investment requirements. These interventions can help stabilize access to energy for farmers and overcome some of the current access shortages.

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