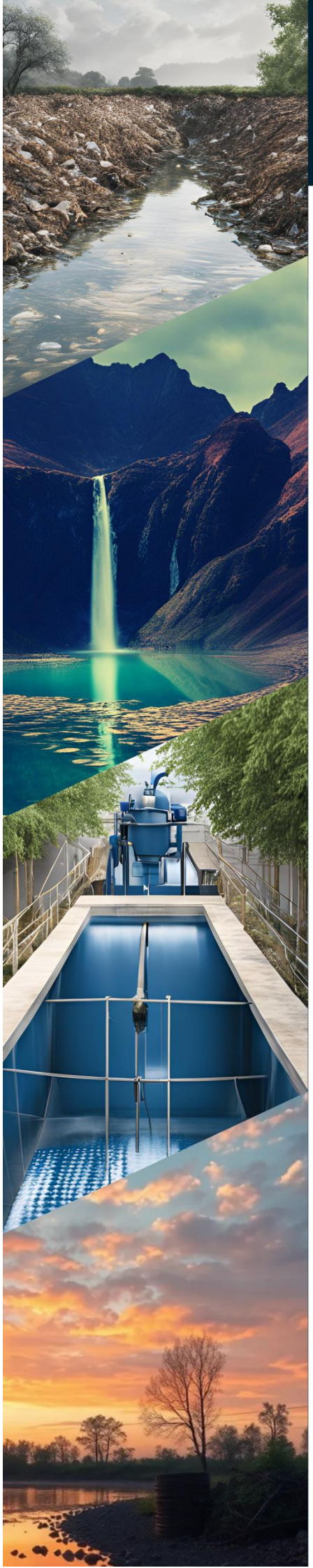
NDC TECHNOLOGY ROADMAP FOR THE WATER AND WASTE SECTORS

NOVEMBER 2024



EXECUTIVE SUMMARY

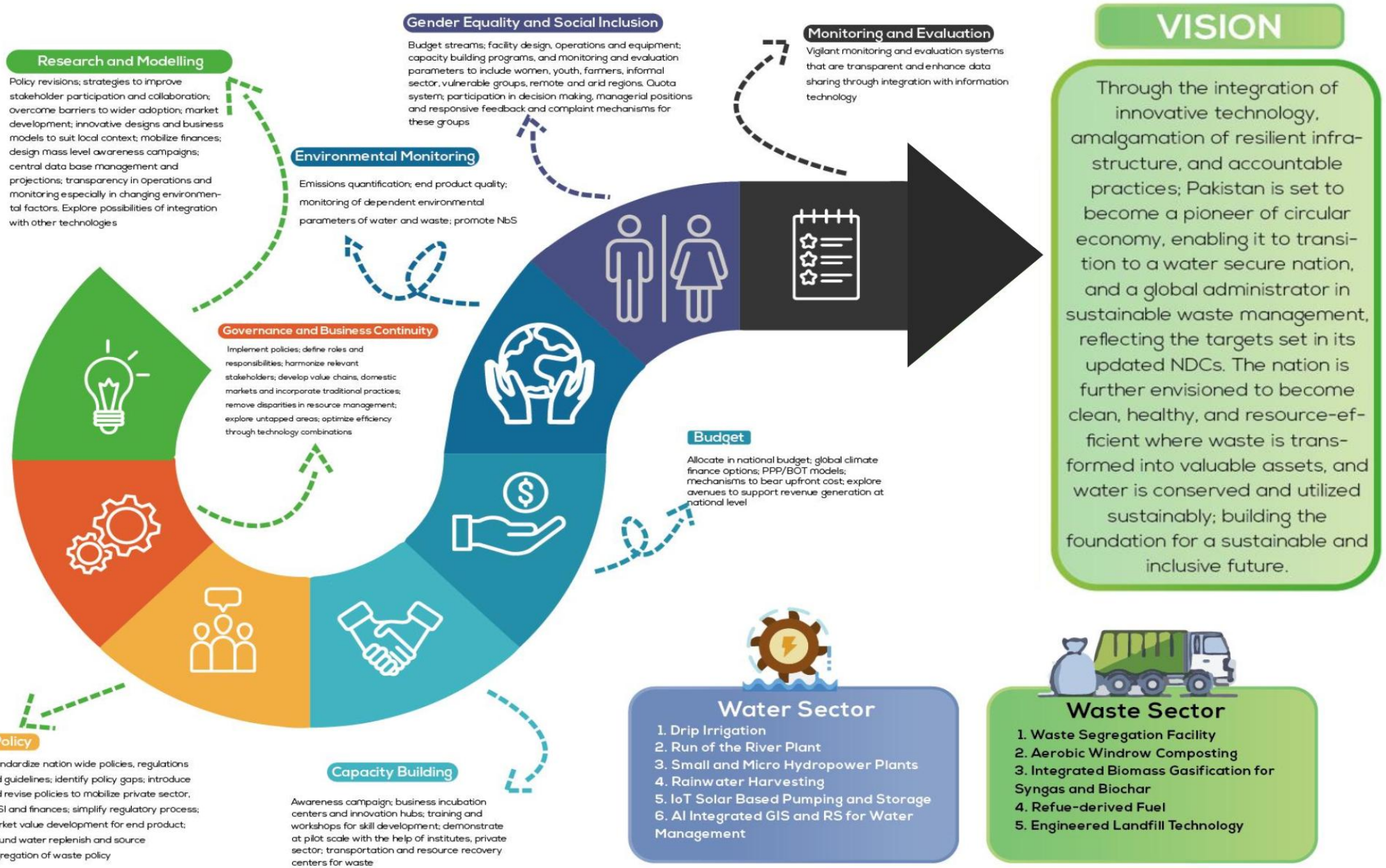
NDC Technology Roadmap of Water and Waste Sector

Pakistan is in the grip of severe climate induced risks, that present themselves predominantly in the form of floods, droughts, and tropical cyclones. The EU's INFORM Risk Index has rated Pakistan as the 6th most exposed nation to climate-related disasters, despite its meager contribution to global greenhouse gas (GHG) emissions. Amongst the numerous climate-induced hazards, floods stand out as the most disastrous risk, with its highest average annual occurrence of 39% (World Bank, Pakistan: Climate vulnerability overview, 2024). The floods of 2022 alone have caused 33 million people to be affected, with 8 million being displaced, and incurring a loss of $14.9 billion USD (UN-Habitat, 2023). Despite the despairing situation, Pakistan is not only committed to building a safer and sustainable nation, but has also expressed perseverance to deliver its contribution in the effort for GHG emissions reduction through its Nationally Determined Contributions (NDCs) targets. The NDC Technology Roadmap for the Waste and Water Sectors, therefore, provides an action plan for the deployment of technology required for successful NDC implementation.

The Ministry of Climate Change and Environmental Coordination (MoCC&EC) has partnered with the Climate Technology Centre and Network (CTCN) for technical and financial support to formulate a Technology Roadmap for the Water and Waste Sectors. Through the establishment of Waste and Water Technical Committees, and a Technical Roadmap Committee, key stakeholders have been engaged in identifying subsectors and prioritizing technologies based on their current standing including legal, financial, social and technical criteria with the aim to achieve the triple bottom line.

High-level stakeholder engagements have been undertaken, drawing upon top-tier expertise and a comprehensive review of existing literature, pilot projects, and large-scale ventures. The presented roadmap is aimed at devising an action plan that is comprehensible, realistic and adaptable. The designed approach gathered information at both national and provincial levels for each technology. This was followed by mapping the shortlisted technologies on the technology readiness level chart. The current standing of technologies gave direction to the action plan, that is further segmented into advising immediate action for certain technologies that have been stacked above others as more urgent, considering their ease of adoption and positive expected outcomes.

This Technology Roadmap, following a detailed assessment and a methodological approach, and is designed to meet the sector and time specific NDCs targets including; goals of renewable energy mix, improved water resource management and GHG emission reduction. Adhering to the proposed action plan, Pakistan can present its climate action in quantifiable terms setting the stage for mobilization of climate finance, and technical assistance. The impact is topped with expected outcomes as a result of a targeted approach towards aligning climate efforts with gender specific considerations, social inclusivity, good governance and capacity building all of which lead to a sustainable and progressive future.


Research and Modelling
Policy revisions; strategies to improve stakeholder participation and collaboration; overcome barriers to wider adoption; market development; innovative designs and business models to suit local context; mobilize finances; design mass level awareness campaigns; central data base management and projections; transparency in operations and monitoring especially in changing environmental factors. Explore possibilities of integration with other technologies
Gender Equality and Social Inclusion
Budget streams; facility design, operations and equipment; capacity building programs, and monitoring and evaluation parameters to include women, youth, farmers, informal sector, vulnerable groups, remote and arid regions. Quota system; participation in decision making, managerial positions and responsive feedback and complaint mechanisms for these groups
Monitoring and Evaluation
Vigilant monitoring and evaluation systems that are transparent and enhance data sharing through integration with information technology
Environmental Monitoring
Emissions quantification; end product quality; monitoring of dependent environmental parameters of water and waste; promote NbS
Governance and Business Continuity
Implement policies; define roles and responsibilities; harmonize relevant stakeholders; develop value chains, domestic markets and incorporate traditional practices; remove disparities in resource management; explore untapped areas; optimize efficiency through technology combinations
Budget
Allocate in national budget; global climate finance options; PPP/BOT models; mechanisms to bear upfront cost; explore avenues to support revenue generation at national level
Policy
Standardize nation wide policies, regulations and guidelines; identify policy gaps; introduce and revise policies to mobilize private sector, GESI and finances; simplify regulatory process; market value development for end product; ground water replenish and source segregation of waste policy
Capacity Building
Awareness campaign; business incubation centers and innovation hubs; training and workshops for skill development; demonstrate at pilot scale with the help of institutes, private sector; transportation and resource recovery centers for waste
VISION
Through the integration of innovative technology, amalgamation of resilient infrastructure, and accountable practices; Pakistan is set to become a pioneer of circular economy, enabling it to transition to a water secure nation, and a global administrator in sustainable waste management, reflecting the targets set in its updated NDCs. The nation is further envisioned to become clean, healthy, and resource-efficient where waste is transformed into valuable assets, and water is conserved and utilized sustainably; building the foundation for a sustainable and inclusive future.
Water Sector
1. Drip Irrigation
2. Run of the River Plant
3. Small and Micro Hydropower Plants
4. Rainwater Harvesting
5. IoT Solar Based Pumping and Storage
6. AI Integrated GIS and RS for Water Management
Waste Sector
1. Waste Segregation Facility
2. Aerobic Windrow Composting
3. Integrated Biomass Gasification for Syngas and Biochar
4. Refue-derived Fuel
5. Engineered Landfill Technology

Acknowledgement

Placeholder xxxx.

Abbreviations

ABAD	Agency for Barani Areas Development
AEDB	Alternative Energy Development Board
AJK	Azad Jammu & Kashmir
AWM	Agriculture Waste Management
BCM	Billion Cubic Meters
CB	Capacity Building
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CPPA	Central Power Purchasing Agency
CTCN	Climate Technology Centre and Network
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EPD	Environmental Protection Department
FFC	Federal Flood Commission
GB	Gilgit Baltistan
GBDMA	Gilgit-Baltistan Disaster Management Authority
GCISC	Global Change Impact Studies Centre
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GoP	Government of Pakistan
HEC	Higher Education Commission
IBG	Integrated Biomass and Gasification
ILO	International Labor Organization
IMO	International Migration Organization
IoT	Internet of Things
ISWA	International Solid Waste Association
KPK	Khyber Pakhtunkhwa
MAF	one Million Acre Feet
M&E	Monitoring & Evaluation
MHPs	Micro Hydro Power Plants
MNFSR	Ministry of National Food Security & Research
MoCC&EC	Ministry of Climate Change & Environmental Coordination
MoE	Ministry of Energy
MoF	Ministry of Finance
MoHR	Ministry of Human Rights
MoIP	Ministry of Industries and Production
MoIT	Ministry of Information Technology
MoST	Ministry of Science and Technology
$MtCO_2e$	Million tons of Carbon Dioxide equivalent

MSW	Municipal Solid Waste
MRF	Material Recovery Facility
MW	Megawatt
m^3/ person	Cubic meters per person
NARC	National Agriculture Research Centre
NDCs	Nationally Determined Contributions
NDMA	National Disaster Management Authority
NEPRA	National Electric Power Regulatory Authority
NGOs	Non-Governmental Organizations
OGRA	Oil and Gas Regulatory Authority
P@SHA	Pakistan Software Houses Association
PARC	Pakistan Agriculture Research Council
PBR	Provincial Board of Revenue
PBS	Pakistan Bureau of Statistics
PCIW	Pakistan Commissioner for Indus Waters
PCRET	Pakistan Council of Renewable Energy Technology
PCRWR	Pakistan Council of Research in Water Resources
PCST	Pakistan Council for Science and Technology
PCSIR	Pakistan Council of Scientific and Industrial Research
PDMA	Provincial Disaster Management Authority
PECRA	Pakistan Council of Renewable Energy Technology
PFS	Pre-Feasibility Study
PHED	Public Health Engineering Departments
PIDC	Pakistan Industrial Development Corporation
PIPIP	Punjab Irrigated-Agriculture Productivity Improvement Project
PITAC	Pakistan Industrial Technical Assistance Centre
PPIB	Private Power and Infrastructure Board
PPID	Private Power Infrastructure Board
PPP	Public-Private Partnership
PPPA	Public-Private Partnership Authority
PSEB	Pakistan Software Export Board
PSF	Pakistan Science Foundation
R&D	Research and Development
SECP	Securities and Exchange Commission of Pakistan
SIA	Social Impact Assessment
SMEDA	Small and Medium Enterprises Development Authority
SOM	Soil Organic Matter
SRSP	Sarhad Rural Support Program
SWM	Solid Waste Management
SUPARCO	Space & Upper Atmosphere Research Commission

tpd	tons per day
TRL	Technology Readiness Level
UNDP	United Nations Development Program
WAPDA	Water and Power Development Authority
WASAs	Water and Sanitation Agencies

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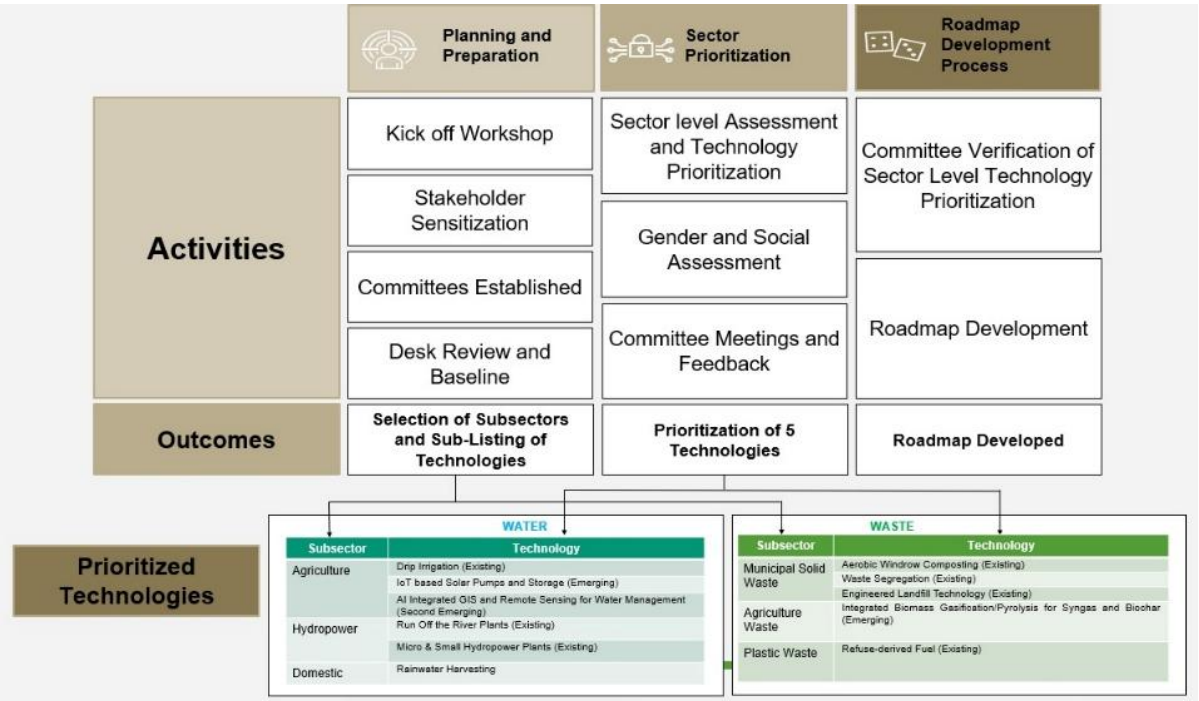
1 Sustainable Water and Waste Management: A Technological Roadmap

The aim of an extensive Technology Roadmap for Nationally Determined Contributions (NDCs) is to serve, primarily, as a strategic guiding tool; one that offers a structured approach needed to identify, prioritize, and sequence the deployment of sustainable technologies. These technological interventions are vital for addressing climate change challenges and promote sustainable development in Pakistan. Pakistan's 2021 NDCs prioritizes technology-based interferences as a means towards climate action, calling for the technology transfer and interventions for key sectors in Pakistan, including water and waste. This commitment to the incorporation of technology in the climate agenda will be fundamental in shaping an enabling environment for effective incorporation of technology for NDCs implementation, in order to ensure efficiency, inclusive access and adequate management of its water and waste sectors.

1.1 A Data-Driven Approach: Selected Water and Waste Technologies

With a vision of a climate resilient Pakistan, the Government of Pakistan (GoP), backed by the technical and financial support provided by the Climate Technology Centre and Network (CTCN), has taken the initiative to develop a detailed Technology Roadmap for key NDC adaptation and mitigation sectors. The objective was to ensure collaboration, and work towards an inclusive, data-driven and effective process, needed to formulate this roadmap. The overarching aim, therefore, was to produce a roadmap that promotes not only climate resilience, but also supports socio-economic upliftment through economic savings, improved health, and employment opportunities amongst others. The infographic below depicts a concise summary of the steps adopted:



This roadmap is based on a data-driven approach, governed by a thorough analysis of the selected sectors, subsectors and their respective technologies. The formulation of the roadmap initiated with extensive stakeholder engagements; with each step being further supported by field experts, forming the Technology Roadmap Committee and the Technical Committees for water and waste sectors. The overall process initiated with highlighting the predominant challenges in the water and waste subsectors, with focus being placed on identifying related technologies for further review.

For the water sector, subsequent stakeholder consultation shortlisted the following sub-sectors to be explored from a technological perspective: Agriculture, Domestic and Hydropower. A similar process was followed for the waste sector, with the following sub-sectors being identified for extensive exploration: Municipal Solid Waste, Plastic Waste and Agriculture Waste. Following this, an extensive list of respective technologies was prepared and communicated to the Water and Waste Technical Committees, respectively. A scoring criterion was established that encompassed the following: Current legal, regulatory and financial landscape; Economical and Technical Feasibility; and Potential for Inclusive Development and Climate Impact.

The selected technologies, for both water and waste sectors, along with additional details being presented as **ANNEX-I**

1.2 Vision

Through the integration of innovative technology, amalgamation of resilient infrastructure, and accountable practices; Pakistan is set to become a pioneer of circular economy, enabling it to transition to a water secure nation, and a global administrator in sustainable waste management, reflecting the targets set in its updated NDCs. The nation is further envisioned to become clean, healthy, and resource-efficient where waste is transformed into valuable assets, and water is conserved and utilized sustainably, building the foundation for a sustainable and inclusive future.

1.3 Objectives

The technology roadmap aims to cover the following objectives:

Evaluate the technology readiness level of the prior short-listed water and waste technologies, while exploring the associated challenges, opportunities, and potential benefits to be provided by the integration of these technologies.
Develop comprehensive action plans for the selected technologies, addressing public-private partnerships, capacity building, and regulatory compliance.

Ensure that the action plans prioritize marginalized communities, address barriers hindering their access to sustainable water and services, along with fostering community engagement to promote social inclusivity.
Present Action Plans, serving as a potential roadmap for the implementation and scaling up of these technologies, outlining immediate priorities, long-term goals, and a conclusive way-forward.

1.4 Preamble to the Technology Roadmap

This document, therefore, presents an extensive and detailed Technology Roadmap that paves the pathway for the adoption and implementation of innovative technologies that are vital for helping Pakistan achieve water security and transform its waste management sector. By meticulously evaluating the technology readiness level of existing and emerging solutions, and recognizing the associated challenges and opportunities; comprehensive action plans have been developed for both the water and waste sectors, respectively. These will then facilitate the successful integration of each of the selected technologies into the subsequent sector. This roadmap further prioritizes immediate plans that address critical areas such as gender inclusivity, public-private partnerships, and capacity building to ensure equitable and effective implementation. Moreover, a clear way forward has been outlined that envisions a future where sustainable water and waste management practices can be successfully integrated in our society.

2 Aligning Water and Waste Technologies with NDCs

In its status as a developing nation, it perhaps comes as no surprise that Pakistan ranks 6th in the list of nations exposed to natural hazards, such as floods, heatwaves and droughts (IASCEC, 2024). Pakistan's water sector has emerged to be the most vulnerable, with the 2022 floods alone causing $1 billion in damages and persistent health risks due to contaminated water supplies (GoP M. o., 2022). Areas governed by natural water flows, are susceptible to fluctuations in temperature and precipitation; with their vulnerability further exacerbated by indigenous water management systems that govern irrigation channels. This is reflected in Pakistan's status as an existing water stressed country, with this nation ranking 14 among the 17 'extremely high-water risk' countries (Maqbool, Impact of climate change on water on Pakistan, n.d.).

A similar story is observed in the waste sector. It has emerged as a primary contributor to greenhouse gas emissions (GHGs), via solid waste disposal sites, waste handling, and waste incineration. With most of the municipal waste being disposed of in the form of burning, dumping, or being buried in empty areas, this sector is further associated with extensive environmental degradation, and excessive damage to human health. Despite the waste sector representing less than 2% of Pakistan's GHG emissions, between now and 2030 these values are expected to double in number (CDKN, n.d.). A compromised waste management infrastructure is further vulnerable to extreme weather events making the situation worse by exacerbating concerns for human health. The culmination of these factors results in the need for an integrated framework and action plan for improved water and sanitation access. The development of Nationally Determined Contributions (NDCs) was a progressive step taken by Pakistan that exhibits the nation's commitment to address the adverse impacts of climate change. In order to achieve the ambitions outlined in the NDCs, localized technology intervention is pertinent, particularly sectors where vulnerability is high, making mitigation and adaptation actions essential.

With the identification of the water and waste sectors as the target for the development of a Technology Roadmap, mitigation action is the need for achieving sustainability. The water sector urgently demands adaptation strategy due to the significant rise in temperature (0.1 to 0.55°C per decade, likely to exacerbate the issue of food security (UNDP U. N., Vulnerability of Pakistan's water sector to climate change: Identification of gaps and recommendations for action, n.d.). Mitigation action is needed in the waste sector, that is known to generate 26.94 million tons of carbon dioxide equivalent (MtCO2e) (Ijaz, 2024). The NDCs targets of 60% mix for renewable energy by 2030, reduced flood risk and enhanced water recharge by the same year provides a great opportunity to explore the potential of hydroelectric and solar power generation along with waste-to-energy projects and at the same time improving disaster risk management and country's valuable resources, such as groundwater table levels (MoCC&EC, 2021).

In Pakistan, technologies stand at different entry points especially in the context of provincial scenarios. Some technologies are emerging while others exist at pilot or small-scale facing barriers

in scaling up mainly due to limited resources and lack of investment. Furthermore, public private partnerships need mobilization particularly in developing nature-based solutions that have both mitigation and adaptation potential. This document addresses the need to chalk out a socially-inclusive pathway for technology integration into climate action in Pakistan, keeping in mind the different entry points of each technology after prioritizing them based on how closely they align with NDCs targets.

WATER SECTOR

3 Overview of the Water Sector

3.1 Situational Analysis

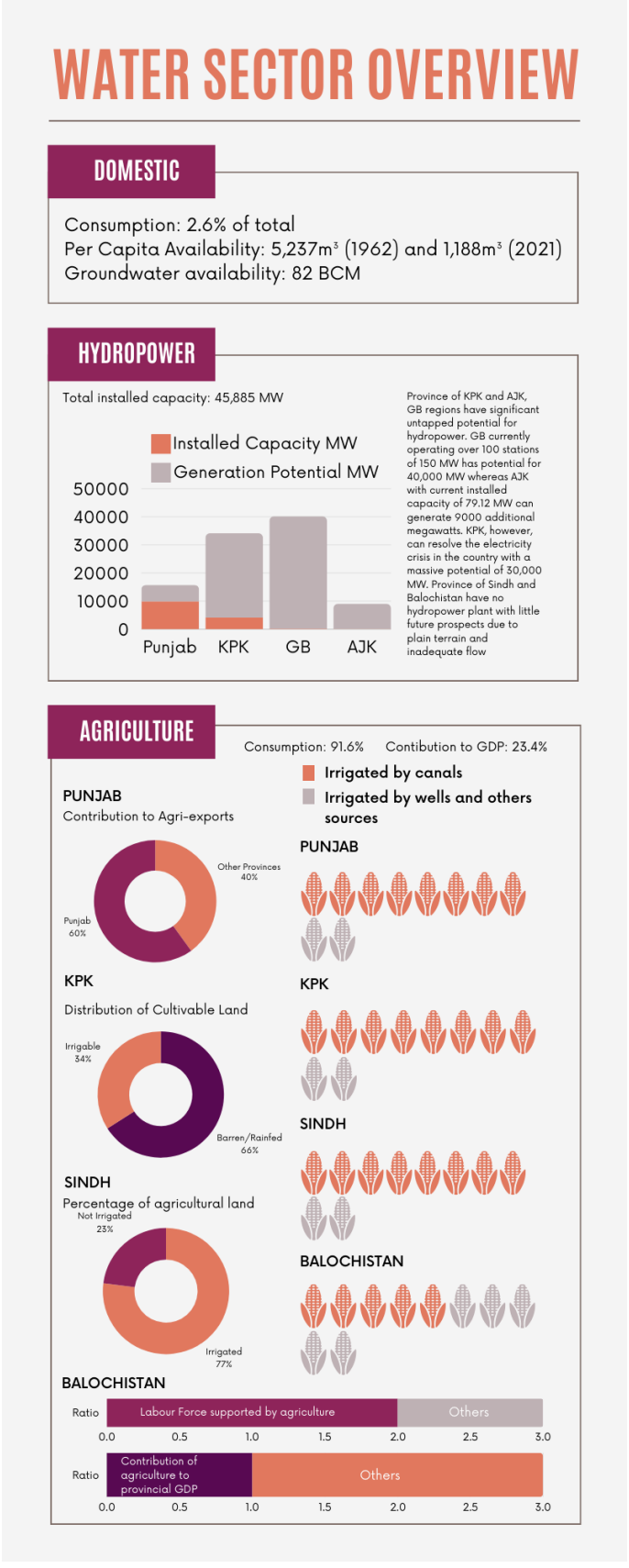
The water sector in Pakistan exhibits distinct characteristics in three prioritized sub-sectors: agriculture, domestic use, and hydropower. The agriculture sector consumes around 91.6% of the total annual water use in the country (UNDP, Pakistan: A country of migrants Understanding the migration dynamics, 2023), engaging 60% of the population (SDPI, 2019) and contributing roughly 22% to the National Gross Domestic Product (GDP) (MoF, 2023). Water shortage in the agriculture sector has the potential to reduce the national GDP by more than 4.6% (World Bank, Punjab Solid Waste Management Project: Gender analysis of solid waste management in Punjab, 2023).

The domestic sector encapsulates both residential and commercial sectors, and further accounts for 2.6% of water consumption in Pakistan (UNDP, Understanding migration dynamics in Pakistan, 2023). According to the Pakistan Council of Research in Water Resources (PCRWR), the per capita availability of water in Pakistan has declined (PCRWR, 2021) from 5,260 cubic meters per person (m^3/ person) in 1951, to 1,017m^3/ person in 2021. These values fall well below the recommended threshold of 1,700 m^3/ person per year (Ding & Sumita, 2017). Groundwater is further a major source of domestic water supply, with sources of recharge including rivers, tributaries, canal irrigation, and rain, contributing to an estimated 82 billion cubic meters (BCM) of ground water reserve (Majeed & Piracha, 2011). The water sector further plays a pivotal role in power generation, particularly hydropower: Pakistan's total installed capacity of hydropower generation is operational and estimated to be 10,852.85 Megawatt (MW) (GoP G. o., 2022). Currently, about 25% of Pakistan's energy generation is sourced through hydropower (MoF, 2023). An overview can be observed in the infographic and accompanying text below:

The Technology Roadmap looks at the domestic, hydropower and agriculture subsectors for the water sector. With the consumption of 2.6% (UNDP, 2016) of the total water resources for the domestic subsector, Pakistan is quickly reaching the peak of water stress level. The groundwater availability at 82 BCM (UNDP, 2016) is an alarming figure for a country like Pakistan that is heavily dependent on it for domestic and irrigation purpose. The issue is further exacerbated by the rapid decline in per capita water availability which stands at 1188 m^3/year (FAO, 2021) and is expected to further fall at 860 m^3/year by 2025 (Planning and Development Department, 2023).

One of the subsectors identified for strategic water resource management through technology intervention is hydropower generation with current installed capacity of 45,885 MW (NEPRA, 2023). Tremendous potential lies in GB, KPK and AJK and with 40,000 MW (The World Bank, 2018), 30,000 MW (KP Board of Investment & Trade, 2024) and 9000 MW (The Express Tribune, 2022) respectively. Although out of scope of this document, water resource management through hydropower generation can be coupled with utilizing storage capacities for irrigation purposes to facilitate the agriculture sector supporting about 37.4% of the population through livelihood generation and 22.9% of the GDP (Economic Adviser's Wing, 2023).

This extensive revenue generating sub-sector heavily relies on surface and ground waste resources. Sindh, KPK and Punjab irrigate 75% to 80% of their agricultural land with canal system while the remaining land utilizes other sources out of which the most prominent is groundwater extracted through wells and tubewell (PBS, Area Irrigated by Different Source, 2022). While 77% of Sindh's agricultural land is irrigated (World



Bank, 2022), 66% of KPK's agricultural land is rainfed (Planning and Development Department, 2023). Two third of labor force and one third of the provincial GDP is supported by the activities of the agricultural sector in Balochistan (Rana, Moeen, Shikoh, & Davies, 2021). Punjab plays a major role in the sector by contributing 60% to the exports (Agriculture Department, 2024).

3.2 Promoting Gender Equality & Social Inclusion

Gender disparity and limitations of certain social groups in Pakistan is a prevalent concern that will be exacerbated with time due to the impacts of climate change. Discrimination, particularly in the agriculture sector, are prominent for females that represent half of the population (World Bank, Population, female (% of the total population) - Pakistan, n.d.) of the country. They face violence, poor living standards, and low literacy rates that lead to their significant lapse in achieving inclusion in decision making, financial security, mobility and leadership positions, The Labour Force Survey 2020-2021 indicates this with 7.6 proportion of female managerial positions in rural areas and 4.9 in urban setups. On the other hand, in the water sector, each year, more than 3 million Pakistanis get infected by water-borne diseases Due to inadequate water supply and sanitation facilities in lower-income households inducing a burden of PKR 116.13 billion of the health cost (Business Recorder, 2024). The restricted mobility of women and limited access to safe water makes it difficult for them to fulfil their primary duties in households.

Climate induced issues such as water scarcity further add difficulty in safe water collection specifically for the 72% of the water that is carried by women from far-flung areas (Jamshed, 2022). This time-consuming activity accounts for health issues and the largest out-of-school female population of 12 million (Baron & Bend, 2023) eventually leading unachieved social and financial security. Therefore, ender and social concerns need to be incorporated in the action plan for technology intervention to build a more holistic approach to water resource management. Consequently, a positive impact will be ensured on the well-being of social groups specifically women and youth. This saving of time and effort resulting in better access to safe water will enable them to improve their income generating capacity through building cottage industry with local skills, knowledge and materials. Ease of access to water will also significantly improve the living standards, economic opportunities and health of women and other vulnerable groups. Inclusion of women in decision making and managerial positions will help sustain these technologies through a diverse and holistic approach whereas integration of gender specific considerations in emerging fields like information technology will also empower women and provide exposure enabling a progressive approach. The action plan with its focus on gender and social groups will substantially improve the technical and leadership skills, advocacy rights financial and digital literacy and learning business management and models giving a major boost to the economic activity of the country.

3.3 The Impacts of Climate Related Disaster

Amongst the plethora of challenges that Pakistan faces due to accelerating climate change, perhaps none are as harrowing as those felt via its depleting water resources, and increasing water scarcity. As an existing water stressed country, Pakistan ranks 14 among the 17 'extremely high-water risk' countries (Maqbool, Impact of climate change on water on Pakistan, n.d.). Where climate change in the form of rising temperatures and extreme predictable weather patterns are projected to affect patterns of rainfall, snowmelt, river flows, groundwater and water quality. In the North, heating in the troposphere will result in the melting of glaciers leading to variation in the flow in the Indus River, with resulting floods damaging Pakistan's already vulnerable economy and ecology. Floods and droughts exacerbate infrastructure damage, human loss, and economic setbacks as development budgets are diverted for emergency relief and rehabilitation phases. A vicious monsoon cycle will further worsen flooding and landslides, causing mortality and morbidity.

Beyond the direct impact on water availability, climate change is also driving up water demand in Pakistan, especially during long summer seasons. Rising temperatures increase the agricultural sector's need for water due to higher evapotranspiration rates and drier soils. The increased reliance on energy, especially during winter, combined with pressure on natural resources like oil and gas, and the lack of alternative use of clean energy, further compound these challenges.

In recent years, floods have been responsible for extensive damage to agriculture, livestock, and associated infrastructure; with the loss to the national economy being estimated to be at a harrowing US$3.7 billion (World Bank, Pakistan floods 2022: Post-disaster needs assessment (PDNA) main report, 2022). The 2022 floods further damaged the quantity and quality of crops, standing in-season crops, and huge quantities of grain in the storage, livestock, and infrastructure (Qamer, et al., 2023). Apart from the plant damage due to incidental rainfall at critical crop development phases, flood-induced water logging in cropland can also trigger abiotic stress in crops by reducing light availability, depletion of oxygen, and changing the chemical properties of soil. These alterations in the environment can significantly impede crop growth, vigor and yield, leading to food insecurity and high costs of fruits and vegetables, ultimately putting pressure on consumers (Qamer, et al., 2023).

The devastating 2022 floods in Pakistan severely compromised essential Water, Sanitation, and Hygiene (WASH) services. In the aftermath, over 8 million people remain without access to safe drinking water, highlighting the urgent need for effective WASH responses to climate-related disasters. As a lower-middle-income country, Pakistan is particularly vulnerable to such crises. To ensure the resilience and sustainability of WASH services in the face of increasing climate uncertainty, innovative strategies, improved governance, and community-driven initiatives are crucial (PCRWR, International Conference on Transformative Pathways for Water and Food Systems in a Climate Resilient Pakistan, 2023).

With dwindling water resources per capita and rising demand for food production, Pakistan faces a critical water crisis that threatens its food security. This crisis also has significant implications for the government's aspirations to achieve upper-middle-income status by 2025 and maintain long-term peace and security. Women, girls, people with disabilities and the older people are among the most affected groups due to their heightened vulnerability in disasters.

3.4 Policy Gaps Analysis

Nationally, the federal government has introduced the National Water Policy 2018, which aims to lay down a broad policy framework and a set of principles for water security on the basis of which the provincial governments can formulate their respective Master Plans and projects for water conservation, water development and water management. The Climate Change Policy 2021 aims to protect water bodies from pollution and degradation while the National Climate Resilience and Adaptation Plan 2023 is focused on installation of resilient water management infrastructures. Moreover, the Power Generation Policy 2015 promotes renewable energy sources while the National Food Security Policy 2018 looks to promote sustainable food production systems (crop, livestock and fisheries) by achieving an average growth rate of 4% per annum and make agriculture more productive, profitable, climate resilient and competitive.

All these policy ambitions are well aligned with NDC targets indicated through their support for goals such as increasing the percentage of indigenous sources (hydropower included) of power generation to over 50%, enhancing the water storage capacity to 90 days and improving the efficiency of water usage in the agriculture sector by 20%.

At the provincial level, the water policies have been presented for optimal water management in the provinces including Punjab Water Policy 2018, Sindh Water Policy 2023, Integrated Water Resource Management Strategy Government of Khyber Pakhtunkhwa and Balochistan Drinking Water Supply Policy/ Strategy 2015-2025. In the Agriculture Sector, there are Punjab Agriculture Policy 2018, Sindh Agriculture Policy 2018-2030, Agriculture Policy KP (2015-2025) and Balochistan Agriculture Sector Policy and Strategy aimed at addressing food security and promoting good agricultural practices in the province. For the Hydropower Sector, KP has developed its Hydropower Policy 2016 for the promotion of hydropower fostering cost effective and clean energy generation in the province.

However, despite all these policies being in place promoting the transition to a sustainable infrastructure in the water sector, there is a lapse in continuous updating in the wake of newly developed tools, mechanisms, frameworks and instruments along with lack of incorporation of technology innovations especially integrated with IT. Some social considerations have been addressed in terms of youth engagement and relief in cost of resources but deeper level reflection on technical skills development at a larger scale, disaster risk management in response to climate induced disasters and inclusion of women in decision making and at managerial positions still have

a long way to go. Regardless that these policies encourage technology intervention, barriers to wider adoption are prevalent. Some examples of these are lack of awareness and capacity building for the end user, no evidence of large-scale technology implementation despite the existence of pilot scale projects and lack of research and technical skills and expertise leading to failure of projects due to incompatibility with indigenous factors. Operational inefficiencies are caused by absent or inactive monitoring and evaluation systems. Another major issue is regulations and enforcement of these policies to enable a systemized and orderly management of water management resources indicated by uncontrolled pumping and groundwater depletion.

One of the purposes of this technology roadmap is to advise on policy revisions that must include an integrated approach facilitating communication and exchange of information and skills between departments. NGOs working for vulnerable social groups and on gender-based issues must be made an integral part of policy to encourage traditional practices and community involvement leading to a sense of ownership in locals. Prospects of artificial intelligence must be explored to bring ease of adoption for technology intervention and to develop vigilant monitoring systems. In addition, one of the most effective actions would be to continually revise current schemes, mechanisms and frameworks in place to include and incorporate improvements in already proposed technology intervention. An example of this could be to revise the policy enabling solar pumps installations to upgrade to IOT based solar pumps. Institutional Frameworks and Financial Allocations: Water Sector

The institutional framework for water management in Pakistan is complex and fragmented, with multiple agencies involved at various levels. Lack of inter and intra organizational linkages coupled with transparency on reporting mechanisms hinder cooperation between agencies. This fragmentation often leads to coordination challenges and overlapping responsibilities. The Ministry of Water Resources (MoWR) plays a crucial role in overall water management, but its capacity to coordinate and manage water resources effectively is limited due to various factors, including financial constraints and technical expertise.

These challenges in the institutional framework and financial flows limit Pakistan's ability to invest in climate-resilient technologies and innovative approaches to water management. This hinders the country's efforts to adapt to the impacts of climate change and ensure water security for its growing population. Figure 2 illustrates the complex flow of financial resources and decision-making processes within the water sector:

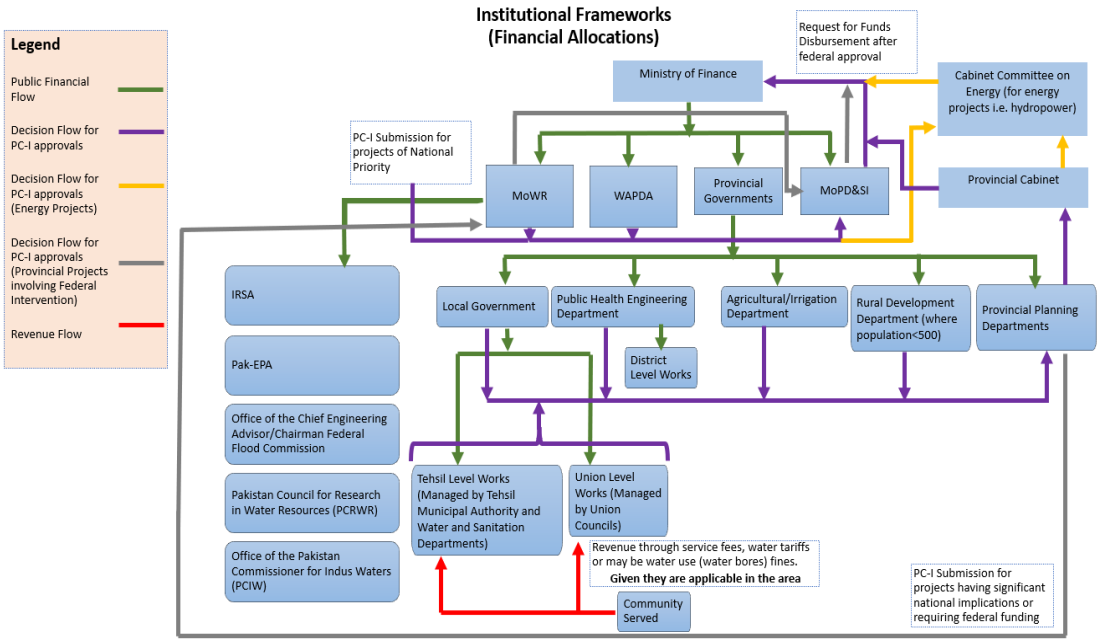


Figure 2: Institutional Framework for financial allocations in the Water Sector.

Some key areas where financial flows between entities shown in Figure 2 are not administered as intended include:

Limited funding for water sector projects: The allocation of funds for water sector projects is often inadequate, hindering the implementation of critical infrastructure projects and water conservation measures.

Inefficient use of funds: Funds allocated for water sector projects may not be utilized efficiently, leading to delays and cost overruns.

Lack of transparency in financial flows: The lack of transparency in financial flows can hinder accountability and make it difficult to track the utilization of funds.

4 Water Technology Roadmap: A Blueprint for Sustainable Water Management

4.1 Challenges and Opportunities

An overview of the challenges identifies that the water sector in Pakistan exhibits challenges across three prioritized sub sectors i.e. agriculture, hydropower and domestic use. Water shortage in agriculture sector could reduce the GDP by more than 4.6% (World Bank, Pakistan: Strengthening the housing sector for inclusive and sustainable growth, 2023). According to the PCRWR, the per capita availability of water in Pakistan has declined (Ashraf, 2021) from 5,260 cubic meters per person in 1951 to 1,017 cubic meters per person in 2021, which is well below the recommended threshold of 1,700 cubic meters per person per year (Ding & Sumita, 2017).

Water scarcity is a growing concern, exacerbated by climate change and recurring floods and droughts. Furthermore, aging infrastructure, chronic underfunding for maintenance, and inefficient water management practices have led to low water conveyance efficiencies and inequitable water distribution. More than 90% (ADB, 2006) of Punjab's agricultural output relies on irrigated land and it is concluded that 60-75% (World Bank, Factsheet: Sindh water and agriculture transformation project, 2022) withdrawn water is lost, either through surface water evaporation (26.6 and 41.7 MAF) or seepage into saline groundwater. Agricultural water demand is expected to surge if existing irrigation and cropping practices remain unchanged and due to climate induced damages like caused by the 2022 floods. This is particularly a concern for areas like KPK where agriculture supports 90% of the population (SJBIPP, 2019).

Heavy reliance on groundwater extracted through tube wells face significant challenges due to recurrent droughts and aquifer depletion in Sindh. 70% (USAID, 2023) of Balochistan's farmers lack access to a consistent water source like canals or minor irrigation schemes.

The selection of shortlisted technologies for both water and waste sector were based on a thorough analysis majorly guided by stakeholder engagement that helped in the prioritization of the introduced technologies through assessment against a diverse criterion. To design a technology roadmap, it is vital to assess the current standing of the selected sectors and subsectors while at the same time the entry points for each technology for all provinces and regions.

Technology	Challenges	Opportunities
	EXISTING	
Drip Irrigation	80% subsidy in Punjab for water management financing (Dawn, 2019) but upfront cost remains a barrier. Technology design is susceptible to emitter clogging, and suitability concerns for certain crops hinder widespread adoption. Farmers frequently encounter challenges in accessing adequate after-sales support from both the agricultural department and system vendors (Dawn, 2019). The effectiveness of drip irrigation can be reduced on uneven or sloped land (Muhammad, et al., 2016).	Support from government and private sector mobilization. The Punjab Irrigated-Agriculture Productivity Improvement Project (PIPIP), initiated in 2012 with support from the World Bank, specifically targets the improvement of water productivity. Significant water savings ranging from 30% to 70% (CFP, n.d.) and increased crop production by up to 100% (CFP, n.d.). Time savings for women farmers Technology's ability to reduce water usage by 60% (CFP, n.d.) compared to traditional flood irrigation methods, as well as its 50% reduction in fertilizer usage (CFP, n.d.), contributes to climate adaptation Drip irrigation, combined with optimized irrigation scheduling, can lead to reductions in emissions of CO2, N2O, and NO by up to 62% (Andrews, Homyak, Oikawa, Wang, & Jenerette, 2022). Integration with Rainwater Harvesting
Run of the River Plants	Financial uncertainties may arise due to fluctuations in electricity generation, influenced by the volume of water in the river and weather conditions. Land acquisition issues lead to delays Diversion of significant quantities of water from rivers without precautionary measures Construction and operational efficiency affected by weather variability	Huge opportunity for scaling up exists as in KPK with about 150 potential sites (PPIB, 2011) Subsidies in the form of foreign investments Job creation for locals during the construction phase

	Severe damages during floods and landslides Operational and maintenance issues at times Advanced technology and technical expertise are limited.	Emission reduction by displacing carbon-intensive energy sources like coal Inclusive development by involving and facilitating women
Micro and Small Hydro Power Plants	Limitations like receiving decreased water flow in winters Cost of construction and maintenance Land acquisition issues lead to delays	10% of total energy mix to be from hydropower plants. Policies offer a supportive environment for the growth of MHPs. NEPRA regulates connection with national grid Currently only 14% of 50,000 MW potential explored (UNEP DTU Partnership, 2016) Cost benefits, cheap electricity solutions for remote areas, and foreign grants, such as a joint program between China and Pakistan, have increased its adoption. Installation by PCRET and the Sarhad Rural Support Program (SRSP) (Uddin, et al., 2019). MHPs are domestically manufactured in Pakistan creating business opportunities in construction phase (Paradigm Shift, 2023) Ability to meet peak electricity demand, Local community involvement Potential sites in Chitral More time for women and girls for education and household chores

Rainwater Harvesting	Supportive legal environment but absence of clear guidelines on installation and use of system. Lack of awareness among masses and insufficient technical knowledge and skills about different rainwater harvesting models for high rise and small buildings whether in public or private sectors Assumed high costs for establishment of rainwater harvesting system particularly in public buildings and household level Traditional land tenure systems and limited community involvement can be hurdles Limited access to finance for infrastructure development and maintenance, Siltation, unpredictable rainfall patterns and the risk of low rainfall or floods can also lead to crop failures and economic burdens High labor demand for construction Reliance on donor funding for projects raises uncertainties about the sustainability and ownership in the long run	Traditional practices and policy revision to expand the scope of technology Women empowerment through gender considerate NGOs Technology widely employed due to heavy dependency in cities like Nathiagali, Ayubia, Batgram, and certain parts of Abbottabad and Mansehra in Khyber Pakhtunkhwa Government sector investments are available Alleviating the burden of water collection on women, freeing up time for education and income generation (Rashid, Awan, Ullah, & Hassan, 2018) Beneficial for communities affected by desertification Integration with other technologies
EMERGING		
IOT Solar pumps (First Emerging)	The challenge of a 100% up-front payment (Hussain, 2023) along with unclear progress for existing financial allocation poses financial challenges Solar water pumps typically have lower flow rates compared to diesel pumps (SELF, 2008) PV solar pumping may cause uncontrolled Pumping (Hussain, et al., 2023). Solar water pumps are less effective on cloudy days or during extended periods of low sunlight (Hussain, 2023). Absence of solar groundwater pumping policy (Hussain, 2023)	Adding value to existing, well-developed technology using information technology Harnessing the power of sensors and real-time data analysis Conversion of existing pumps to IOT based on solar Inclusive development by addressing gender disparities Integration with rainwater harvesting for ground water recharge

	Technical expertise for operation and maintenance of solar water pumps are required (Hussain, 2023).	
AI Integrated GIS and Remote Sensing for Water Management (Second Emerging)	Lack of specialized skills and training Financial barriers to widespread implementation Inadequate data for large-scale groundwater modelling Limited access to advanced hardware and software and lack of reliable internet and real-time monitoring capabilities Underrepresentation of women in the remote sensing community Weak cybersecurity measures to safeguard sensitive groundwater data.	Supportive legal and regulatory framework Increased efficiency in water usage Lead to more hydropower generation with less waste and sustainable groundwater use Data collection for technical feasibility Ability to address flood risks Long term benefit outruns initial investment and ongoing costs

4.2 Evaluation of Selected Water Technologies

To develop a well-informed Action Plan, the current standing of each technology has been marked as seen in the heatmap below. This positioning has been defined through assessment in the existing legal and financial frameworks, economic and technical feasibility of the technology and the capacity to incorporate social considerations and reduce environmental impacts. The scoring ranges from 1 to 5 where 1 represents minimal adoptability and is depicted by red and 5 represents maximum adoptability indicated by green. The hues of both colors symbolize intensity of ease of adoption whereas yellow given to score 3 signifying a neutral score.

4.2.1 Technology Readiness

The following heatmap scores each technology against the assessment criteria and it can be seen that Drip Irrigation has the highest score and visually represents hues of green except for the resilience factor. Similarly other three existing technologies are majorly represented by dark and light green with a solid chunk of neutral yellow for the 'Inclusivity and Climate Impact' section. Legal and financial barriers are observed for all three technologies with some technical and economic feasibility issues for hydropower plant projects.

IOT based solar pumps is the technology with the least score representing difficulty in adoption where a targeted approach to focus on developing guidelines and regulation, building model projects and including social and gender consideration can bring about a positive outcome. AI integrated GIS and Remote Sensing for Water Management despite a low score has been included in the list of prioritized technologies. This is in response to the recommendation from the Ministry of Water Resources to align the NDC Technology Roadmap with the National Flood Management Plan. Floods are noted to be the most frequently occurring climate induced disasters in Pakistan. The floods of 2022 have been called for an urgent need of climate action in the country inviting global collaboration to address the issue designing mitigation and adaptation measures.

Therefore, the need to include this technology for flood management and its integration with other prioritized technologies is expected to bring efficiency and informed technology implementation and water resource management.

		Existing				Emerging	
Category	**Parameters**	**Drip Irrigation**	**Run of the River Plant**	**Micro and Small Hydropower**	**Rainwater Harvesting**	**IOT Solar Based Pumps and Storage**	**AI Integrated GIS and Remote Sensing for Water Management (Second Emerging) ***
Legal and Financial Framework	Guidelines/ Regulations	5	5	5	3	2	2
	Financial Structure	5	3	3	4	3	3
	Private Sector Mobilization	5	4	5	3	3	2
Economic and Technical Feasibility	Resource Efficiency	4	5	4	4	5	2
	Management Efficiency	5	4	3	5	4	2
	Economic Feasibility	4	3	4	4	4	3
	Existing Project	4	4	4	4	1	2
	Skill Capacity	5	3	4	4	3	2
	Capacity Building	5	4	4	4	3	3
Inclusivity and Climate Impact	Emissions Reduction	4	5	4	2	3	2
	Building Resilience	2	4	3	3	2	3
	Quality of Life	4	4	4	4	4	1
	Inclusive Development	4	3	3	3	3	2
	Social Equality	4	3	3	3	3	2
	Gender Considerations	4	3	3	3	3	2
	TOTAL	**64**	**57**	**56**	**53**	**46**	**33**

Prioritized to align with Ministry of Water Resources' recommendation to align NDC Technology Roadmap with National Flood Management Plan*

Legend

1	2	3	4	5

This current standing of technologies based on the assessment through scoring criteria above is then translated and mapped onto the Technology Readiness Level (TRL) Chart after incorporating the challenges and barriers for the technology specifically considering local context. The following scale with description for each level was used to assess readiness level.

TRL Level Number	Description
TRL 1: Basic Principles	Scientific research is beginning, and results are being translated into future research and development.
TRL 2: Concept Formulated	Technology is very speculative, as there is little to no experimental proof of concept for the technology.
TRL 3: Proof of Concept	Both analytical and laboratory studies are required to see if a technology is viable and ready to proceed further through the development process.
TRL 4: Lab Validation	Multiple component pieces are tested with one another.
TRL 5: Integrated Simulation	Simulations should be run in environments that are as close to realistic as possible.
TRL 6: Prototype Demonstration	Technology has a fully functional prototype or representational model.
TRL 7: Operational Demonstration	Technology requires that the working model or prototype be demonstrated in actual environment.
TRL 8: Final Technology Demonstration	Technology has been tested and ready for implementation into an already existing technology or technology system.
TRL 9: Operational Development Demonstration	Technology has been 'flight proven' in actual system through successful operations

The table below indicates where the technology currently stands in the different progress phases of readiness. The placement of each technology within the three progressive phases ranging from Research, Development and Deployment provides a clear direction for the action plan and the strategy that needs to be adopted in the successful implementation to achieve the targeted outcome.

Drip Irrigation, although having the highest score in the assessment criteria, falls down to level 6 of prototype demonstration due to lack of compatibility with indigenous factors as mentioned in the description. Hydropower generation technologies of Run-of-the River Plant and Micro and Small Hydropower Plants are considered as fully ready for adoption mainly due to the existence of fully developed projects and models utilizing traditional practices in some provinces. Rainwater Harvesting is also seen with high readiness of Level 9 of operational deployment because of existing projects and the involvement of research institutions for design development.

IOT Solar Based Pumps, despite being heavily supported with formulated policy and facilitating schemes has lowest readiness owing to the integration of information technology that entails effort on awareness, capacity building and technical skills. AI Integrated GIS and Remote Sensing for Water Management also has a low score due to the need to include latest technology and tools, technical skills and high costs of setting up labs.

Seb-sector	Technology	Phase	TRL No	Readiness Level	Description
EXISTING					
Agriculture	Drip Irrigation	Development	6	Prototype Demonstration	Although strongly supported by policy, clear mechanisms of implementation but regulatory framework is still evolving. Despite subsidies the upscaling is hindered by upfront cost and maintenance of the technology. Furthermore, the major cash crops (wheat, maize, rice) produced by Pakistan are not supported by the technology. Research and innovation is needed to adapt the technology to indigenous requirements and to reduce maintenance issues which are a main barrier to adoption.
Hydropower	Run Off the River Plant	Deployment	9	Operational Deployment	Supported by policy and guidelines and engagement of private sector and foreign investment. Scaled-up projects are operational and opportunity to tap into unexplored potential is promising.
Hydropower	Micro and Small Hydropower	Deployment	9	Operational Deployment	Policy exists to support growth and incentivize proponents. Wider scale adoption facilitated by foreign grants. Community engagement plays a vital role in success.
Domestic	Rainwater Harvesting	Research	9	Operational Deployment	Policy and framework exist with the absence of clear guidelines and monitoring. Widescale adoption in some provinces integrated with traditional technology.
EMERGING					
Agriculture	IOT Based Solar Power Plants	Research	2	Concept Formulated	Numerous schemes are operational to promote the solar technology but IOT based pumps need further development. Financial assistance is available for projects that have gone unmonitored and were poorly managed. The need for capacity building especially technical skill development for operation and maintenance along with the absence of proof of concept in expected environment is the reason for low TRL score.
	AI Integrated GIS and Remote Sensing for Water Management	Research	2	Concept Formulated	Implemented for hydropower plant. Need for specialized skills and training. Financial barriers to widespread implementation. Inadequate data for large-scale groundwater modelling. Need to update with latest machines and tools.

	(Second Emerging)				

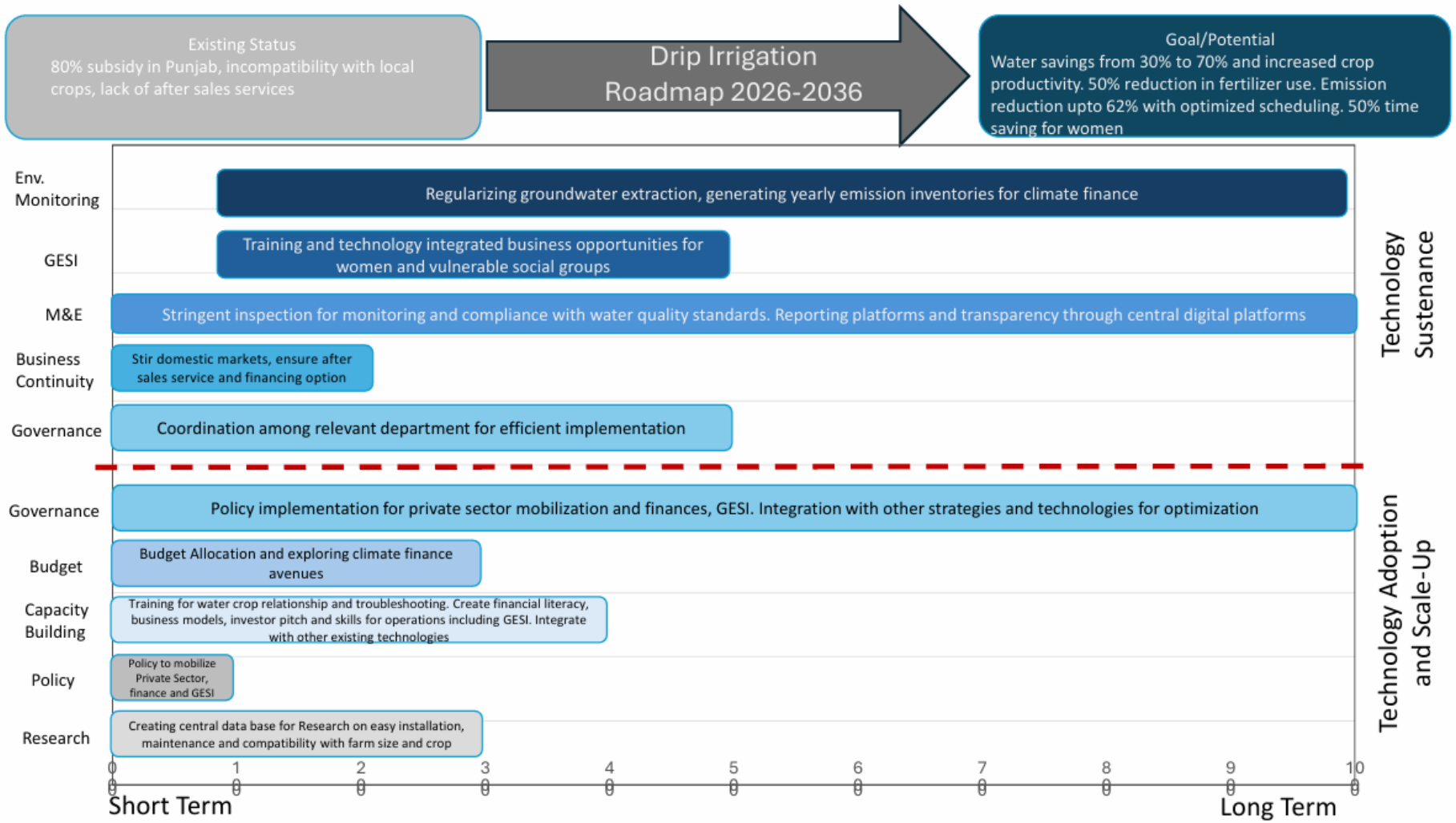
Legend

4.3 A Roadmap for Water Sector Transformation: Action Plans

The water sector holds significant potential to contribute to NDCs targets through technology intervention. Some existing and well-developed options such as hydropower generation and rainwater harvesting can play a major role in achieving 60% renewable energy mix by 2030 and goals like groundwater recharge and reduced flood risks. This technology roadmap and its action plan is a guide to incorporate capacity building which has been identified as one of the prominent barriers to wider scale adoption of currently existing technologies. Training on technology outcome application, financial literacy, integration of information technology and preparing emissions inventories are the key features of the action plan for the water sector that are targeted towards the private sector to align sustainable development with climate action. All proposed actions have been strengthened by policy revisions, vigilant monitoring and evaluation systems, identification of responsible stakeholders and coordination among them and social considerations such as gender specific roles and capacities of the technology end user like farmers.

4.3.1 Rationale for an Integrated Water Management Approach to Technology Intervention

The roadmap for the water sector has been developed keeping in mind all the information gathered around the prioritized technologies and the local context. Stakeholder consultation meeting was a vital part of this process where on ground realities were discussed to assess the viability of each technology. Some of the prominent challenges identified were the mismatched demand and supply of water resources, unavailability of data for water resource management, ground water depletion specifically in the province of Punjab and KPK and climate change. Furthermore, for technology adoption, lack of capacity building programs was identified as an issue. In Gilgit Baltistan a separate set of challenges included melting of glaciers, drying of springs and overexploitation of water resources for agriculture. The action plan for each technology has been developed individually, however some technology integrations have been suggested to achieve efficient water resource management. An example of this is utilizing AI integrated GIS labs for monitoring and mapping of ground water for a sustainable use of IoT Based Solar Pumping technology


Existing Status
80% subsidy in Punjab, incompatibility with local crops, lack of after sales services
Drip Irrigation Roadmap 2026-2036
Goal/Potential
Water savings from 30% to 70% and increased crop productivity. 50% reduction in fertilizer use. Emission reduction upto 62% with optimized scheduling. 50% time saving for women
Env. Monitoring
Regularizing groundwater extraction, generating yearly emission inventories for climate finance
GESI
Training and technology integrated business opportunities for women and vulnerable social groups
M&E
Stringent inspection for monitoring and compliance with water quality standards. Reporting platforms and transparency through central digital platforms
Business Continuity
Stir domestic markets, ensure after sales service and financing option
Governance
Coordination among relevant department for efficient implementation
Governance
Policy implementation for private sector mobilization and finances, GESI. Integration with other strategies and technologies for optimization
Budget
Budget Allocation and exploring climate finance avenues
Capacity Building
Training for water crop relationship and troubleshooting. Create financial literacy, business models, investor pitch and skills for operations including GESI. Integrate with other existing technologies
Policy
Policy to mobilize Private Sector, finance and GESI
Research
Creating central data base for Research on easy installation, maintenance and compatibility with farm size and crop
Technology Sustenance
Technology Adoption and Scale-Up
0
1
2
3
4
5
6
7
8
9
10
Short Term
Long Term

Drip Irrigation (TRL Level 6: Prototype Demonstration)				
TECHNOLOGY ADOPTION & SCALE-UP				
Action Item	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify Stakeholders**
RESEARCH				
Long Term				
Initiate research and development programs with industry-academia partnership on identified technical, environmental and social issues for the technology	Focused research to design policy sensitive to barriers faced by marginalized groups, such as women and smallholder farmers, in accessing and using the technology. Study, socio-cultural norms, financial constraints, and knowledge gaps in local context. Research on innovative designs for easy installation, maintenance, compatibility with farm size and sown crop.	0-3 y	**High**	MoCC & EC MoWR MNFSR MoST Provincial EPDs and EPAs Provincial Agriculture and Irrigation Departments PARC PCRWR HEC

	Research on technology designs that are cost effective.			Academic Institutes NGOs
Facilitate development of central data base with clear data sharing protocols.	Display of roles and responsibilities of stakeholders along with responsiveness to performance parameters Improved water resource management through transparent dissemination of existing projects information among relevant departments	0-2 y	**High**	MoIT Provincial EPDs and EPAs Provincial Agriculture and Irrigation Departments
POLICY				
Short Term				
Identify gaps and shortcomings of existing policies and guidelines for drip irrigation and incorporate revisions for improvement	Develop demand-side agriculture water management policies incorporating drip irrigation Improve the support of government for widespread adoption of technology.	0-1 y	**Very High**	MoCC & EC MoWR MNFSR
Develop regulations that mobilize private sector for	Incorporate private sector for wider	0-1 y	**Very High**	MoCC & EC

the implementation, operations and maintenance of drip irrigation technology	adoption and less reliance on donor fundings through low interest loans, public private partner ships and impact bonds. Offer tax exemption and subsidies to companies investing in drip irrigation infrastructure in terms of land acquisition, purchasing machinery, managing operations etc. Provide long term concession agreements in exchange of revenue sharing business models to accommodate high upfront cost of technology adoption			MoWR MNFSR Provincial EPDs and EPAs SECP Provincial Agriculture and Irrigation Departments
Develop regulations that mobilize finances other than private sector investment for the implementation, operations and maintenance of drip irrigation technology	Enable microfinance programs for small scale farmers Collaborate with development sector bank funding, grants and schemes to secure financial assistance at low-interest	0-1 y	**Very High**	MoCC & EC MoWR MNFSR Provincial EPDs and EPAs

	Initiate government programs for youth loans and development of small medium enterprises for installation and maintenance purpose Promote crowd funding programs along with venture capital as financing solution Introduce water pricing policy to reduce excessive use of ground water			Provincial Agriculture and Irrigation Departments Development Sector MicroFinancing Banks, Institutes SMEDA
Develop regulations that ensure gender equality and social inclusion in implementation and, operation and maintenance of drip irrigation technology	Gender/socially responsive recruitment to include a percentage of women, youth and individuals from marginalized groups especially belonging to the local community targeted for positions within governance structures Promote female-led farmer organisations and ensure gender responsive workplace policies such as	0-1 y	**Very High**	MoCC & EC MoHR, MoWR, MNFSR Provincial EPDs and EPAs Provincial Agriculture and Irrigation Departments

	flexible workhours and antiharassment rules. Designate a percentage of women employment as a qualification criteria for grants/funding			NGOs Civil Societies Multilateral Organizations
CAPACITY BUILDING				
Short Term				
Create awareness among communities for water saving and wider adoption of the technology	Capacity building of regulatory authorities for effective implementation of climate resilient measures in drip irrigation. Workshops and field visits, conducted with onsite engagement of farmers on topics of water-crop relationship, system maintenance and troubleshooting, crop selection and management	0-2 y	**Medium**	MoWR, MNFSR PARCPCRWR Provincial Irrigation and Agricultural Departments and Extensions Farmer Organizations Multilateral Organisations
Long Term				
Promote and establish innovation hubs and business incubation centres to develop research and	Develop knowledge and skills to prepare and develop business models, business	2-4 y	**Medium**	MoIP MoC

foster innovation along with business management skills for the drip irrigation	plans, proposals and elevator pitch for drip irrigation facilities to present business ideas to potential investors and to secure donor funding. Develop financial literacy covering topics of budgeting, cost control and revenue management especially targeting women and youth Research various combinations of machinery and integration with other technologies such as Rainwater Harvesting and Solar Pumping for optimization of water resource management			Provincial EPDs and EPAs PARC PCRWR Academic Institutes SMEDA PITAC
Evaluate the existing knowledge of potential local project proponents about technology and business management pertaining to drip irrigation and design an awareness campaign accordingly.	Conduct training sessions for local engineers, technicians and facility operators to design, run and maintain drip irrigation technology with a special focus on managerial training for women farmers, youth, informal sector and marginal groups.	Ongoing	**Medium**	Provincial Agriculture and Irrigation Departments PARC PCRWR

				Academic Institutes
BUDGET				
Short Term				
Allocate an annual quota in the fiscal budget for development of schemes for drip irrigation infrastructure	Allocation of budget with clear guidelines for utilization.	0-6 m	**Very High**	MoCC & EC MoWR, MNFSR, MoF
Long Term				
Explore national and international climate finance options by establishing mechanisms	Enable access to green financing options of low-interest loans and green bonds especially to youth as a vulnerable group to climate change impacts. Establish frameworks that enable initiatives to earn blue carbon credits for revenue generation from national and international carbon markets	1-3 y	**Very High**	MoCC & EC MoWR, MNFSR, MoF Provincial EPDs and EPAs Development Sector Pakistan Stock Exchange

				Multilateral financial institutions Carbon crediting entities
GOVERNANCE				
Short Term				
Incorporate combination of actions to optimize efficiency	Drip irrigation combined with optimized scheduling	Ongoing	**Very High**	Provincial EPDs and EPAs Provincial Agriculture and Irrigation Departments
Ensure policy implementation of public-private partnership for efficiency and upscaling and wider scale adoption of the technology.	Define roles and responsibilities, compliance requirements and accountability measures of all stakeholder including private sector, government agencies and local authorities Facilitate establishing public private partnerships in the first 3 years of technology implementation	0-3 y	**Very High**	Provincial EPAs and EPDs Provincial Agriculture and Irrigation Departments PPPA

	Mandate compliance with water management standards to be reported to EPAs and EPDs			
Ensure policy implementation of gender equality and social inclusion in technology implementation and operations	Introduce 2% quota of women at managerial positions Introduction of women and youth led business initiatives in the market Target communities in arid areas to adopt drip irrigation in response to water scarcity	0-3 y	**Very High**	MoCC & EC MoHR Provincial Agriculture and Irrigation Departments
TECHNOLOGY SUSTENANCE				
Action Plan (short-term and long-term) and Milestones	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify stakeholders**
GOVERNANCE				
Short Term				
Balance disparities and inconsistencies in water resource management regulations across regions and provinces.	Achieve effective coordination among different stakeholder organizations and the private sector	0-5 y	**High**	MoCC&EC MoWR

	Attained equal distribution of water in all provinces and regions			MNFSR Provincial EPDs and EPAs Provincial and Regional Agriculture and Irrigation Departments
BUSINESS CONTINUITY				
Short Term				
Facilitate wider adoption of the technology by exploring untapped areas and developing markets	Initiated projects in identified potential sites stirring domestic markets and local production Mobilize private sector specifically in accessories and after sales service provision for maintenance using locally available material in domestic markets for cost reduction and	0-2 y	**High**	PARC/NARC PCRWR PBR PPPA MicroFinance Banks and Institutions WAPDA

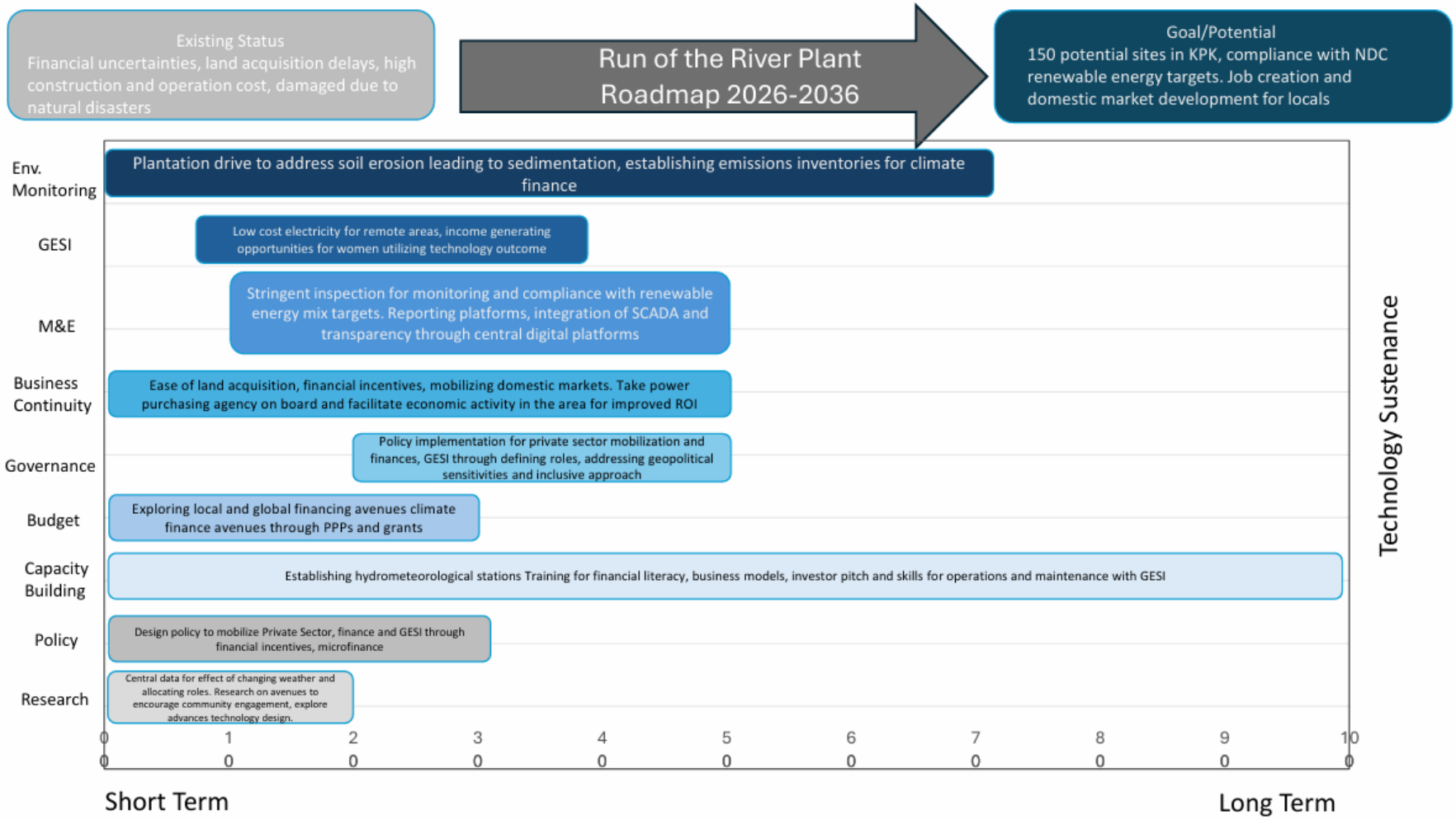
	employment generation for locals Provide easy loans with low interest and microfinancing options especially in remote areas			
Long Term				
Integrate technology with other technologies for long term sustenance and business continuity	Integrate drip irrigation with hydropower project diverting water in reservoirs to irrigation channels equipped with drip irrigation after power generation Integrate with GIS mapping for identification of potential sites in need of drip irrigation and efficient water resource management	0-2 y	**Medium**	MoCC & EC MoWR MNFSR MoE Provincial Energy Departments Provincial Agriculture and Irrigation Departments
MONITORING AND EVALUATION				
Short Term				
Develop and implement balanced but vigilant monitoring and evaluation protocols	Stringent inspection of technology to monitor compliance with water, energy and food nexus along with water management standards	1-3 y	**Very High**	Provincial EPDs and EPAs

	e.g ground water depletion rate and quality, water efficiency etc Ensure compliance with 2030 and 2050 targets to ensure water security			Provincial Agriculture and Irrigation Departments PARC/NARC
Ensure vigilant inspection of gender equality and social inclusion indicators to monitor policy implementation outcome	Develop anonymous reporting platform for gender specific complaints Implementation of regular inspection and audits to assess reasons for failure for policy improvement indicators.	1-3 y	**High**	MoHR NGOs Civil SocietiesMulti lateral Organizations supporting such groups
Long Term				
Bring transparency to monitoring and evaluation system through integration of information technology	Generate lists on digital platform for central database with rankings of entities along with their performance based on efficient operations, water saving practices etc. for a transparent review that will drive factors such as license	2-5 y	**Very High**	Provincial EPDs and EPAs Provincial Agriculture and Irrigation Departments

	renewal, incentive provision etc. Generate a performance feedback system indicative of level of execution of the technology through operational private sector entities Regular assessment of strong coordination among stakeholders			PARC/NARC
GENDER EQUALITY AND SOCIAL INCLUSION				
Short Term				
Incorporate gender equality and social inclusion considerations	Technical training sessions conducted regularly to train women in drip irrigation and its efficiency optimization techniques Design and introduce women operated orchids with drip irrigation	2-5 y	**Very High**	Provincial EPDs and EPAs Provincial Agriculture and Irrigation Departments PARC PCRWR NGOs

	Ensure that training sessions are scheduled keeping in mind household responsibilities of women			
ENVIRONMENTAL MONITORING				
Short Term				
Regularize ground water extraction for a well informed integration with technology adoption	Collect data on ground water depletion reduction specifically in response to technology adoption Integrate with AI integrated GIS and RS technology for better resource mapping and decision making	0-3 y	**High**	Provincial EPDs and EPAs Provincial Agriculture and Irrigation Departments PARC PCRWR
Long Term				
Quantify emission reduction potential and on ground achieved targets to align with NDCs goals and qualify for carbon markets	Implementation of blue carbon accounting protocols to quantify baseline scenario carbon emissions. Generation of yearly inventories to quantify	0-10 y	**Very High**	Provincial EPDs and EPAs Provincial Agriculture and Irrigation Departments

	achieved emissions reduction.			PARC PCRWR Carbon Accounting Entities


Existing Status
Financial uncertainties, land acquisition delays, high construction and operation cost, damaged due to natural disasters
Run of the River Plant Roadmap 2026-2036
Goal/Potential
150 potential sites in KPK, compliance with NDC renewable energy targets. Job creation and domestic market development for locals
Env. Monitoring
Plantation drive to address soil erosion leading to sedimentation, establishing emissions inventories for climate finance
GESI
Low cost electricity for remote areas, income generating opportunities for women utilizing technology outcome
M&E
Stringent inspection for monitoring and compliance with renewable energy mix targets. Reporting platforms, integration of SCADA and transparency through central digital platforms
Business Continuity
Ease of land acquisition, financial incentives, mobilizing domestic markets. Take power purchasing agency on board and facilitate economic activity in the area for improved ROI
Governance
Policy implementation for private sector mobilization and finances, GESI through defining roles, addressing geopolitical sensitivities and inclusive approach
Budget
Exploring local and global financing avenues climate finance avenues through PPPs and grants
Capacity Building
Establishing hydrometeorological stations Training for financial literacy, business models, investor pitch and skills for operations and maintenance with GESI
Policy
Design policy to mobilize Private Sector, finance and GESI through financial incentives, microfinance
Research
Central data for effect of changing weather and allocating roles. Research on avenues to encourage community engagement, explore advances technology design.
0
10
20
30
40
50
60
70
80
90
100
Short Term
Long Term
Technology Sustenance

Run of the River Plant (TRL Level 9: Operational Deployment)				
TECHNOLOGY SUSTENANCE				
Action Item	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify Stakeholders**
RESEARCH				
Long Term				
Initiate research and development programs with industry-academia partnership on identified technical, environmental and social issues for the technology and encourage development of central data base with clear data sharing protocols.	Focused research on business models suited to local factors, pathways for mobilizing finances. Encourage participation and cooperation of indigenous community through establishing mechanisms of compensation and awareness of community benefits introduced by technology. Research on advanced turbines for varying river flows and enhanced efficiency. Focus on solution for	0-2 y	**High**	MoCC & EC MoWR MoST MoE Provincial EPDs and EPAs Provincial Energy and Power Development Organizations and Boards WAPDA NEPRA

	siltation and sedimentation. Study the effect of changing weather and glacial melt in the long run and potential for harmonized water resource management among provinces.			PPIB PCRWR HEC Academic Institutes NGOs
Facilitate development of central data base with clear data sharing protocols.	Transparent display of roles and responsibilities of stakeholders along with their responsiveness to performance parameters Store and manage data, track key performance indicator, and integrate GIS mapping to identify potential sites for run of the river plants and spatial relationships	0-2 y	**High**	MoIT MoE WAPDA NEPRA PPIB Provincial Energy and Power Development Organizations and Boards
POLICY				
Short Term				

Identify gaps and shortcomings of existing policies and guidelines for run of the river plants and incorporate revisions for improvement	Develop demand-side agriculture water management policies incorporating run of the river plants Provide an enabling environment for exploring the potential of untapped sites suitable for technology adoption.	0-1 y	**Very High**	MoCC & EC MoWR MoE WAPDA NEPRA
Develop regulations that mobilize private sector for the implementation, operations and maintenance of run of the river plant technology	Incorporate private sector for wider adoption and less reliance on donor fundings through low interest loans, public private partnerships and impact bonds. Offer tax exemption and subsidies to companies investing in run off the river infrastructure in terms of land acquisition, construction, managing operations etc. Provide long term concession agreements in exchange of revenue sharing business models and public land	0-1 y	**Very High**	MoCC & EC MoWR MoE Provincial EPDs and EPAs Provincial Energy Departments WAPDA NEPRA PPIB SECP

	leases offered to build and operate facility			PPPA
Develop policies and regulations that mobilize finances other than private sector investment for the implementation, operations and maintenance of run of the river plant technology	Enable microfinance programs for project proponents Collaborate with development bank funding, grants and schemes to secure financial assistance at low-interest Promote crowd funding programs along with venture capital as financing solution Dedicated Micro financing available through existing programmes and schemes in mountainous areas and watercourse	0-3 y	**Very High**	MoCC & EC MoWR MoE Provincial EPDs and EPAs Provincial Energy Departments WAPDA NEPRA PPIB Development Sector MicroFinance Banks and Institutes

				SMEDA
Develop policy and regulations that ensure gender equality and social inclusion in implementation and, operation and maintenance of run of the river technology	Gender/socially responsive recruitment to include a percentage of women, youth and individuals from marginalized groups especially belonging to the local community targeted for positions within governance structures Ensure gender responsive workplace policies such as flexible workhours and antiharassment rules. Designate a percentage of women employment as a qualification criteria for grants/funding	0-1 y	**Very High**	MoCC & EC MoWR MoE MoHR Provincial Energy Departments Provincial EPDs and EPAs WAPDA NEPRA PPIB NGOs Civil Societies Multilateral Organizations
CAPACITY BUILDING				
Long Term				
Evaluate the existing knowledge of potential	Conduct training sessions for local	Ongoing	**Medium**	MoCC & EC

project proponents about technology and business management pertaining the facility and design an awareness campaign accordingly.	engineers, technicians and facility operators to design, run and maintain technology with a special focus on managerial training for women, youth, informal sector and marginal groups. Develop hydrometeorological stations for well informed data on water flows for efficient management			MoWR MoE Provincial EPDs and EPAs Provincial Energy and Power Development Organizations and Boards WAPDA NEPRA PPIB PARC PCRWR Academic Institutes
Promote and establish business hubs and incubation centres to develop research and foster innovation along with	Develop knowledge and skills to prepare and develop business models, business plans, proposals and	2-5 y	**Medium**	MoCC & EC MoWR

business management skills for the developing run of the river plants	elevator pitch for run of of the river technology to present business ideas to potential investors and to secure donor funding. Develop financial literacy covering topics of budgeting, cost control and revenue management especially targeting women and youth			MoST MoE Provincial EPDs and EPAs Provincial Energy and Power Development Organizations and Boards WAPDA NEPRA PPIB PARC PCRWR Academic Institutes SMEDA PITAC

BUDGET				
Short Term				
Explore avenues to enhance available budget	Acquire PPP models, bilateral aid from other countries and grants from international organizations to develop new revenue generating run of the river plants.	0-6 m		MoCC & EC MoWR MoE MoF
Long Term				
Explore national and international climate finance options by establishing assisting mechanisms	Enable access to green financing options of low-interest loans and green bonds especially to youth as a vulnerable group to climate change impacts. Establish frameworks that enable initiatives to earn blue carbon credits and carbon credits for revenue generation from national and international carbon markets	1-3 y	**Very High**	MoCC & EC MoWR MoE Provincial EPDs and EPAs WAPDA NEPRA PPIB Development Sector Pakistan Stock Exchange

				Multilateral financial institutions Carbon Crediting entities
GOVERNANCE				
Short Term				
Ensure policy implementation of public-private partnership for efficiency and upscaling and wider scale adoption of the technology.	Define roles and responsibilities, compliance requirements and accountability measures of all stakeholders including private sector, government agencies and local authorities Take measures such as stakeholder consultations and compensation strategies to accommodate geopolitical sensitivities Mandate compliance with efficiency of technology operations	2-5 y	**Very High**	Provincial EPDs and EPAs WAPDA NEPRA PPIB Provincial Energy and Power Development Organizations and Boards PPPA

	and social inclusions metrics			
Ensure policy implementation of gender equality and social inclusion in technology implementation and operations	Introduce 2% quota of women at managerial positions Introduction of women and youth led business initiatives in the domestic market	2-4 y	**Very High**	Provincial EPDs and EPAs WAPDA NEPRA PPIB
BUSINESS CONTINUITY				
Short Term				
Facilitate wider adoption of the technology by exploring untapped areas	Ease of land acquisition through fair compensation and livelihood restoration Initiated projects in identified potential sites Mobilize private sector specifically in service provision for maintenance using locally available material in domestic markets Provide easy loans with low interest and	0-2 y	**High**	MoCC & EC MoWR MoE Provincial EPDs and EPAs WAPDA NEPRA PPIB Provincial Energy and Power

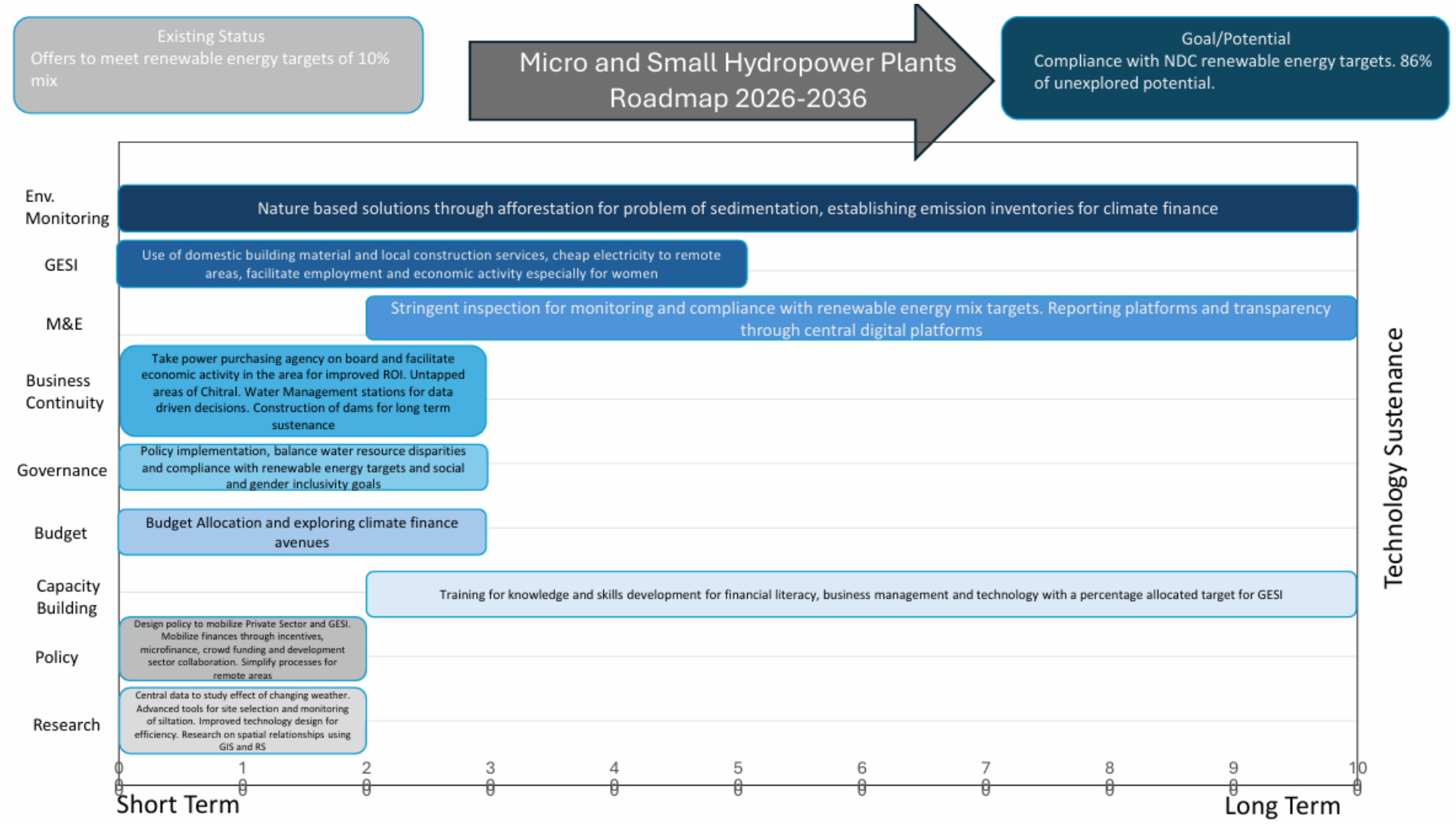
	microfinancing options especially in remote areas			Development Organizations and Boards MicroFinance Banks and Institutions PBR PPPA
Improve market by harmonization of relevant stakeholders	On-board Central Power Purchasing Agency for every developed project to ensure electricity purchase Facilitate economic activity especially in remote areas to increase use of electricity for better return on investment	2-5 y	**Very High**	MoIP MoC Provincial EPDs and EPAs WAPDA NEPRA PPIB Provincial Energy and Power Development Organizations and Boards Provincial Energy

				DepartmentsNEPRA PPIB CPPA Project Proponent Private Sector
MONITORING AND EVALUATION				
Short Term				
Develop and implement balanced but vigilant monitoring and evaluation protocols	Stringent inspection of project for delivery of low cost electricity to remote areas and compliance with renewable energy mix targets Use SCADA to monitor flow meters, turbines, generators for smooth running and predictive maintenance	1-5 y	**Very High**	Provincial EPAs and EPDs Provincial Energy and Power Development Organizations and Boards WAPDA NEPRA
Ensure vigilant inspection of gender equality and social inclusion indicators	Develop anonymous reporting platform for	3-5 y	**High**	Provincial Energy and Power

to monitor policy implementation outcome and assessment of necessary revision in policy for achieving targets	gender specific complaints Implementation of regular inspection and audits to assess relevant indicators. Ensure that training sessions are scheduled keeping in mind household responsibilities of women			Development Organizations and Boards MoHR NGOs Civil Societies WAPDA NEPRA
GENDER EQUALITY AND SOCIAL INCLUSION				
Short Term				
Ensure provision of cheap electricity to remote areas and facilitate consequent potential to opportunity to improve income generation	Ensure connection with national grid for provision of electricity for remote areas.	1-3 y	**Very High**	Provincial EPDs and EPAs Provincial Energy and Power Development Organizations and Boards WAPDA NEPRA

Develop schemes to facilitate women led cottage industry	Enable women leveraging the time saving by the use of this technology for other income generating opportunities through small scale business e.g exhibition centres for handicraft	3-5 y	**Very High**	MoIP MoC MoWR PIDC
ENVIRONMENTAL MONITORING				
Short Term				
Utilize nature based solutions for technology maintenance	Encourage and facilitate plantation drives to reduce soil erosion and sedimentation in reservoirs	1-3 y	**High**	Provincial Forest Departments
Long Term				
Quantify emission reduction potential and on ground achieved targets to align with NDCs goals.	Implementation of blue carbon accounting protocols to quantify baseline scenario carbon emissions. Generation of yearly inventories to quantify achieved emissions reduction.	0-10 y	**Very High**	MoE and Provincial Energy Departments Provincial EPDs and EPAs Provincial Energy and Power Development Organizations and Boards

				PCRWR


Existing Status
Offers to meet renewable energy targets of 10% mix
Micro and Small Hydropower Plants Roadmap 2026-2036
Goal/Potential
Compliance with NDC renewable energy targets. 86% of unexplored potential.
Env. Monitoring
Nature based solutions through afforestation for problem of sedimentation, establishing emission inventories for climate finance
GESI
Use of domestic building material and local construction services, cheap electricity to remote areas, facilitate employment and economic activity especially for women
M&E
Stringent inspection for monitoring and compliance with renewable energy mix targets. Reporting platforms and transparency through central digital platforms
Business Continuity
Take power purchasing agency on board and facilitate economic activity in the area for improved ROI. Untapped areas of Chitral. Water Management stations for data driven decisions. Construction of dams for long term sustenance
Governance
Policy implementation, balance water resource disparities and compliance with renewable energy targets and social and gender inclusivity goals
Budget
Budget Allocation and exploring climate finance avenues
Capacity Building
Training for knowledge and skills development for financial literacy, business management and technology with a percentage allocated target for GESI
Policy
Design policy to mobilize Private Sector and GESI. Mobilize finances through incentives, microfinance, crowd funding and development sector collaboration. Simplify processes for remote areas
Research
Central data to study effect of changing weather. Advanced tools for site selection and monitoring of siltation. Improved technology design for efficiency. Research on spatial relationships using GIS and RS
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Short Term
Long Term
Technology Sustenance

Micro and Small Hydropower Plants (TRL Level 9: Operational Deployment)

TECHNOLOGY SUSTENANCE

Action Item	Milestones/Targets	Deadline	Priority Level	Identify Stakeholders
RESEARCH				
Long Term				
Initiate research and development programs with industry-academia partnership on identified technical, environmental and social issues for the technology and encourage development of central data base with clear data sharing protocols.	Focused research on business models suited to local factors and based on realistic on ground studies. Pathways for mobilizing finances and inconvenience (displacement) and benefits to the community to encourage cooperation and participation in technology implementation Research using advanced tools for site selection, siltation and sedimentation, advanced turbines for varying river flows	0-2 y	**High**	MoCC & EC MoWR MoST MoE Provincial EPDs and EPAs and Energy Departments Provincial Energy and Power Development Organizations and Boards

	and enhanced efficiency. Study the effect of changing weather and glacial melt in the long run and potential for harmonized water resource management among provinces.			WAPDA NEPRA PPIB PCRWR HEC Academic Institutes NGOs
Facilitate development of central data base with clear data sharing protocols.	Transparent display of roles and responsibilities of stakeholders along with their responsiveness to performance parameters Store and manage data, track key performance indicator, and integrate GIS mapping to identify potential sites for micro and small hydropower plants and spatial relationships	0-2 y	**High**	MoIT MoE WAPDA NEPRA PPIB Provincial Energy and Power Development Organizations and Boards
POLICY				
Short Term				

Simplify regulatory process to facilitate wider adoption of technology	Simplfy processes and navigation of requirements especially for remote areas where wide scale adoption needs encouragement	0-1 y	**High**	MoCC & EC MoWR MoE
Develop policy and regulations that mobilize private sector for the implementation, operations and maintenance micro and small hydropower plants	Offer tax exemption and subsidies to companies investing in micro and small hydropower plants technology infrastructure in terms of land acquisition, purchasing machinery, managing operations etc. Incorporate private sector for wider adoption and less reliance on donor fundings through low interest loans, public private partner ships and impact bonds. Provide long term concession agreements in exchange of revenue sharing business models and public land leases offered to build and operate facility	1-2 y	**Very High**	MoCC & EC MoWR MoE Provincial EPDs and EPAs Provincial Energy Departments WAPDA NEPRA PPIB SECP

Develop policies and regulations that mobilize finances other than private sector investment for the implementation, operations and maintenance of micro and small hydropower plants	Collaborate with development sector bank funding, grants and schemes to secure financial assistance at low-interest Initiate government programs for youth loans and development of small medium enterprises for installation, operation and maintenance Promote crowd funding programs along with venture capital as financing solution Dedicated Micro financing available through existing programmes and schemes in mountainous areas and watercourse	1-2 y	**Very High**	MoCC & EC MoWR MoE Provincial EPDs and EPAs Provincial Energy Departments WAPDA NEPRA PPIB Development Sector MicroFinance Banks and Institutes SMEDA

Develop regulations that ensure gender equality and social inclusion in implementation and, operation and maintenance micro and small hydropower plants	Gender/socially responsive recruitment to include a percentage of women, youth and individuals from marginalized groups especially belonging to the local community targeted for positions within governance structures Ensure gender responsive workplace policies such as flexible workhours and antiharassment rules.	0-1 y	**Very High**	MoCC & EC MoWR MoE Provincial EPDs and EPAs Provincial Energy Departments WAPDA NEPRA PPIB MoHR NGOs Civil Societies Multilateral Organizations
CAPACITY BUILDING				
Long Term				
Promote business hubs and incubation centres to develop research and foster innovation along with business management skills for the technology	Develop knowledge and skills to prepare and develop business models, business plans, proposals and elevator pitch for	2-10 y	**Medium**	MoWR MoE Provincial EPDs and

	micro and small hydropower plants to present business ideas to potential investors and to secure donor funding. Develop financial literacy covering topics of budgeting, cost control and revenue management especially targeting women and youth			EPAs and Energy Departments Provincial Energy and Power Development Organizations and Boards WAPDA NEPRA PPIB PCRWR Academic Institutes SMEDA PITAC
Evaluate the existing knowledge of potential project proponents about technology and business management pertaining to facility and design an	Conduct training sessions for local engineers, technicians and facility operators to design, run and maintain technology	Ongoing	**Medium**	MoWR MoE Provincial EPDs and

awareness campaign accordingly.	with a special focus on managerial training for women, youth, and marginal groups. Design awareness campaign to encourage participation of women through timings, locations and medium of trainings decided through gender consideration			EPAs and Energy Departments Provincial Energy and Power Development Organizations and Boards WAPDA NEPRA PPIB PCRWR Academic Institutes
BUDGET				
Short Term				
Allocate an annual quota in the fiscal budget for development of water management infrastructure	Allocation of budget with clear guidelines for utilization.	0-6 m	**Very High**	MoCC & EC MoWR MoE MoF

Explore national and international climate finance options by establishing mechanisms and	Enable access to green financing options of low-interest loans and green bonds especially to youth as a vulnerable group to climate change impacts. Establish frameworks that enable initiatives to earn blue carbon credits for revenue generation from national and international carbon markets	1-3 y	**Very High**	MoCC & EC MoWR MoE Provincial EPDs and EPAs and Energy Departments Provincial Energy and Power Development Organizations and Boards State Bank of Pakistan Pakistan Stock Exchange Multilateral financial institutions

				Carbon Crediting entities
GOVERNANCE				
Short Term				
Balance disparities and inconsistencies in water resource management regulations across regions and provinces.	Attained equal distribution of water in all provinces and regions	0-3 y	**High**	MoCC&EC MoWR MoE Provincial EPDs and EPAs Provincial Energy and Power Development Organizations and Boards WAPDA NEPRA PPIB
Ensure policy implementation of public-private partnership for efficiency and upscaling	Define roles and responsibilities, compliance requirements and accountability	1-3 y	**Very High**	Provincial Energy and Power Development

and wider scale adoption of the technology.	measures of all stakeholder including private sector, government agencies and local authorities Take measures such as stakeholder consultations and compensation strategies to accommodate geopolitical sensitivities Mandate compliance with water management standards to be reported in terms of efficiency of technology and social inclusions metrics			Organizations and Boards PPPA Local authorities
Ensure policy implementation of gender equality and social inclusion in technology implementation and operations	Presence of women at managerial positions as per allocated quota Existence of women and youth led business initiatives	1-2 y	**Very High**	Provincial EPDs and EPAs Provincial Energy and Power Development Organizations and Boards

				WAPDA
BUSINESS CONTINUITY				
Short Term				
Improve market by harmonization of relevant stakeholders	On-board Central Power Purchasing Agency for every developed project to ensure electricity purchase Facilitate economic activity especially in remote areas to increase use of electricity for better return on investment	0-3 y	**Very High**	Provincial Energy and Power Development Organizations and Boards CPPA Project Proponent Private Sector Local Development Authorities
Facilitate wider adoption of the technology by exploring untapped areas	Improve utilization of unexplored sites more than current 14% by untapping potential in Chitral	0-2 y	**High**	Provincial EPDs and EPAs WAPDA NEPRA PPIB

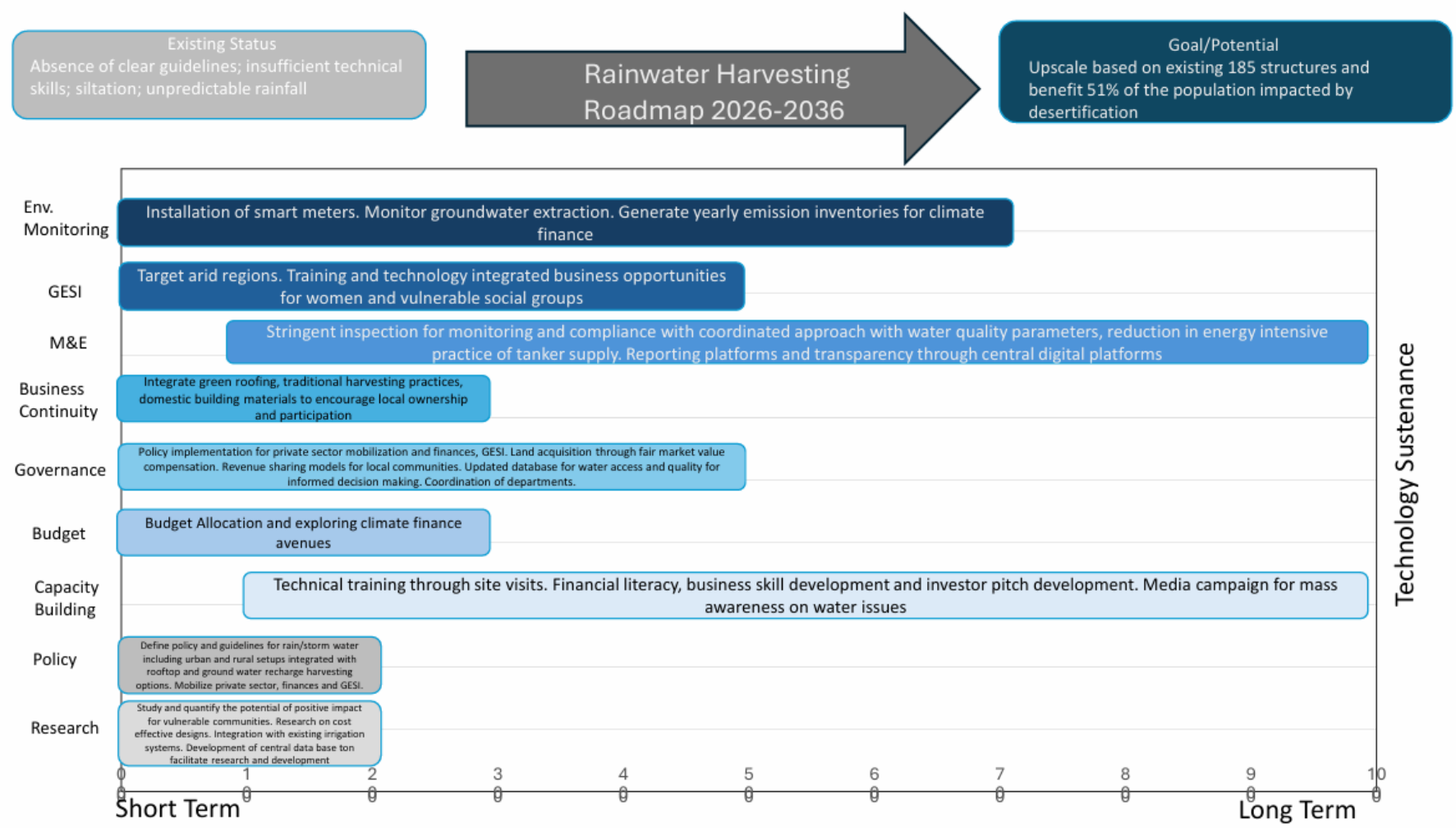
	Ease of land acquisition through compensation Initiated projects in identified potential sites Mobilize private sector for wider adoption			PCRWR PBR PPPA
Long Term				
Manage inconsistent water flows through storage infrastructure	Construction of dams and reservoirs Develop hydrometeorological stations for well-informed data on water flows for efficient management	Ongoing	**High**	Provincial Energy and Power Development Organizations and Boards Meteorological Department WAPDA
MONITORING AND EVALUATION				
Long Term				
Develop and implement balanced but vigilant monitoring and evaluation protocols	Stringent inspection of project for delivery of low cost electricity to remote areas and compliance with	Ongoing	**Very High**	Provincial EPDs and EPAs

	renewable energy mix targets			Provincial Energy and Power Development Organizations and Boards WAPDA NEPRA
Ensure vigilant inspection of gender equality and social inclusion indicators to monitor policy implementation outcome and assessment of necessary revision in policy for achieving targets	Ensure compliance of GESI inclusion in budget and planning Develop anonymous reporting platform for gender specific complaints Implementation of regular inspection and audits to assess relevant indicators. Ensure that training sessions are scheduled keeping in mind household responsibilities of women	Ongoing	**High**	Provincial EPDs and EPAs Provincial Energy and Power Development Organizations and Boards MoHR NGOs Civil Societies

Bring transparency to monitoring and evaluation system through integration of information technology	Generate lists on digital platform with rankings of private sector entities for a transparent review that will drive private sector mobilization factors such as license renewal, incentive provision etc. Generate a performance feedback system on the digital platform indicative of level of execution of the technology through operational private sector entities	2-10 y	**Very High**	Provincial EPDs and EPAs Provincial Energy and Power Development Organizations and Boards WAPDA NEPRA
GENDER EQUALITY AND SOCIAL INCLUSION				
Short Term				
Facilitate local businesses to achieve pronounced positive social impact and reduce cost of construction and maintenance	Use of domestic building material and local construction services Improved income generation, employment opportunities and local business support.	0-2 y	**Medium**	Provincial EPDs and EPAs Provincial Energy and Power Development Organizations and Boards

				Local construction companies SMEDA PIDC
Ensure provision of cheap electricity to remote areas and facilitate consequent potential to opportunity to improve income generation	Ensure connection with national grid for provision of electricity for remote areas.	0-3 y	**Very High**	Provincial EPDs and EPAs Provincial Energy and Power Development Organizations and Boards WAPDA NEPRA PPIB
Develop schemes to facilitate women led cottage industry	Enable women leveraging the time saving by the use of this technology for other income generating opportunities through small scale business	3-5 y	**Very High**	Provincial EPDs and EPAs Provincial Energy and Power Development

	e.g exhibition centres for handicraft			Organizations and Boards WAPDA NEPRA PIDC PPPA SMEDA
ENVIRONMENTAL MONITORING				
Short Term				
Utilize nature based solutions for technology maintenance	Encourage and facilitate plantation drives to reduce soil erosion and sedimentation in reservoirs	0-3 y	**High**	Provincial Forest Departments
Long Term				
Quantify emission reduction potential and on ground achieved targets to align with NDCs goals.	Implementation of blue carbon accounting protocols to quantify baseline scenario blue carbon emissions. Generation of yearly inventories to quantify achieved emissions reduction.	0-10 y	**Very High**	Provincial EPDs and EPAs WAPDA NEPRA PCRWR


Existing Status
Absence of clear guidelines; insufficient technical skills; siltation; unpredictable rainfall
Rainwater Harvesting Roadmap 2026-2036
Goal/Potential
Upscale based on existing 185 structures and benefit 51% of the population impacted by desertification
Env. Monitoring
Installation of smart meters. Monitor groundwater extraction. Generate yearly emission inventories for climate finance
GESI
Target arid regions. Training and technology integrated business opportunities for women and vulnerable social groups
M&E
Stringent inspection for monitoring and compliance with coordinated approach with water quality parameters, reduction in energy intensive practice of tanker supply. Reporting platforms and transparency through central digital platforms
Business Continuity
Integrate green roofing, traditional harvesting practices, domestic building materials to encourage local ownership and participation
Governance
Policy implementation for private sector mobilization and finances, GESI. Land acquisition through fair market value compensation. Revenue sharing models for local communities. Updated database for water access and quality for informed decision making. Coordination of departments.
Budget
Budget Allocation and exploring climate finance avenues
Capacity Building
Technical training through site visits. Financial literacy, business skill development and investor pitch development. Media campaign for mass awareness on water issues
Policy
Define policy and guidelines for rain/storm water including urban and rural setups integrated with rooftop and ground water recharge harvesting options. Mobilize private sector, finances and GESI.
Research
Study and quantify the potential of positive impact for vulnerable communities. Research on cost effective designs. Integration with existing irrigation systems. Development of central data base ton facilitate research and development
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Short Term
Long Term
Technology Sustenance

Rainwater Harvesting (TRL Level 9: Operational Deployment)				
TECHNOLOGY SUSTENANCE				
Action Item	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify Stakeholders**
RESEARCH				
Long Term				
Initiate research and development programs with industry-academia partnership on identified technical, environmental and social issues for the technology and encourage development of central data base with clear data sharing protocols.	Study the effect of changing weather and precipitation in the long run and impact on communities especially vulnerable groups in terms of increased access to water, recharged groundwater, improved sanitation and reduced water costs. Focused research on technology design that is cost effective, and locally adaptable for both urban and rural setting with a focus on siltation issue caused by technology.	0-1 y	**High**	MoCC & EC MoWR MNFSR MoST Provincial EPDs and EPAs Provincial Development Authorities, PHEDs, Agriculture and Irrigation Departments PARC

	Explore integration with existing water systems, irrigation system for farm holders, filtration options, storage solutions and ground water recharge.			PCRWR HEC Academic Institutes NGOs Private Housing Societies Builders, Developers, Local Building Control Authorities, Architects and Town Planning Associations
Facilitate development of central data base with clear data sharing protocols.	Transparent display of roles and responsibilities of stakeholders along with their responsiveness to performance parameters Predictive modelling for optimal water storage and usage, automated alerts for maintenance and repairs and provide	0-2 y	**High**	MoIT MoWR Provincial and City Development Authorities, PHEDs Municipalities

	data-driven insights for policy decisions must be achieved			
POLICY				
Short Term				
Expand the scope of existing policy and develop clear guidelines for installation to ensure broader adoption	Design rainwater harvest system with separate drainage for rain and storm water Inverted well for groundwater recharge for housing societies with more than 250 houses. Household level design should incorporate harvested water for toilet flushing and lawn irrigation. Mandate technology installation for renovations and expansions as well with a special focus on arid regions. Explore potential of technology	0-1 y	**Medium**	MoCC & EC MoWR Capital, Provincial and City Development Authorities, PHEDs NGOs Private Housing Societies PARC Builders, Developers, Local Building Control Authorities, Architects and Town

	implementation in urban and rural context with rooftop harvesting designin urban setups and groundwater recharge in rural. regions Introduce water pricing policy to encourage utilization of rainwater harvested through technology			Planning Associations
Develop policies and regulations that mobilize private sector for the implementation, operations and maintenance of rainwater harvesting	Incorporate private sector for wider adoption and less reliance on donor fundings through low interest loans, public private partner ships and impact bonds. Offer tax exemption and subsidies to companies investing in rainwater harvesting in terms of land acquisition, construction, managing operations etc. Provide long term concession agreements in exchange of revenue sharing models and	0-1 y	**Very High**	MoCC & EC MoWR Provincial EPDs and EPAs Provincial and City Development Authorities, PHEDs SECP Provincial and City Development Authorities

	public land leases offered to build and operate facility			NGOs
Develop policies and regulations that mobilize finances other than private sector investment for the implementation, operations and maintenance of rainwater harvesting	Collaborate with development bank funding, grants and schemes to secure financial assistance at low-interest Initiate government programs for youth loans and development of small medium enterprises	0-2 y	**Very High**	MoCC & EC MoWR Provincial EPDs and EPAs Provincial and City Development Authorities, PHEDs Capital Development Authority, Provincial and City Development Authorities NGOs Development Sector

				SMEDA
Develop policies and regulations that ensure gender equality and social inclusion in implementation and, operation and maintenance of rainwater harvesting	Ensure inclusion of women and vulnerable social groups in decision making Promote women-led rainwater harvesting initiatives Prioritize projects in marginalized communities	0-1 y	**Very High**	MoCC & EC Provincial EPDs and EPAs Capital Development Authority, Provincial Development Authorities, PHEDs MoHR NGOs Civil Societies Multilateral Organizations
CAPACITY BUILDING				
Short Term				
Utilize existing sites and models for technical support and improvement	Site visits organized by responsible authorities Identification of flaws and gaps in current	1-4 y	**Medium**	Capital, Provincial and City Development Authorities, PHEDs

	design and infrastructure			WASAs PARC PCRWR NGOs
Long Term				
Promote and establish business hubs and incubation centers to develop research and foster innovation along with business management skills for the technology	Develop knowledge and skills to prepare and develop business models, business plans, proposals and elevator pitch for rainwater harvesting technology to present business ideas to potential investors and to secure donor funding. Develop financial literacy covering topics of budgeting, cost control and revenue management especially targeting women and youth	2-5 y	**Medium**	Provincial EPAs and EPDs WASAs PARC PCRWR Academic Institutes SMEDA PITAC NGOs
Evaluate the existing knowledge of potential project proponents about technology and business management pertaining to	Design media campaigns for awareness of communities regarding water stress	Ongoing	**Medium**	Provincial EPAs and EPDs

facility and design an awareness campaign accordingly.	Conduct training sessions for local engineers, technicians and facility operators with leading builders and townplanners included to design, run and maintain rainwater harvesting technology with a special focus on managerial training for women, youth, informal sector and marginal groups.			Provincial and City Development Authorities, PHEDs WASAs PARC PCRWR Academic Institutes NGOs
BUDGET				
Short Term				
Allocate an annual quota in the fiscal budget for development of waste management infrastructure	Allocation of budget with clear guidelines for utilization.	0-6 m	**Very High**	MoCC & EC MoF MoWR
Long Term				
Explore national and international climate finance options by establishing mechanisms	Enable access to green financing options of low-interest loans and green bonds especially	1-3 y	**Very High**	MoCC & EC MoWR

	to youth as a vulnerable group to climate change impacts. Establish frameworks that enable initiatives to earn blue s for revenue generation from national and international carbon markets			Provincial EPDs and EPAs State Bank of Pakistan Pakistan Stock Exchange Multilateral financial institutions Carbon Crediting entities
GOVERNANCE				
Short Term				
Ensure policy implementation of public-private partnership for efficiency and upscaling and wider scale adoption of the technology.	Define roles and responsibilities, compliance requirements and accountability measures of all stakeholder including private sector, government agencies and local authorities	0-2 y	**Very High**	Provincial EPDs and EPAs Provincial and City Development Authorities, PHEDs

	Mandate compliance with water management standards to be reported in terms of efficiency of technology operations, groundwater recharge rate and social inclusions metrics			Public-Private Partnership Authority WASAs Private Housing Societies
Ensure policy implementation of gender equality and social inclusion in technology implementation and operations	Presence of women at managerial positions as per allocated quota Existence of women and youth led business initiatives	0-2 y	**Very High**	MoCC & EC MoWR Provincial EPDs and EPAs Provincial and city Development Authorities, PHEDs WASAs NGOs
Develop mechanisms for land acquisition for technology infrastructure	Acquisition of land for technology and development through	0-3 y	**Very High**	MoCC & EC

and harvested rainwater storage capacity	timely payments at a fair market value or alternative land compensation. Shares in benefits from rainwater harvesting projects as a compensation option			MoWR Provincial EPDs and EPAs Provincial and city Development Authorities, PHEDs WASAs Pakistan Board of Revenue
Create and update database for better access to rainfall patterns groundwater quality and drainage	Ensure improvement in data base	1-2 y	**High**	Provincial EPDs and EPAs Provincial and city Development Authorities, PHEDs WASAs PCRWR

				Pakistan Meteorological Department
Facilitate harmonization among relevant departments for a coordinated approach to water resource management	Exchange of data between departments Informed decisions through coordinated data exchange	2-5 y	**Medium**	MoCC&EC MoF MoWR Provincial EPDs and EPAs Provincial and city Development Authorities, PHEDs PBR WASAs SECP WAPDA Pakistan Development Fund PPIB PCRWR
BUSINESS CONTINUITY				

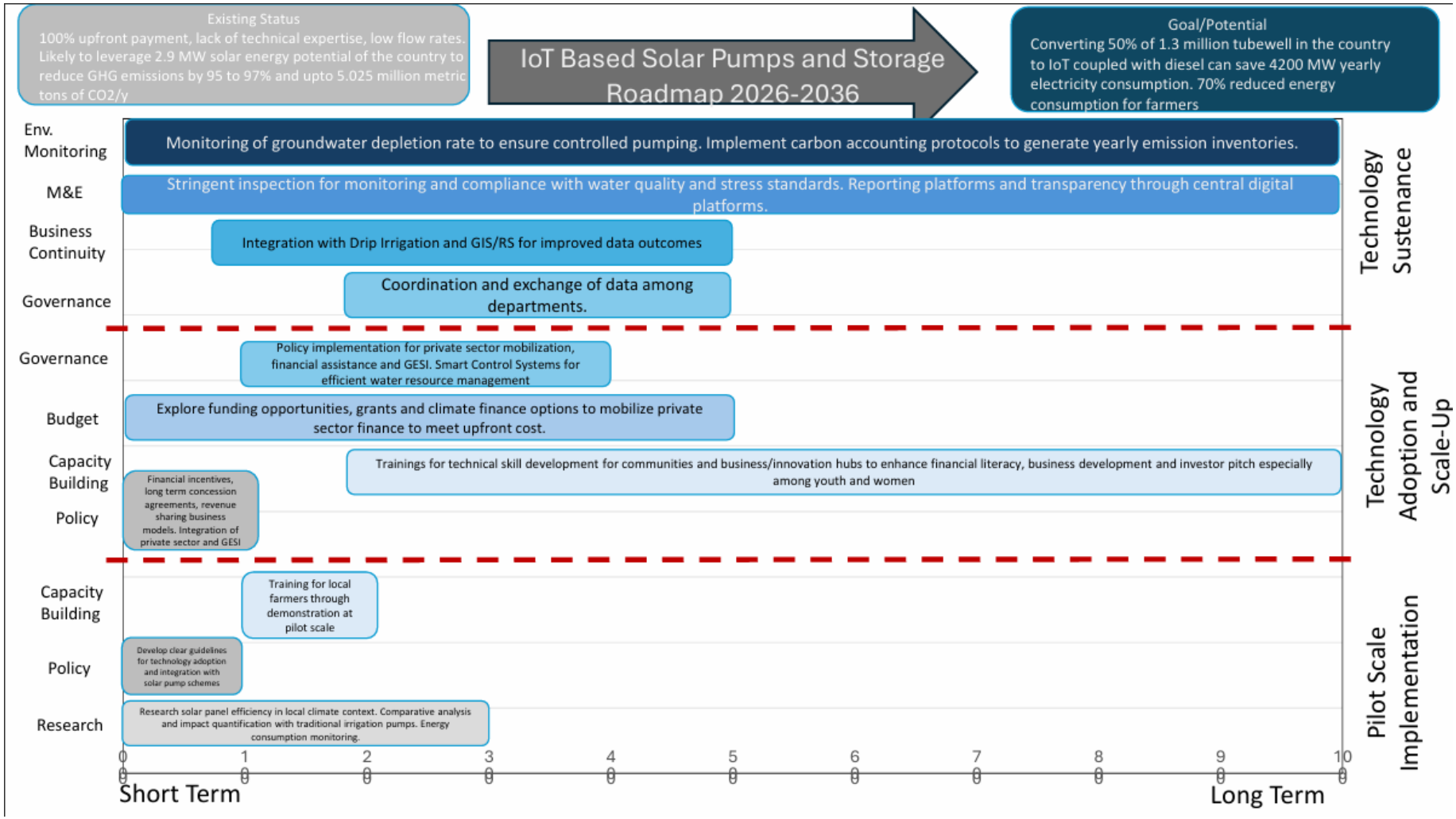
Short Term				
Incorporate traditional practices for technology development and innovation	Incorporate green roofing and permeable pavements to increase rainwater capturing capacity Stepwells (Baolis or Vav) to facilitate access to harvested and stored water	0-3 y	**Medium**	Provincial EPDs and EPAs Provincial and city Development Authorities , PHEDs WASAs PARC PCRWR NGOs
Facilitate local businesses to achieve pronounced positive social impact	Use of domestic building material and local construction services Improved income generation, employment opportunities and local business support.	0-2 y	**Medium**	Provincial EPDs and EPAs Provincial and city Development Authorities, PHEDs Local construction companies SMEDA PIDC

MONITORING AND EVALUATION				
Short Term				
Develop and implement balanced but vigilant monitoring and evaluation protocols	Monitor consistent coordination between government bodies, communities and private sector through feedback and strengthened involvement in technology implementation Stringent inspection of project for environment quality parameters such as water erosion and water borne diseases Monitor and ensure reduction in water tanker supply as a result of replenished ground water	1-Ongoing	**Very High**	EPA Capital Development Authority, Provincial Development Authorities Private Housing Societies PARC
Ensure vigilant inspection of gender equality and social inclusion indicators to monitor policy implementation outcome and assessment of necessary revision in policy for achieving targets	Develop anonymous reporting platform for gender specific complaints Implementation of regular inspection and	1-Ongoing	**High**	MoHR NGOs Civil Societies IMO Capital Development Authority,

	audits to assess relevant indicators. Ensure that training sessions are scheduled keeping in mind household responsibilities of women			Provincial Development Authorities Municipalities
GENDER EQUALITY AND SOCIAL INCLUSION				
Short Term				
Target communities affected by desertification	Prioritize implementation of projects in areas and communities affected by desertification	0-2 y	**High**	MoCC & EC MoCC & EC MoWR MoHR
Incorporate the role of women in rainwater harvesting technology	Assign quota for inclusion of women in decision making roles Registration of women entrepreneurs with SECP Women-led businesses in construction and selling of harvested water	2-4 y	**Very High**	Provincial EPDs and EPAs Provincial and city Development Authorities NGOs SECP

Develop schemes to facilitate education and women led cottage industry	Incentivize education of women and youth as a result of this time saving through employment opportunities with quota system Enable women leveraging the time saving by the use of this technology for other income generating opportunities through small scale business e.g exhibition centres for handicraft	3-5 y	**Very High**	Provincial EPDs and EPAs Provincial and city Development Authorities PIDC
ENVIRONMENTAL MONITORING				
Short Term				
Incorporate smart water meters for the monitoring of harvested rainwater	Installation of smart meters and incoming data of water usage Utilization of this data for policy revision	2-5 y	**Very High**	Provincial EPDs and EPAs NEPRA WAPDA Private Housing Societies

Regularize ground water extraction to optimize technology outcome	Collect data on ground water replenish rates specifically in response to technology adoption	Ongoing	**High**	Provincial EPAs and EPDs PARC PCRWR
Long Term				
Quantify emission reduction potential and on ground achieved targets to align with NDCs goals.	Implementation of blue carbon accounting protocols to quantify baseline scenario carbon emissions. Generation of yearly inventories to quantify achieved emissions reduction.	0-10 y	**Very High**	Provincial EPAs and EPDs PARC PCRWR


Existing Status
100% upfront payment, lack of technical expertise, low flow rates. Likely to leverage 2.9 MW solar energy potential of the country to reduce GHG emissions by 95 to 97% and upto 5.025 million metric tons of CO2/y
IoT Based Solar Pumps and Storage Roadmap 2026-2036
Goal/Potential
Converting 50% of 1.3 million tubewell in the country to IoT coupled with diesel can save 4200 MW yearly electricity consumption. 70% reduced energy consumption for farmers
Env. Monitoring
Monitoring of groundwater depletion rate to ensure controlled pumping. Implement carbon accounting protocols to generate yearly emission inventories.
M&E
Stringent inspection for monitoring and compliance with water quality and stress standards. Reporting platforms and transparency through central digital platforms.
Business Continuity
Integration with Drip Irrigation and GIS/RS for improved data outcomes
Governance
Coordination and exchange of data among departments.
Technology Sustenance
Governance
Policy implementation for private sector mobilization, financial assistance and GESI. Smart Control Systems for efficient water resource management
Budget
Explore funding opportunities, grants and climate finance options to mobilize private sector finance to meet upfront cost.
Capacity Building
Trainings for technical skill development for communities and business/innovation hubs to enhance financial literacy, business development and investor pitch especially among youth and women
Policy
Financial incentives, long term concession agreements, revenue sharing business models. Integration of private sector and GESI
Technology Adoption and Scale-Up
Capacity Building
Training for local farmers through demonstration at pilot scale
Policy
Develop clear guidelines for technology adoption and integration with solar pump schemes
Research
Research solar panel efficiency in local climate context. Comparative analysis and impact quantification with traditional irrigation pumps. Energy consumption monitoring.
Pilot Scale Implementation
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Short Term
Long Term

IoT Based Solar Pumps (TRL Level 2: Concept Formulated)

PILOT SCALE IMPLEMENTATION

Action Item	Milestones/Targets	Deadline	Priority Level	Identify Stakeholders
RESEARCH				
Long Term				
Initiate research and development programs with industry-academia partnership on identified technical, environmental and social issues for the technology and encourage development of central data base with clear data sharing protocols.	Research on solar panel efficiency in context of local climate and predictive maintenance models for reduced downtime and repair cost. Extensive research on impact of technology on water use efficiency and crop yields compared to traditional pump systems. Developing business models with a focus on achieving viable economic modelling for attracting	0-3 y	**High**	MoCC & EC MoWR MNFSR MoST MoE Provincial EPDs and EPAs Agriculture and Irrigation Departments

	investment and private sector.			Provincial Energy Departments PARC/NARC PCRWR HEC Academic Institutes NGOs PSF PCST
Facilitate development of central data base with clear data sharing protocols.	Monitoring of energy consumption and production. Managing and storing data from various sensors	1-3 y	**High**	MoIT MoE MoWR MNFSR
POLICY				
Short Term				
Develop guidelines for the implementation of IOT based solar pumps for standardization, monitoring compliance	Develop guidelines and ensure implementation to be integrated with solar pump scheme and	0-1 y	**Very High**	MoCC&EC MoWR MNFSR

and optimized system performance	groundwater extraction policy Introduce water pricing policy for efficient utilization solar pumps Surface water pumping through technology to reduce stress of ground water resources.			MoE MoST MoIT Provincial EPDs and EPAs Provincial Energy Departments Provincial Agriculture and Irrigation DepartmentsPPIB AEDB PCRET
CAPACITY BUILDING				
Short Term				
Utilize the capacity of water research institutes to train on the technology and bring innovation	Conduction of training workshops specifically for farmers Demonstrate technology at pilot scale for research, development and investment	1-2 y	**High**	MoCC & EC MoWR MoE MoST MoIT Provincial EPDs and EPAs

				Provincial Agriculture, Energy and Irrigation Departments PARC/NARC PCRWR PSF PCST

TECHNOLOGY ADOPTION & SCALE-UP

Action Plan (short-term and long-term) and Milestones	Milestones/Targets	Deadline	Priority Level	Identify Stakeholders
POLICY				
Short Term				
Develop policy and regulations that mobilize private sector for the design, development, implementation, operations and maintenance of IoT Based Solar Pumps	Incorporate private sector to meet upfront cost requirements for wider adoption and less reliance on donor fundings through low interest loans, public private partner ships and impact bonds. Offer tax exemption and subsidies to companies investing in IoT Solar Based Pumps in terms of land	0-1 y	**Very High**	MoCC & EC MoWR MNFSR MoE MoIT Provincial EPDs and EPAs Provincial Agriculture,

	acquisition, purchasing machinery, managing operations etc. Provide long term concession agreements in exchange of revenue sharing business models and public land leases offered to build and operate facility			Energy and Irrigation Departments SECP
Develop policy and regulations that mobilize finances other than private sector investment for the implementation, operations and maintenance of IoT Based Solar Pumps	Enable microfinance programs for small scale facilities Collaborate with development bank funding, grants and schemes to secure financial assistance at low-interest Initiate government programs for youth loans and development of small medium enterprises Promote crowd funding programs along with venture	0-1 y	**Very High**	MoCC & EC MoWR MoE MoIT Provincial EPDs and EPAs Provincial Agriculture, Energy and Irrigation Departments Development Sector

	capital as financing solution			MicroFinance Banks and Institutes SMEDA
Develop regulations that ensure gender equality and social inclusion in implementation and, operation and maintenance of IoT Based Solar Pumps and Storage	Gender responsive recruitment to include a percentage of women, youth and individuals from marginalized groups especially belonging to the local community targeted for managerial positions and within governance structures Address privacy and security concerns for women and marginalized groups.	0-1 y	**Very High**	MoCC & EC MoWR MoE MoIT Provincial EPDs and EPAs Provincial Agriculture, Energy and Irrigation Departments MoHR NGOs Civil Societies Multilateral Organizations
CAPACITY BUILDING				
Long Term				
Promote business incubation centres to develop research and foster innovation along with	Develop knowledge and skills to prepare and develop business models, business	2-10 y	**Medium**	MoCC & EC MoWR

business management skills for the technology	plans, proposals and elevator pitch for IoT Based Solar Pumps to present business ideas to potential investors and to secure donor funding. Develop financial literacy covering topics of budgeting, cost control and revenue management especially targeting women and youth			MoE MoIT MoST MoC MoIP Provincial EPDs and EPAs Provincial Agriculture and Irrigation Departments PARC PCRWR Academic Institutes SMEDA PITAC
Evaluate the existing knowledge of potential project proponents about technology and business management pertaining to facility and design an awareness campaign accordingly.	Conduct training sessions for local engineers, technicians and facility operators to design, run and maintain IoT Based Solar Power Plants with a special focus on	Ongoing	**Medium**	Provincial EPDs and EPAs Provincial Agriculture

	managerial training for women, youth, farmers and marginalized groups.			and Irrigation Departments PARC PCRWR Academic Institutes
BUDGET				
Short Term				
Allocate an annual quota in the fiscal budget for incorporation of IOT in solar pump infrastructure.	Annual quota allocated for upgrading existing solar pumping schemes to include IoT	0-6 m	**Very High**	MoF MoCC & EC MoWR, MNFSR
Facilitate upfront cost for implementation of technology	Facilitate implementation of technology through low-interest loans by government for private sector to pay 100% up front cost Target international donors funding renewable energy projects	1-3 y	**Very High**	MoF MoCC & EC MoWR, MNFSR
Long Term				
Explore national and international climate	Enable access to green financing options of low-interest loans and	3-5 y	**Very High**	MoCC & EC

finance options by establishing mechanisms	green bonds especially to youth as a vulnerable group to climate change impacts. Establish frameworks that enable initiatives to earn blue carbon credits for revenue generation from national and international carbon markets			MoWR Provincial EPDs and EPAs State Bank of Pakistan Pakistan Stock Exchange Multilateral financial institutions Carbon Crediting entities
GOVERNANCE				
Short Term				
Ensure policy implementation of public-private partnership for efficiency and upscaling and wider scale adoption of the technology.	Define roles and responsibilities, compliance requirements and accountability measures of all stakeholder including private sector, government agencies and local authorities	2-4 y	**Very High**	Provincial EPDs and EPAs Provincial Agriculture and Irrigation Departments

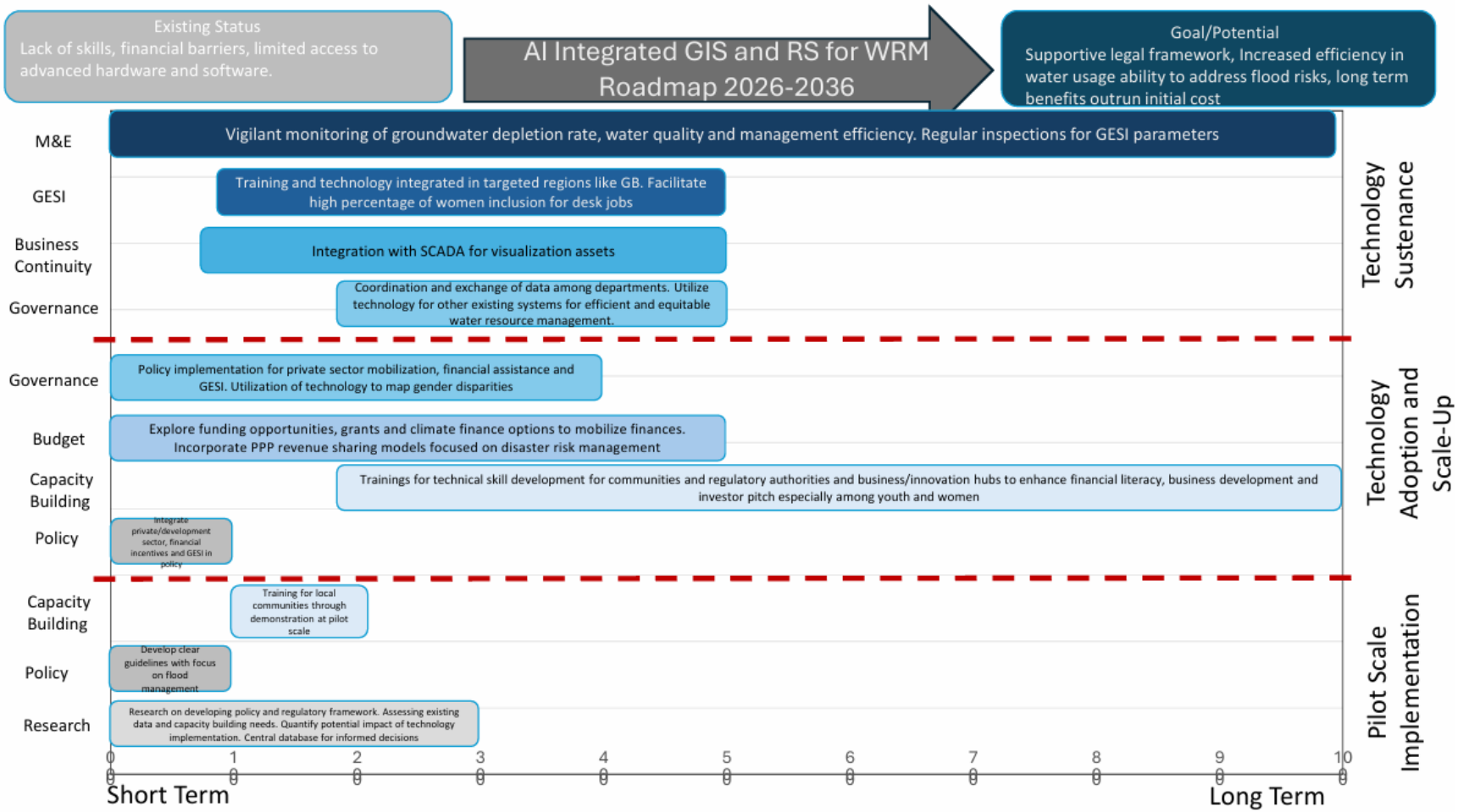
	Mandate compliance with water management standards to be reported in terms of efficiency of technology operations and social inclusions metrics			Public-Private Partnership Authority
Utilize Smart Control Systems for efficient water resource management while creating benefits for farmers	Monitoring real time flow rates, pressure and pump performance using IOT to avoid uncontrolled pumping Design automated controls based on incoming data using IOT for optimal performance despite low flow rates	1-3 y	**Very High**	MoWR Provincial EPDs and EPAs Provincial Agriculture and Irrigation Departments WAPDA Private Technology Companies Research Institutions
Ensure policy implementation of gender equality and social inclusion in technology implementation and operations	Presence of women at managerial positions as per allocated quota Presence of women and youth led business initiatives incorporating IoT with solar pumping	2-3 y	**Very High**	MoCC & EC MoE Provincial EPDs and EPAs Provincial Agriculture

	Ensure that training sessions are scheduled keeping in mind household responsibilities of women			and Irrigation Departments
TECHNOLOGY SUSTENANCE				
Action Item	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify stakeholders**
GOVERNANCE				
Short Term				
Facilitate harmonization among relevant departments for a coordinated approach to water resource management	Exchange of data among departments Informed decisions through coordinated data exchange	2-5 y	**Medium**	MoCC & EC MoF MoWR MoIT MoIP MoC MNFSR Provincial EPDs and EPAs Provincial Agriculture and Irrigation Departments

				Research Institutions Pakistan Board of Revenue Capital and Provincial Development Authorities SECP WAPDA Pakistan Development Fund PPIB PARC PCRWR PCRET Private Sector
BUSINESS CONTINUITY				
Short Term				
Integrate other technologies for efficient and improved outcome	Integrate IoT Solar Pumping with Drip Irrigation for a smart and automated irrigation systems Integrate with GIS and RS for improved data outcomes	1-5 y	**Medium**	Provincial Agriculture Departments and Extensions Provincial Irrigation Departments

MONITORING AND EVALUATION				
Short Term				
Develop and implement balanced but vigilant monitoring and evaluation protocols	Stringent inspection of technology to monitor compliance with water management standards e.g ground water depletion rate and quality, water efficiency. Include a factor of transparency and data sharing in monitoring and evaluation on district level by establishing and strengthening real time, centralized digital platforms to oversee system performance	Ongoing	**Very High**	Provincial EPDs and EPAs Provincial Agriculture, Energy and Irrigation Departments PARC PPIB
Ensure vigilant inspection of gender equality and social inclusion indicators to monitor policy implementation outcome and assessment of necessary revision in policy for achieving targets	Develop anonymous reporting platform for gender specific complaints Implementation of regular inspection and audits to assess relevant indicators.	Ongoing	**High**	MoWR NGOs Civil Societies IMO

ENVIRONMENTAL MONITORING				
Long Term				
Quantify emission reduction potential and on ground achieved targets to align with NDCs goals.	Implementation of carbon accounting protocols to quantify baseline scenario carbon emissions. Generation of yearly inventories to quantify achieved emissions reduction. Monitor and quantify reduced diesel consumption a result of transition to solar pumps	0-10 y	**Very High**	Provincial EPDs and EPAs Provincial Agriculture, Energy and Irrigation Departments PARC/ NARC PCRWR
Monitoring of ground water depletion rates	Control of ground water pumping based on incoming data for groundwater depletion Implementation of technology according to zoning of areas with crucial ground water depleting rates	2-Ongoing	**Very High**	Provincial EPDs and EPAs Provincial Agriculture and Irrigation DepartmentsPMD PARC/NARC PCRWR PBS


Existing Status
Lack of skills, financial barriers, limited access to advanced hardware and software.
AI Integrated GIS and RS for WRM Roadmap 2026-2036
Goal/Potential
Supportive legal framework, Increased efficiency in water usage ability to address flood risks, long term benefits outrun initial cost
M&E
Vigilant monitoring of groundwater depletion rate, water quality and management efficiency. Regular inspections for GESI parameters
GESI
Training and technology integrated in targeted regions like GB. Facilitate high percentage of women inclusion for desk jobs
Business Continuity
Integration with SCADA for visualization assets
Governance
Coordination and exchange of data among departments. Utilize technology for other existing systems for efficient and equitable water resource management.
Technology Sustenance
Governance
Policy implementation for private sector mobilization, financial assistance and GESI. Utilization of technology to map gender disparities
Budget
Explore funding opportunities, grants and climate finance options to mobilize finances. Incorporate PPP revenue sharing models focused on disaster risk management
Capacity Building
Trainings for technical skill development for communities and regulatory authorities and business/innovation hubs to enhance financial literacy, business development and investor pitch especially among youth and women
Policy
Integrate private/development sector, financial incentives and GESI in policy
Technology Adoption and Scale-Up
Capacity Building
Training for local communities through demonstration at pilot scale
Policy
Develop clear guidelines with focus on flood management
Research
Research on developing policy and regulatory framework. Assessing existing data and capacity building needs. Quantify potential impact of technology implementation. Central database for informed decisions
Pilot Scale Implementation
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Short Term
Long Term

AI Integrated GIS and Remote Sensing for Water Management (Second Emerging) (TRL Level 2: Concept Formulated)

PILOT SCALE IMPLEMENTATION

Action Item	Milestones/Targets	Deadline	Priority Level	Identify Stakeholders
RESEARCH				
Long Term				
Initiate research and development programs with industry-academia partnership on identified technical, environmental and social issues for the technology	Investigate policy and regulatory framework needed to support technology adoption focused on data privacy, data sharing and harmonized governance. Research on assessing the availability and quality of existing geospatial data integrated with local climate and hydrological conditions. Assess the capacity building needs especially for local authorities, farmers and water managers to design awareness campaigns and encourage degree	0-3 y	**High**	MoCC & EC MoWR MNFSR MoST Provincial EPDs and EPAs Agriculture and Irrigation Departments PARC/NARC PCRWR HEC Academic Institutes

	programs in the field targeted at disengaged provinces, marginalized groups especially women. Assess positive impacts of technology integration in terms of better water access and risk management especially for floods.			NGOs PSF PCST
Facilitate development of central data base with clear data sharing protocols.	Access of relevant departments to GIS mapping data of water resource Access of private sector to operational business models of the technology to analyze economic feasibilities	0-1 y	**High**	MoIT MoE MoWR MNFSR
POLICY				
Short Term				
Develop policy and guidelines for the implementation of AI Integrated GIS and Remote Sensing for Water Management for standardization, monitoring compliance and optimized system performance	Develop guidelines and implementation framework for technology adoption with a special focus on flood management.	0-1 y	**Very High**	MoIT MoCC & EC MoWR MNFSR

				Provincial EPDs and EPAs, Development Authorities, Agriculture Departments, Irrigation Departments, NDMA PDMA FFC
CAPACITY BUILDING				
Short Term				
Utilize the capacity of water research institutes to train on the technology	Demonstrate technology at pilot scale for research, development and investment Train vulnerable groups in technology implementation for water management Ensure that training sessions are scheduled keeping in mind household responsibilities of women	1-2 y	**High**	MoCC & EC MoWR MoE MoST MoIT Provincial EPDs and EPAs Provincial Agriculture, Energy and Irrigation Departments PARC/NARC PCRWR PSF

				PCST
TECHNOLOGY ADOPTION & SCALE-UP				
Action Items	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify Stakeholders**
POLICY				
Short Term				
Develop policy and regulations that mobilize private sector for the implementation, operations and maintenance of AI Integrated GIS and Remote Sensing for Water Management	Incorporate private sector for wider adoption and less reliance on donor fundings through low interest loans, public private partner ships and impact bonds. Offer tax exemption and subsidies to companies investing in AI Integrated GIS and Remote Sensing for Water Management in terms of land acquisition, purchasing technology tools, managing operations etc. Provide long term concession agreements, revenue sharing models and offeres to build and operate facility	0-1 y	**Very High**	MoCC & EC MoIT MoCC & EC MoWR MNFSR Provincial EPDs and EPAs, Development Authorities, Agriculture Departments, Irrigation Departments, ProvincialEPDs and EPAs Capital Development Authority

				Provincial and City Development Authorities SECP
Develop policy and regulations that mobilize finances other than private sector investment for the implementation, operations and maintenance of AI Integrated GIS and Remote Sensing for Water Management	Collaborate with development bank funding, grants and schemes to secure financial assistance at low-interest Initiate government programs for youth loans and development of small medium enterprises Promote crowd funding programs along with venture capital as financing solution	0-1 y	**Very High**	MoCC & EC MoIT MoF MoWR MNFSR Provincial EPDs and EPAs, Development Authorities, Agriculture Departments, Irrigation Departments, NDMA PDMA FFC Development Sector SMEDA
Develop policy and regulations that ensure gender equality and social inclusion in implementation and,	Gender responsive recruitment to include a percentage of women, youth and individuals from	0-1 y	**Very High**	MoCC & EC MoIT

operation and maintenance of AI Integrated GIS and Remote Sensing for Water Management	marginalized groups especially belonging to the local community targeted for managerial positions and within governance structures Ensure gender responsive workplace policies such as flexible workhours and antiharassment rules.			MoWR MNFSR Provincial EPDs and EPAs, Development Authorities, Agriculture Departments, Irrigation Departments, NDMA PDMA FFC MoHR NGOs Civil Societies Multilateral Organizations
CAPACITY BUILDING				
Long Term				
Evaluate the existing knowledge of potential project proponents about technology and business management pertaining to facility and design an awareness campaign accordingly.	Capacity building for regulatory authorities for effective implementation of climate resilient measures Conduct training sessions for local	Ongoing	**Medium**	MoIT MoCC & EC MoWR MNFSR

	engineers, technicians and facility operators to design, run and maintain technology with a special focus on managerial training for women, youth, and marginal groups. Capacitate vulnerable groups to adapt to rising demands of AI, GIS and RS in water resource management			Provincial EPDs and EPAs, Development Authorities, Agriculture Departments, Irrigation Departments, NDMA PDMA FFC SUPARCO PARC PCRWR Academic Institutes
Promote business hubs and incubation centers to develop research and foster innovation along with business management skills for the technology	Develop knowledge and skills to prepare and develop business models, business plans, proposals and elevator pitch for AI Integrated GIS and Remote Sensing for Water Management to present business ideas to potential investors and to secure donor funding.	2-5 y	**Medium**	MoIT MoCC & EC MoWR MNFSR Provincial EPDs and EPAs,

	Develop financial literacy covering topics of budgeting, cost control and revenue management especially targeting women and youth			Development Authorities, Agriculture Departments, Irrigation Departments, NDMA PDMA FFC SUPARCO PARC PCRWR Academic Institutes SMEDA PITAC
BUDGET				
Short Term				
Explore avenues to enhance available budget	Acquire PPP models, bilateral aid from other countries and grants from international organizations to develop new revenue generating labs for disaster risk management.	0-6 m	**Very High**	MoF MoCC & EC MoIT MoWR MNFSR

				Provincial EPDs and EPAs, Development Authorities, Agriculture Departments, Irrigation Departments, NDMA PDMA FFC
Long Term				
Explore national and international climate finance options by establishing assisting mechanisms	Enable access to green financing options of low-interest loans and green bonds especially to youth as a vulnerable group to climate change impacts.	3-5 y	**Very High**	MoIT MoCC & EC MoWR MNFSR Provincial EPDs and EPAs, Development Authorities, Agriculture Departments, Irrigation Departments, NDMA PDMA

				FFC State Bank of Pakistan Pakistan Stock Exchange Multilateral financial institutions
GOVERNANCE				
Short Term				
Ensure policy implementation of public-private partnership for efficiency and upscaling and wider scale adoption of the technology.	Define roles and responsibilities, compliance requirements and accountability measures of all stakeholder including private sector, government agencies and local authorities Mandate compliance with social inclusions metrics	0-3 y	**Very High**	Provincial EPDs and EPAs, Development Authorities, Agriculture Departments, Irrigation Departments, NDMA PDMA FFC PPPA
Ensure policy implementation of gender equality and social	Equal benefits and decision making power for women in AI	0-3 y	**Very High**	MoCC & EC MoIT

inclusion in technology implementation and operations	integrated GIS and RS technology Utilize technology for spatial analysis of gender disparities			MoCC & EC MoWR MNFSR Provincial EPDs and EPAs, Development Authorities, Agriculture Departments, Irrigation Departments, NDMA PDMA FFC
TECHNOLOGY SUSTENANCE				
Action Items	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify stakeholders**
GOVERNANCE				
Short Term				
Facilitate harmonization among relevant departments for a coordinated approach to water resource management.	Exchange of data among departments	2-5 y	**Medium**	MoCC & EC MoF Ministry of Water

	Informed decisions through coordinated data exchange Utilize technology for water flows, ground water depletion, glacial recession, risk mapping, sediment transportation, controlled water flows, early warning systems and feasibility studies for all water management technology adoption apart from flood management Import and introduce latest global technologies for AI integrated GIS and RS			MoIT Resource Management Research Institutions Pakistan Board of Revenue Capital and Provincial Development Authorities SECP WAPDA Pakistan Development Fund PPIB PCRWR PCRET Private Sector
BUSINESS CONTINUITY				
Short Term				
Integrate other technologies for efficient and improved outcome	Utilize SCADA systems into GIS for geospatial visualization assets for holistic view of water networks facilitating better decisions.	1-3 y	**Medium**	Provincial Agriculture Departments and Extensions Provincial Irrigation Departments
GENDER EQUALITY AND SOCIAL INCLUSION				

Short Term				
Inclusion of women in high percentage for GIS and RS labs	30-40% quota for women in GIS and RS labs due to less labor-intensive tasks	0-2 y	**High**	Provincial Agriculture Departments and Extensions Provincial Irrigation Departments NDMA PDMA
Prioritize technology implementation in Gilgit Baltistan	Develop AI integrated GIS and RS lab to monitor water resource management efficiency focusing on the following parameters: Hydroflows Glacier melting Risk mapping	0-2 y	**High**	MoCC & EC GBDMA WAPDA
MONITORING AND EVALUATION				
Short Term				
Develop and implement balanced but vigilant monitoring and evaluation protocols	Stringent inspection of technology to monitor compliance with water management standards e.g ground water depletion rate and quality, water efficiency.	1-3 y	**Very High**	EPA Capital Development Authority, Provincial Development Authorities

				SUPARCO
Ensure vigilant inspection of gender equality and social inclusion indicators to monitor policy implementation outcome and assessment of necessary revision in policy for achieving targets	Develop anonymous reporting platform for gender specific complaints Implementation of regular inspection and audits to assess relevant indicators.	1-2 y	**High**	Ministry of human Rights NGOs Civil Societies IMO SUPARCO

4.4 Immediate Action

Introducing new technologies in a developing economy like Pakistan can demand significant efforts in terms of policy design and implementation, mobilizing the finances and managing technical capacities. For these reasons, identifying an immediate plan is vital. Rainwater harvesting is a technology in the water sector which has already received significant investment in terms of finances, research, policy design and infrastructure design and development. However, its adoption at a wide scale is still a challenge the cause of which needs to be identified and addressed.

To design an immediate plan, one of the reasons that could assist in stacking one technology upon another is the ease of adoption and the support it has from traditional practices that have prevailed over hundreds of years. These practices have been the coping mechanism of the local communities but have not seen wider adoption due to lack formalization of technology implementation with absence of relevant stakeholders' coordination. Therefore, the immediate focus of the action plan should be these regions and provinces where the technology already exists in some form.

4.4.1 Rainwater Harvesting

The technology is informally practiced in several parts of KPK and AJK and has numerous small scale operational demonstrations in Balochistan and Sindh that can be utilized for demonstration and capacity building purpose. Regarding Rainwater Harvesting, in stakeholder meetings, participants highlighted the necessity for local development departments to incorporate rainwater harvesting into construction by-laws, emphasizing its importance in both domestic and commercial settings. They stressed the need for thorough regulation across all settlements and proposed the introduction of rooftop harvesting into these by-laws. Furthermore, they suggested implementing a uniform policy at the provincial level and underscored the role of water pricing as an enabler to encourage rainwater harvesting adoption, particularly in areas like the Cholistan desert. Media campaigns were also recommended to alleviate stress on groundwater sources.

Apart from groundwater recharge, rainwater harvesting technology has far reaching gender specific impacts. It can considerably save time and effort for rural women who are mostly designated with the role of water collection for drinking, cooking and sanitation purpose. However, immediate action also calls for participation of women in decision making and capacity building programs which is extremely essential for a diverse approach to implementation. As this is a lacking factor due to cultural restrains, it results in improper and insufficient communication of issues faced by these groups. The most essential action in the implementation plan is to remove the barriers in the way of wider adoption and provide an enabling environment for smooth land acquisition and encouraging community engagement through incorporation of traditional practices utilizing and promoting locally available resources. For social inclusivity such community engagement sessions must ensure that exchange of knowledge should be reciprocated by conveying the benefits of rainwater

harvesting for the community especially targeted groups like women, children and farmers. This will not only build a trust between the developers and indigenous civil authorities but also garner an enabling environment through creating a sense of inclusion and ownership for the natives.

Government support in context of mandating rainwater harvesting through policy and extensive research of plant design and availability of technical capacity building by institutions like PCRWR leaves the action takers to ensure implementation and enforcement of the technology at a wider scale. However, private sector involvement capable of bearing upfront costs and efficient operations is needed. SECP can play their part in facilitating the private sector entities backed by incentives provided by Ministry of Commerce, Ministry of Finance and FBR to encourage entrepreneurs to fill in the gaps for technology implementation and sustenance.

As the technology is interconnected with other environmental factors where a positive outcome is also expected, quantifying impacts like ground water recharge and flood risk reduction through improved control of water resource management, qualifying it for climate finance could be a fruitful way to mobilize finances. Financial literacy and technical skills must be developed and improved through capacity building for the people who would be responsible for sustenance and maintenance of the technology. All these actions require a good governance structure where a harmonization exists between all the departments like MoCC&EC, MoF, Ministry of Water Resource and research institutes such as PCRWR. Such coordination would help in mobilizing agents and filling in gaps in the research without which a smooth and successful implementation of the action plan is not possible.

4.4.2 Micro and Small Hydropower Plants

Hydropower generation is one of the most valuable assets of Pakistan which aligns well with the NDCs targets for 60% renewable energy mix by 2030. This technology demands immediate action mainly owing to its current stable standing in the deployment phase of readiness level. Several identified potential sites in KPK and Gilgit Baltistan funded by schemes such as Sarhad Rural Support Program hold potential for expansion of scope through the Ministry of Water Resource and NEPRA. However, as identified by stakeholders, purchase of generated electricity at proposed rates needs to be ensured. Moreover, in hydropower, financial barriers, policy constraints, and technical challenges are primary hurdles, though significant opportunities exist for small and micro-hydropower projects, particularly in regions like AJK and GB.

Women and children who are more vulnerable to the impacts of climate change must be focused for the action plan of hydropower generation projects which can reduce lack of electricity access and associated problems for these groups. Community engagement and stakeholder consultation sessions are essential to convey the impactful outcomes of the projects and to reach a well informed and inclusive decision-making process. The most important aspect to focus on in this action plan would be to prioritize local communities, their social wellbeing and maximizing gender and social equity which will eventually lead to achieving national

interests. This can be exemplified through engagement of local communities in construction projects utilizing indigenous resources and building materials. Moreover, formalizing quantification of emissions reduction and streamlining the associated climate finance mechanisms towards local community welfare can build trust and resilient water resource management infrastructure essentially because these areas are also prone to climate disasters.

The wider adoption needs to begin with stabilizing the political atmosphere associated with the deployment of the technology in difficult areas. Local EPAs and development authorities can help direct actions towards balancing disparities and inconsistencies in water resource management across all regions and provinces as the first and foremost responsibility of the Ministry of Water Resource. Land acquisition also becomes one of the barriers especially with the involvement of any political aspect. Pakistan Board of Revenue must facilitate this process by designing and implementing compensation strategies in a smooth manner. Support from military can be utilized in situations where communities are displaced through compensation.

Other than the efficiency achieved through incorporation of private sector in the environmental impact assessment, construction and maintenance of the technology, this sector can also ensure timely completion of projects that create employment opportunities for locals. Public private partnership project like the Gulpur Hydropower Project and similar partnership promoted by EPA are also application for this technology. Capacity building is terms of development of technical skills, knowledge of climate markets, availing fund acquiring opportunities and creating awareness can not only benefit the private sector in systemizing the implementation process but also ensures the successful execution and sustenance of the project by acquiring the required skills and support. Furthermore, there is a need for strict regulations for electricity sale to encourage private sector involvement especially in the mountainous regions where inclusion of CPPA and NEPRA is crucial.

4.4.3 Run of the River Plant

Run of the River Plants is also a well-established technology having the same potential to achieve NDCs targets as Micro and Small Hydropower Plants. This technology has tremendous capacity to be up-scaled especially in the province of KPK where 150 sites have been identified. PPIB, WAPDA and public private partnerships can play a vital role in untapping these sites.

Run of the River Plant technology needs immediate action because of its expected positive impact not only in generating renewable energy but specifically for the wellbeing of the local community. As per the stakeholder meetings, A strict policy ensuring revenue from electricity bill payments is needed. Installing hydro-meteorological stations is crucial for resource monitoring and management. Upstream mitigation of climate events benefits downstream areas, as supported by GCISC findings.

This technology can be particularly rewarding in areas where seasonal tourism boosts business and provides an opportunity for the locals to make money to support them for the rest of the year. The technology is also likely to improve the lifestyle of the community, especially the

women who will have an increased capacity to develop the cottage industry of handicrafts enabling them to maintain their privacy, social structure and values while improving their chances of increasing their income level. Women are also heavily involved in the agriculture sector and need support in building resilient irrigation infrastructure especially after the floods of 2022. As a result of better access to electricity, women can reduce the time taken for their business operations and optimize production through use of machinery. SMEDA, National Rural Support Program and women empowerment organization can provide a supportive role in formalization and promotion of women led initiatives. In case of resistance from the local community, capacity building sessions and awareness campaigns can signify the role of women in Pakistan's economy and the well-being of a household.

Run of the river plants can also be financially and operationally supported by the private sector which must be incorporated in the action plan. Public private partnership such as in Karot Hydropower Project, also used for the economic analysis of this technology is a viable example of this approach. This sector can play a major role is accelerating progress of deployment which will put community wellbeing on fast track.

WASTE SECTOR

5 Overview of Waste Sector

5.1 Situational Analysis

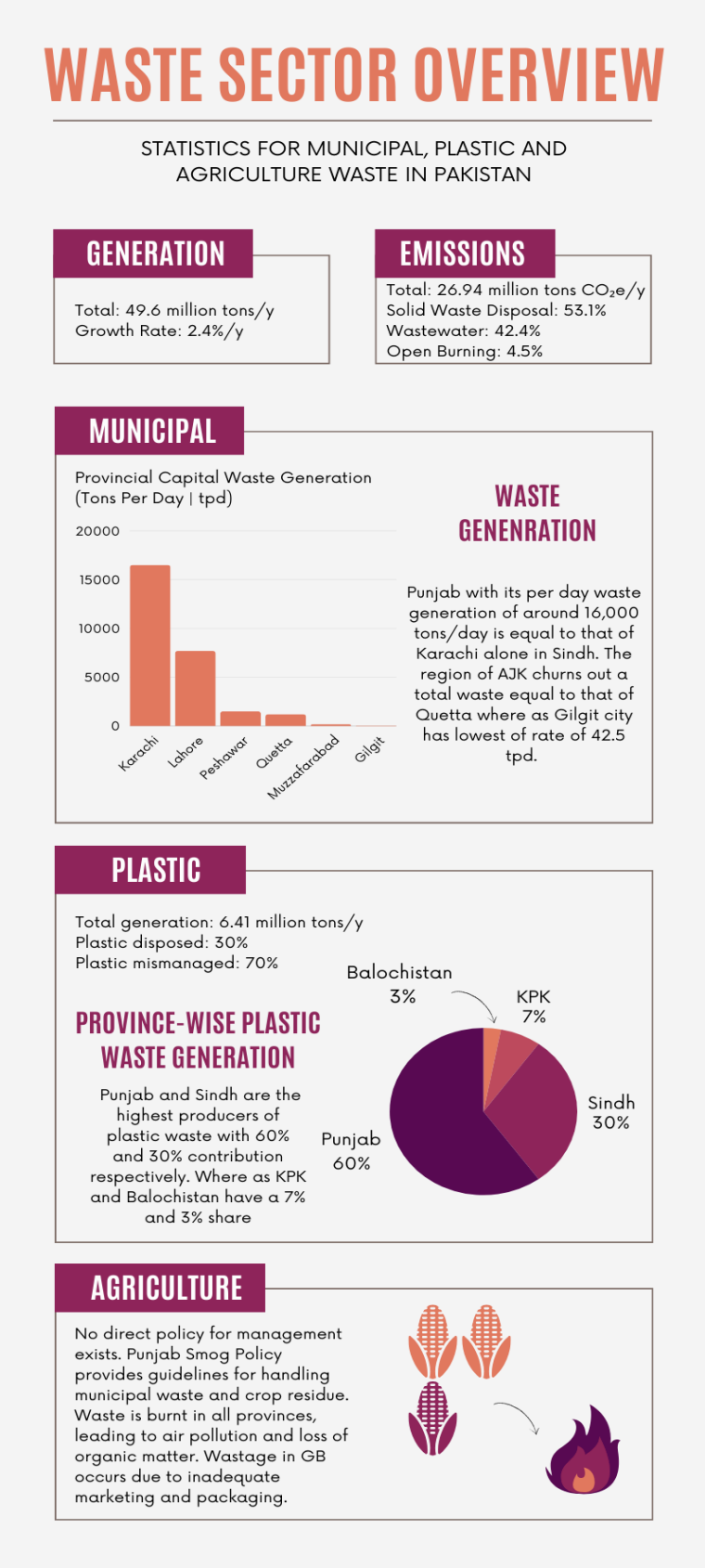
The country generates approximately 49.6 (U.S. Department of Commerce, 2024) million tons of solid waste annually, 32.6 million tons of which is municipal solid waste with a collection efficiency of only 50% to 60% (Hilal Magazine, 2024). Characterization studies show that a major portion of this waste is organic, biodegradable, amounting to 60% to 65% of the total generated waste. Another significant volume is that of plastic waste where according to UNDP, Pakistan generates 6.41 million tons of plastic waste annually and alarmingly only 30% of this waste ends up in dumpsites or landfills while the rest 70% remains mismanaged (UNDP U. N., Baseline study: Current scenario of plastic waste management in Rahim Yar Khan, 2021). Pakistan is ranked as the second largest country with a domestic market for recycled plastic but unfortunately with also a limited recycling potential of 18% and only 3% for plastics (Dawn, Pakistan's plastic waste crisis: Challenges and solutions, 2023).

The World Bank estimates that MSW in Pakistan will increase to 42 million tonnes in 2030 and over 66 million tonnes in 2050, based on current urbanization and population growth rates (Jabeen, Dogra, Ghimire, Ahuja, & Bhada Tata, 2021). The agriculture sector generates substantial agricultural waste, and mismanagement has led to harmful practices like crop burning, which significantly degrades air quality (Muhammad SulemanTahir, n.d.). Moreover, other environmental factors like water and soil are also affected where the soil water retention capacity and fertility reduce by 20 to 30% (UNEP, 2021). Water resources are harmed and ground water quality is specifically impacted by the leaching of contaminants. Soil infertility and reduced water retention exacerbates the use of water for irrigation aggravating the mismanagement of the depleting water resources. Agricultural waste burning accounts for an increase in GHG emission to about 40% (Azhar, Zeeshan, & Fatima, 2019) predominantly in the province of Punjab and Sindh which highlights the critical need for agriculture waste management (AWM) technology.

Pakistan generates a total of 49.6 million tons of waste per year which is increasing at the rate 2.4% (Shafique & Clark, 2022) . This waste is responsible for 26.94 million CO^2e emissions per year majorly coming from solid waste disposal activities (Ijaz, 2023). Municipal solid waste generation varies in provinces with the highest rate in the provincial capitals of Sindh and Punjab. Karachi produces around 16,000 tpd whereas Lahore generates 7,690 tpd (Haider, 2024). Quetta produces about 1200 tpd (Noor, Panezai, Achakzai, & Kakar, 2018) which is a little less than Peshawar and equal to that of entire AJK region. Gilgit city produces the least quantity of 42.5 tpd (Ali, et al., 2015).

Plastic waste, on the other hand, is generated at the rate of 6.41 million tons per year where 70% of it goes unmanaged (UNDP, 2021). Sindh and Punjab again are majorly responsible for plastic pollution with generation percentages of 30% and 60% respectively (Mohmand, 2023)

Agriculture waste is mostly burnt despite Smog policy leading to air pollution and loss of organic matter. According to the Pakistan Social and Living Standards Measurements Survey of 2019-2020, Pakistan only 16.54% of the waste gets collected with the least collection percentage in KPK where 85.79% of the waste openly dumped (PBS, 2020). The main reason for this is the lack of disposal facilities, overfilled dump sites and limited infrastructure.



5.2 Promoting Gender Equality and Social Inclusion

The floods of 2022 have already indicated the issue of lack of access to basic healthcare (Waheed, 2023) and educational facilities, vulnerability to climate-induced displacement and loss of livelihood for social groups like youth, ethnic minorities, elderly and low-income households particularly women. Youth representing 67% (UNCTAD, 2011) of Pakistan's population has been identified as the beneficiary of Updated Nationally Determined Contributions 2021, Pakistan (GoP G. o., 2021). Added to this, vulnerable social groups especially in rural areas exhibit problems such as 71% household with inadequate sanitation facilities (Hakro, 2012). In the waste sector, migrants from rural areas and Afghan refugees are forced to become waste-pickers in order to afford livelihood where they work for long hours exposing themselves to unhygienic conditions and face social stigma, verbal abuse, and even physical violence (ILO, 2023) (Atlas, n.d.).

Women that are performing operations like waste segregation and recycling are under-represented in formal employment by 21% as compared to 52.5% males (PBS, 2022).The main problem is socio-cultural norms particularly in rural areas preventing women for progressing economically in this sector and threatening with concerns for women's health, safety and equal opportunities. Considerations must be included in the technology roadmap to remove disparities and inequalities for gender and threatened social groups to provide a fresh approach and design for both sectors.

Gender and social concerns will be addressed in terms of creating job opportunities, technical skills and economic opportunities for vulnerable groups especially women. The waste sector is a heavily male dominated industry for which the proposed action plan will aim to eliminate the patriarchal aspect. Inclusion of women specifically belonging to the informal sector will earn them the deserved credit for their contributions in activities like waste sorting, collection and reuse. Sustainable waste management practices will ensure an improved health, access to sanitation and energy and increased income generating potential. Targeted capacity building programs for improving technical skills, financial literacy and business management knowledge will help women achieve leadership in their roles.

5.3 The Impacts of Climate Related Disaster

Climate change-induced disasters such as floods, have a significant impact on Pakistan's waste sector. These events disrupt waste collection services, damage infrastructure, and lead to increased waste generation. The generation of solid waste is also reaching unprecedented levels, exceeding the government's capacity for proper management. As a consequence, burning and dumping of garbage have become common practices, leading to an urban environment that not only poses health risks but also negatively impacts overall well-being (UN-HABITAT, Pakistan country report 2023, 2023).

During floods, waste collection vehicles may become inoperable, and landfills may be inundated, leading to the accumulation of waste in urban and rural areas. This can result in the spread of diseases, such as dengue fever and cholera, as well as air pollution. Droughts, on the other hand, can reduce the availability of water for waste treatment and disposal. This can lead to the accumulation of untreated waste, which can contaminate water bodies and soil.

Additionally, droughts can exacerbate the issue of open burning of waste, which releases harmful pollutants into the atmosphere.

5.4 Policy Gaps Analysis

The federal government has introduced the National Hazardous Waste Management Policy 2022 (MoCC&EC, 2022), which supports waste reduction through the 3Rs (Reduce, Reuse, and Recycle). This policy aims to ensure safe disposal and recycling of waste and improve the efficiency of waste management across the country through reducing environmental and health risks. However, no direct policies for managing agricultural waste currently exist in Pakistan. The Punjab Smog Policy provides guidelines for handling municipal waste and crop residue to address smog issues. The policy outlines that the Agriculture Department should promote environmentally friendly disposal methods for crop residue (EPD, 2017).

At the provincial level, several policies promote the 3Rs and seek to enhance waste management efficiency especially through exploring waste-to-energy opportunities. These policies include the Punjab Sanitation Policy 2015, Plastic Management Strategy Punjab 2023, Sindh Solid Waste Management Act 2021, Balochistan Environment Protection Act 2012, Khyber Pakhtunkhwa Environmental Protection Act 2014, and AJK Climate Change Policy 2017.

The policy gaps for the waste sector majorly include failures in implementation of guidelines, lack of monitoring and evaluation systems, insufficient financial assistance and unbalanced economies of scale as evidenced by a policy review against on-ground situation and also identified in the stakeholder meetings. These are the most prominent reasons that explain why sustainable waste management technologies that promote zero-waste and circular economy concepts fail in scaling up and achieving wider adoption.

Another notable factor that remains unaddressed in the policy is the economic viability and market promotion of end products from these technologies. For instance, compost, despite its potential to restore Pakistan's deteriorating agricultural soils, struggles to compete with the more commonly used chemical fertilizers. Large-scale composting projects with strong positive climate potential are finding it difficult to remain financially viable, as compost lacks the economic competitiveness of chemical fertilizers. Consequently, many of these projects are barely breaking even.

Major gaps and hence opportunities in research are evident that can actively be addressed through policy. This includes extensive, comprehensive and updated waste quantification and characterization studies, emissions reduction potentials and lifecycle assessments of scenarios especially in comparison with existing options. Lack of awareness, technical skills and financial literacy remain a barrier that needs to be prioritized in the policies with a focus on vulnerable groups like youth, ethnic and religious minorities and women for a more inclusive, diverse and comprehensive approach to redesigning waste management systems. Financial and private sector mobility that is only just picking pace in the country must be facilitated through

policy and integrated as a part of capacity building. Women and social groups like the informal sector at risk must be the focus of policy in removing the stigma and negative perception associated with the waste sector and the discriminatory and patriarchal nature of the industry.

Achieving NDC targets requires precise quantification of baseline carbon emissions and accurate tracking of reductions from new technologies. To support this, the government should enable entrepreneurs with essential skills, funding, and resources to innovate in information and measurement technologies. The private sector also plays a critical role by promoting decentralized solutions like plastic credits and waste banks, which engage communities in sustainable practices and gather local emissions data. These initiatives provide economic opportunities for marginalized groups and improve emissions tracking in high-density, low-income areas. Integrating ecoinformatics and developing IT platforms to share emissions data and foster collaboration can bridge stakeholder gaps, supporting resilient infrastructures. Well-designed policies that focus on these efforts will significantly advance our ability to meet NDC targets.

5.5 Institutional Frameworks and Financial Allocations

The diagram below illustrates the institutional framework for financial allocations in Pakistan's waste management sector. It outlines the decision-making processes, key players, and funding flows involved in the waste management sector. The diagram shows the flow of funds represented by green arrows, from the Ministry of Finance (MoF) down to Union, Tehsil, and District levels, ensuring allocations align with each institution's responsibilities.

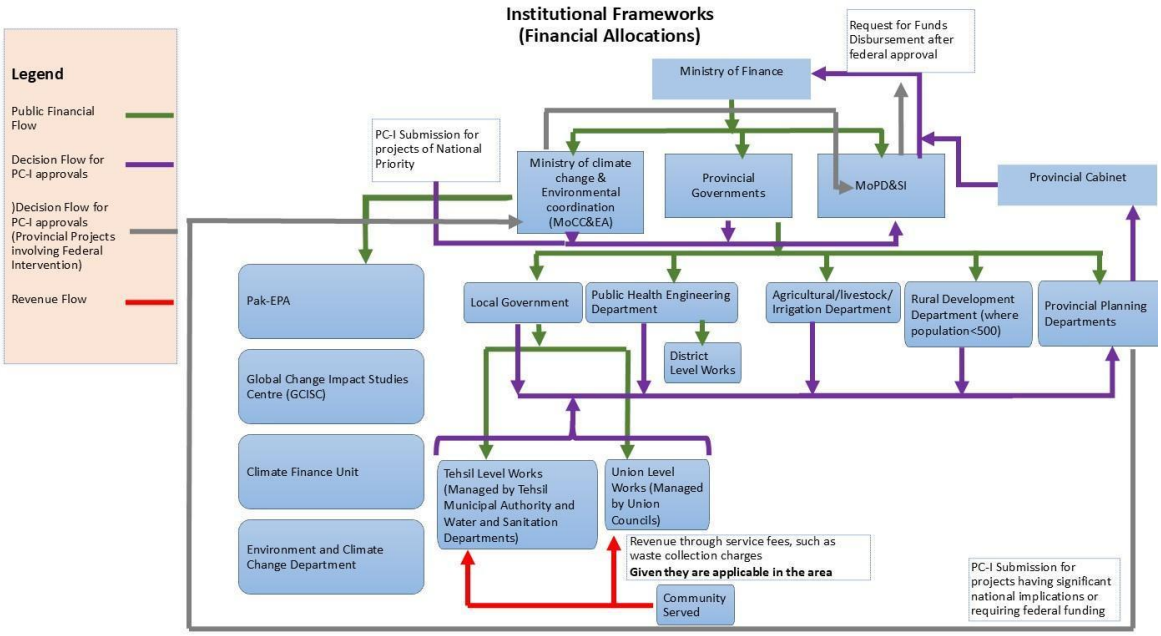


Figure 3: Institutional Framework for financial allocations in the Waste Sector.

The waste sector in Pakistan is beset by a myriad of challenges that hinder its ability to effectively manage and dispose of waste. Institutional fragmentation, characterized by the division of responsibilities among various federal and provincial departments, leads to coordination problems and inefficiencies. Further limitations include hindered ability to invest in necessary infrastructure, such as waste collection facilities, landfills, and recycling plants. The waste sector also faces challenges related to revenue generation, as it struggles to generate sufficient income to cover its operational costs and capital investments. These financial challenges hinder investments in necessary infrastructure and improvements in waste management practices, which in turn exacerbate the sector's environmental and public health problems. Moreover, the burden of debt, which many waste management agencies carry, further constrains their financial flexibility and ability to invest in improvements. Addressing these interconnected challenges requires a comprehensive and integrated approach that involves institutional reforms, increased financial allocations, and improved waste management practices.

6 Waste Technology Roadmap: A Blueprint for a Low-Emission Circular Economy

6.1 Challenges and Opportunities

In the waste sector the challenges begin at the source of waste generation where mixing of waste results in contamination of waste fractions and hence loss of their quality and value. Added to this is the lack of infrastructure which achieves only 50% to 60% collection efficiency. Absence of controlled disposal facilities and reliance on informal sector for collection and segregation of waste further complicates the implementation of sustainable practices. Lack of financial assistance, insufficient gender and social inclusion and incapacitated private sector give birth to the establishment of weak systems that are likely to collapse in the face of harsh climate change impacts.

There is an urgent need to incorporate entrepreneurial perspective to the integration of technology in developing sustainable business models. Additionally, policy intervention to overcome market limitations together with research and innovation to bring technical and economic viability to projects are some other areas that require immediate attention. However, all these challenges must be seen as opportunities to support and build sustainable, resilient and self-sustaining infrastructure and operation especially in developing countries like Pakistan.

Technology intervention in the waste sector offers several such opportunities that would not only achieve NDC targets but also strengthen the economic and social structure specifically for vulnerable communities. This puts the private sector at the forefront that can play a significant role in bringing efficiency, innovation and investment in implementing projects. In the context of waste management, this can begin with increasing the collection efficiency especially in underserved areas leading to a consequent increase in resource recovery potential as well. Other gaps such as the need to improve the efficiency of waste processing facilities, integration of research and innovation approach to achieve technical and economic feasibility and most importantly marketing and adoption of technology end product are waiting to be explored.

Private sector must also be encouraged through incentives and must be engaged with the public sector through mechanisms like Build-Operate-Transfer, Public-Private Partnerships and capacity building programs. Moreover, groups that are more vulnerable to climate change such as youth, marginal communities and women much be specifically focused in terms of private sector engagement and also to achieve an inclusive approach. Private entities operating in sectors other than waste must be integrated into the system by promoting Corporate Social Responsibility initiatives and Extended Producer Responsibility programs that encourage businesses to contribute to waste reduction and recycling goals.

The insights of economic analysis present waste sector proposed technologies as prospective ventures with positive NPV and IRR ranging between 15% to 56%. The longest payback period is noted for refuse-derived fuel which is 6.4 years. Waste sector proposed technologies can

potentially be promising investment opportunities provided that policies and frameworks are in place for implementation and vigilant monitoring and evaluation of the project. Such supporting mechanisms are crucial for mobilization of finances that are needed in addition to the uphold the assistance provided by climate finance in the long run.

To design a technology roadmap, it is vital to assess the current standing of the selected sectors and subsectors while at the same time the entry points for each technology for all provinces and regions

Technology	Challenges	Opportunities
	EXISTING	
Aerobic Windrow Composting	Despite the existence of basic policy and guidelines, technology is practiced on a small-scale composting in Lahore and Karachi (Shafique & Clark, 2022) (ADB, Solid Waste Management in Pakistan: A Roadmap) Lack of space and machinery. Dependency on manual turning of piles leading to incomplete processing of waste Upscaling is a challenge for which financial and infrastructure development support is needed. Existing business models struggle with economic viability due to low market value of end-product. Feedstock capacity and quality of compost needs to be maintained. Feedstock segregation issues, delays in market development, lack of awareness of benefits of compost in comparison with chemical fertilizers and absence of monitoring and evaluation system hinder wider adoption.	Policy revision to mobilize private sector and overcome market limitations. Integrate private sector to meet upfront financial assistance and infrastructure development support supervised by a strong monitoring and evaluation system. Cost saving of landfilling of about $49.76 per ton (Organic, 2024) (ADB, Solid Waste Management in Pakistan: A Roadmap) of waste and of $60 per household Create jobs 2x than landfill and 4x than incineration (Eco-Cycle, n.d.) Carbon reduction potential of over 50% per million metric tons (Drawdown, n.d.) of decomposable waste Capacity building on financial literacy and technical expertise to qualify for financial mechanisms. Develop a source segregation system for efficient operations and exploring other composting methods at household level can significantly reduce waste quantities.

		Achieve gender equality by engaging women in long term community participation programs leading to source segregation and household composting methods for waste reduction.
Waste Segregation	Regulatory acknowledgement and guidelines are available. Support available form “Clean Ambassadors Programme” in Punjab by the Lahore Waste Management Company. Pilot projects exist to promote source separation; widespread segregation at the household level is a challenge due to a lack of awareness, infrastructure for the collection of sorted waste streams and enforcing mechanisms. Policy available but no implementation. Waste sorting carried out by the informal sector in Pakistan that resist formalization of the system, and as financial constrains add to the complexities (Nawaz, et al.). Lack of technical skills to operate and maintain machinery for waste segregation facility is another drawback.	Technical and economic feasibility has been demonstrated. Economic opportunities for marginalized communities through promoting small-scale composting initiatives or buy-back programs for recyclables to incentivize waste segregation and create economic opportunities (Trusha, et al., 2024). Integration of informal sector, especially women, into the system in vital to avoid social disruption. Enforcement of waste segregation regulations Opportunity to improve community engagement through government -led campaigns and private sector partnerships. Promising economic feasibility with payback period of 1.4 years and potential to incorporate plastic crediting mechanisms. Explore available design options considering indigenous factors. Potential to learn from examples abroad and collaboration with international experts. Likely emissions reduction up to 85.48% compared to baseline scenario (Xiao, Dong, Geng, Fujii, & Pan, 2021).

Refuse-Derived Fuel	Guidelines exist for use in cement industry only. Absence of nation-wide policy and regulatory support poses challenges for widespread adoption. Potential for private-sector investment hindered due to technical limitations. Fauji Cement and DG Khan Cement face challenges such as efficient plastic waste segregation, insufficient production quantities, and ensuring RDF quality.	Opportunity to develop nation-wide policy and guidelines. Wider adoption and upscaling of existing facilities (currently having 40% (Rehman & Farzaneh, 2023) requirements being met) to meet 100% fuel quality and quantity requirements through incentivization of private sector as investor. Need for technical research and innovation to address polluting aspect. The technology can further be supported through climate finance and carbon credit potential as a result of reduced fossil fuel consumption, energy recovery efficiency by up to 80%, and 2155.3Kt CO_2 (Shehata, et al., 2022), per year emissions reduction compared to baseline scenario. The operation and maintenance cost is low at 3% and profitability with positive NPV at 6%, 10% and 15% discount rates. Locally available skills just need to be facilitated for large scale implementation. Collaborations between waste plants and private sector entities requiring RDF along with support from government is a vital component of technology implementation. Long term technology intervention can look into ensuring complete combustion to avoid dioxins and furans. Moreover, combination with solar thermal power, waste heat recovery and wind turbines is another option.

Engineered Landfill Technology	Lakhodair landfill site designed and constructed by Turkish companies, with 2 cells completed. Absence of targeted financing mechanisms and limited expertise in design and management. Community resistance in site selection and high infrastructure and maintenance cost. Lack of a monitoring and evaluation framework in Pakistan.	Integration of landfill gas capture technology can address energy crisis. Opportunity for international collaborations for design and maintenance, private sector investment, PPPs for improved collection efficiency and capacity building for upscaling Exceptionally short payback period of 0.02 y. Research on assumptions related to electricity sales and methane recovery potential Potential to reduce 88.07% emissions compared to baseline scenario (Xiao, Dong, Geng, Fujii, & Pan, 2021). Opportunity to improve the currently non-existent women involvement into the value chain. Potential for carbon credit programs.
EMERGING		
Integrated Biomass Gasification for Syngas and Biochar	Proposed policy exists. Lack of clear regulations and standards governing its implementation and the use of syngas as fuel source and biochar as soil amendment. Absence of monitoring and evaluation system. Limited technical expertise and access to financing. Balance of economies for syngas in comparison with natural gas and biochar against chemical fertilizers are a challenge.	Analysis, development and integration of proposed policies with a special focus on technology transfer, cost reduction and unstable economic conditions. Potential to address energy crisis especially in rural agricultural setups. Need for capacity building to develop technical skills and explore various technology combination (electricity, heat etc.) considering indigenous factors. Research and innovation to minimize environmental implications and for economic

		optimization for end product utilization. Potential for 14.7% (Wang & Yang, 2022) reduction in carbon emissions compared to coal power technology Improve depleting soil organic matter of agricultural soils in Pakistan due to intensive agricultural practices Create economic opportunities and improve living standards especially for women and children. Underserved regions and communities can be provided with electricity or

6.2 Evaluation of Selected Waste Technologies

To develop a well-informed Action Plan, the current standing of each technology has been marked as seen in the heatmap below. This positioning has been defined through assessment in the existing legal and financial frameworks, economic and technical feasibility of the technology and the capacity to incorporate social considerations and reduce environmental impacts. The scoring ranges from 1 to 5 where 1 represents low and is depicted by red and 5 represents high indicated by green. The hues of both colors symbolize intensity of ease of adoption with yellow given to score 3 signifying a neutral score.

Out of the 5 technologies shortlisted for the waste sector, Aerobic Windrow Composting technology received the highest score according to the assessment criteria. The only associated repercussion is its impact on the quality of life and lack of social inclusivity that is a prevalent issue in the waste sector and will be addressed in the action plan. Similarly Waste Segregation technology is also a favorable option with some effort needed in privatizing the initiative and mobilizing the finances. RDF has a strong legal and financial infrastructure that needs improvement in incorporating industries other than cement. It also has a reasonable standing in technical and economic feasibility but needs major consideration for inclusivity and climate impact. Engineered Landfill Technology, although the least preferred option in waste management hierarchy, is a viable option to make a transition from dumpsite to proper disposal in developing countries like Pakistan. It has a good legal framework but must incorporate technical skills and social inclusivity in its implementation while also addressing environmental and economic feasibility concerns through landfill gas capture technology. Integrated Biomass Gasification for Syngas and Biochar is an emerging technology in the country that needs work in all areas but promises fruitful outcomes.

6.2.1 Technology Readiness

		Existing				Emerging
Category	**Parameters**	**Aerobic Windrow Composting**	**Waste Segregation Facility**	**Refuse-Derived Fuel**	**Engineered Landfill Technology**	**Integrated Biomass Gasification for Syngas and Biochar**
Legal and Financial Framework	Guidelines/ Regulations	4	5	3	5	3
	Financial Structure	4	2	4	4	1
	Private Sector Mobilization	4	2	4	4	4
Economic and Technical Feasibility	Resource Efficiency	4	5	4	4	4
	Management Efficiency	3	4	3	3	3
	Economic Feasibility	4	3	3	3	3
	Existing Project	4	2	3	2	4
	Skill Capacity	4	3	4	3	2
	Capacity Building	5	4	4	3	3
Inclusivity and Climate Impact	Emissions Reduction	4	5	4	4	3
	Building Resilience	3	4	3	3	3
	Quality of Life	2	4	2	2	3
	Inclusive Development	3	3	3	3	4
	Social Equality	3	3	3	1	4
	Gender Considerations	3	3	2	2	4
	TOTAL	**54**	**52**	**49**	**46**	**48**

Legend

1	2	3	4	5

This current standing according to the assessment through the scoring criteria is then translated and mapped onto the Technology Readiness Level (TRL) Chart after incorporating the challenges and barriers for the technology and prospects considering indigenous scenarios.

The following scale with description for each level was used to assess readiness level.

TRL Level Number	Description
TRL 1: Basic Principles	Scientific research is beginning and results are being translated into future research and development.
TRL 2: Concept Formulated	Technology is very speculative, as there is little to no experimental proof of concept for the technology.
TRL 3: Proof of Concept	Both analytical and laboratory studies are required to see if a technology is viable and ready to proceed further through the development process.
TRL 4: Lab Validation	Multiple component pieces are tested with one another.
TRL 5: Integrated Simulation	Simulations should be run in environments that are as close to realistic as possible.
TRL 6: Prototype Demonstration	Technology has a fully functional prototype or representational model.
TRL 7: Operational Demonstration	Technology requires that the working model or prototype be demonstrated in actual environment.
TRL 8: Final Technology Demonstration	Technology has been tested and ready for implementation into an already existing technology or technology system.
TRL 9: Operational Development Demonstration	Technology has been 'flight proven' in actual system through successful operations

The table below indicates where the technology currently stands in the different progress phases of readiness. The placement of each technology within the three progressive phases ranging from Research, Development and Deployment provides a clear direction for the action plan and the strategy that needs to be adopted in the successful implementation to achieve the targeted outcome.

Refuse-derived fuel with the highest technology readiness level has promising future prospects with a fully operational plant that can be replicated for other industries. Waste Segregation also has great potential with fully developed policies where the technology is extremely important to run most other waste processing facilities, it faces the challenge of scaling up. Aerobic Windrow Composting stands at number 5 on the readiness chart, as it has a policy and some capacity building options. Integrated Biomass Gasification for Syngas and Biochar has a low score owing to the lack of technical skills to operate the facilities. Engineered Landfill Technology does not have a successfully running project currently in the country and also needs heavy capital cost which makes it the least ready technology in the list.

Seb-sector	Technology	Phase	TRL No	Readiness Level	Description
	EXISTING				
Municipal Solid Waste	Aerobic Windrow Composting	Deployment	5	Integrated Simulation	Policy and guidelines are available and technology is operational on small scale in capital cities. Capacity building for farmers available. Failures in market development and the need to integrate other waste types for optimized feedstock capacity are some of the reasons for score 5. Efficiency of aerobic windrow composting depending on weather conditions need further research and innovation when considering commercial upscaling. Other than that, contaminated compost and lack of monitoring system to ensure compost quality is a major barrier in market development and wider adoption resulting in placement of the technology at no 5.
Municipal Solid Waste	Waste Segregation	Development	6	Prototype Demonstration	Policy exists without implementation. Pilot scale is present but upscaling is hindered. Informal sector incorporation into the technology is a major factor to consider while upscaling.
Plastic Waste	Refused-Derived Fuel	Deployment	7	Operational Prototype	Guidelines for utilization in cement industry exist without regulatory support. Skills are available locally, but technology faces technical barriers to its effectiveness. Integration of technology with other feedstock sources can facilitate full scale deployment
Municipal Solid Waste	Engineered Landfill Technology	Development	3	Proof of Concept	Technology exists with technical and financial difficulties which also become a barrier for sustenance and upscaling. Lakhodair site exhibits multiple issues like methane accumulation and lack of consideration for local weather.
	EMERGING				
Agriculture Waste	Integrated Biomass Gasification for Syngas and Biochar	Development	5	Integrated Simulation	Policy exists with lack of clear regulations and standards for the use of syngas and biochar. Technical expertise is limited. Existing biogas plants, popular in rural setups can be used as basis to transition to IBG. Mechanisms for utilization of Syngas and Biochar need infrastructure development as well.

Legend

6.3 A Roadmap for Waste Sector Transformation: Action Plans

Waste sector, while being of the major contributors to greenhouse gas emissions, also holds a substantial capacity to cater to NDCs targets through a technology-based action plan. Sustainable waste management practices, with the potential to reduce about emissions can simultaneously create numerous social benefits such as employment and entrepreneurial opportunities, enhanced agricultural productivity for farmers, formalizing the livelihood of waste sorters belonging to marginalized groups and enabling current waste managers to build resilient infrastructures supported by climate finance. A key benefit is improved environmental health and air quality, leading to improved health amongst citizens. Private sector mobilization for upfront costs and efficient operations of waste management facilities have been identified as a vital aspect for technology deployment whereas engagement and coordination of stakeholder has been incorporated in the action plan for sustenance and wider adoption in the long run.

6.3.1 Rationale for an Integrated Waste Management Approach to Technology Intervention

Extensive stakeholder consultation identified several factors that should make the foundation of the action plan for waste sector. Integrated strategies were suggested for Sindh while tailored solutions were encouraged in Punjab. Overall, small scale and cost-effective technologies were identified as feasible if market demand was created for end-products.

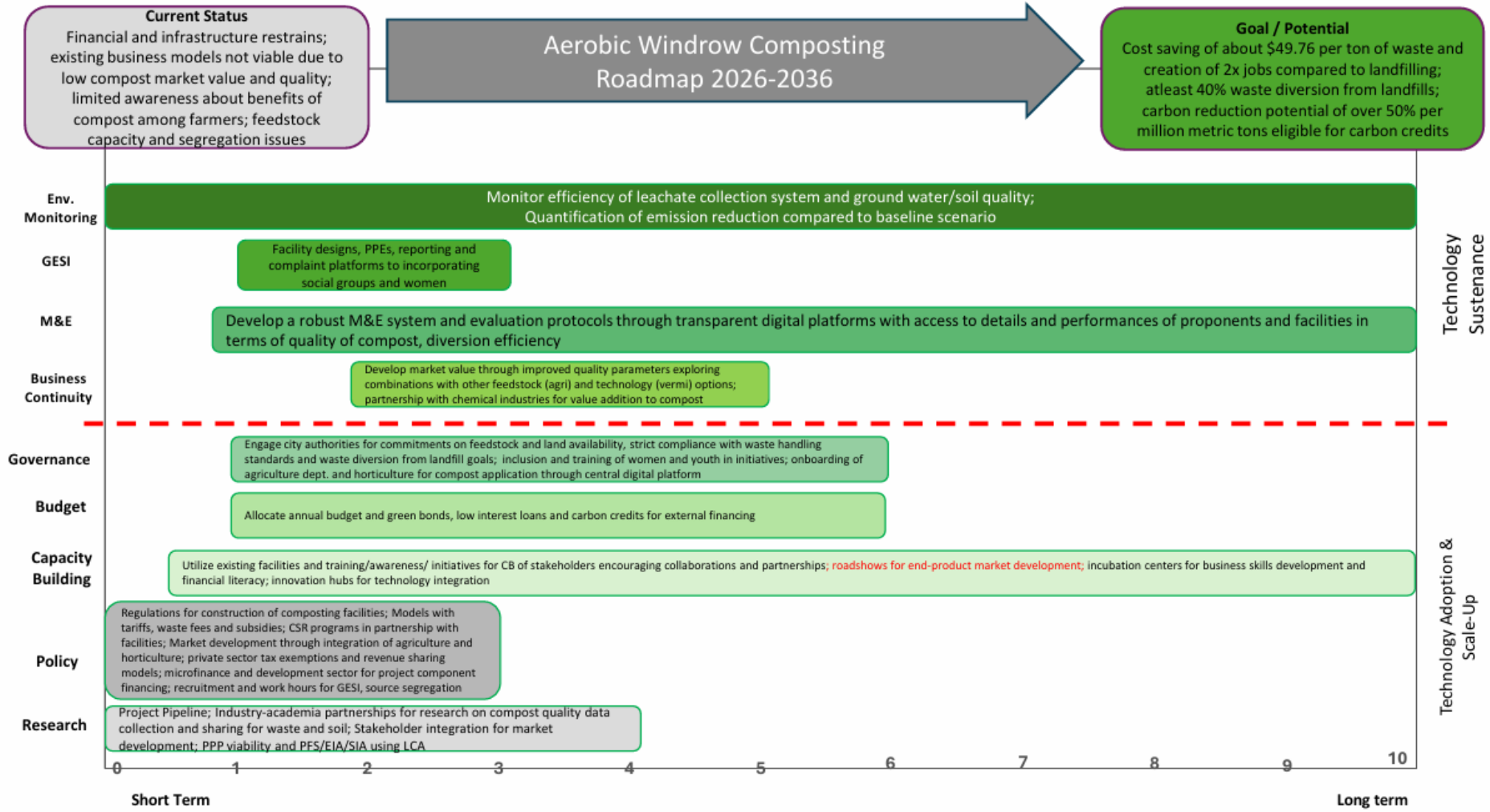
Keeping stakeholder meetings in perspective the action plan is built to propose that a decentralized technology implementation plan should be implemented where housing societies, commercial units and industrial zones should submit a comprehensive plan outlining the establishment of solid waste disposal sites within their premises in an effort to divert waste from landfills into decentralized units. The facility units will utilize a prioritized waste management technology or combination of technologies considering indigenous waste quantification and characterization, weather, market challenges, economic viability etc. in the selection of technology/ies resulting in significant reduction in emissions from fuel burning during the transportation of waste. However, for RDF and waste segregation, centralized models can also be considered for capacity optimization, economic viability and ease of operations while making sure that waste segregation facilities are integrated with the decentralized units to provide segregated feedstock while RDF can be a central unit to receive feedstock from various sources as inability to meet requirements is one of its identified issues.

Engineered landfilling without landfill gas capture, as per the waste hierarchy, must be the least preferred option in sustainable waste management hierarchy applicable only for the disposal of residual waste from other waste treatment and processing facilities. In case of failure to develop decentralized units, landfilling can be integrated with a waste segregation unit combined with a centralized landfill on-site composting or integrated biomass gasification for organic waste management and RDF processing unit for plastics. Engineered landfilling with landfill gas capture should only be considered in case of failure to develop any kind of treatment or

processing facility because for optimized methane generation in a gas capture system, maximum quantities of organic waste would be required to generate sufficient amount of methane for economic viability.

A digital platform must be developed to gather all stakeholders of the implemented technologies on one platform for an improved and well-integrated waste management system where one entity benefits from another utilizing the interdependencies on each other. Such a system can be extremely fruitful in improving market value of end products, optimized stakeholder engagement and vigilant and transparent monitoring system. Media campaigns can also be designed for such digital platforms which can help build awareness in communities. With an ultimate goal of achieving source segregation for any sustainable waste management plan, digital platforms can also play a vital role to disseminating protocols and inform new waste streams if they are generated.

An important aspect to consider here is the possibility of developing a combination of practices, methods and other technologies to improve the efficiency of individual technology. Exploring such interdependencies or symbiotic linkages between the proposed technologies can help achieve optimization and sustenance. An example of such integration is the dependency of composting facility on waste segregation, or the utilization of compost as daily bio covers at engineered landfills all of which have been elaborated upon in the action plan.


Current Status
Financial and infrastructure restrains; existing business models not viable due to low compost market value and quality; limited awareness about benefits of compost among farmers; feedstock capacity and segregation issues
Aerobic Windrow Composting Roadmap 2026-2036
Goal / Potential
Cost saving of about $49.76 per ton of waste and creation of 2x jobs compared to landfilling; atleast 40% waste diversion from landfills; carbon reduction potential of over 50% per million metric tons eligible for carbon credits
Env. Monitoring
Monitor efficiency of leachate collection system and ground water/soil quality; Quantification of emission reduction compared to baseline scenario
GESI
Facility designs, PPEs, reporting and complaint platforms to incorporating social groups and women
M&E
Develop a robust M&E system and evaluation protocols through transparent digital platforms with access to details and performances of proponents and facilities in terms of quality of compost, diversion efficiency
Business Continuity
Develop market value through improved quality parameters exploring combinations with other feedstock (agri) and technology (vermi) options; partnership with chemical industries for value addition to compost
Technology Sustenance
Governance
Engage city authorities for commitments on feedstock and land availability, strict compliance with waste handling standards and waste diversion from landfill goals; inclusion and training of women and youth in initiatives; onboarding of agriculture dept. and horticulture for compost application through central digital platform
Budget
Allocate annual budget and green bonds, low interest loans and carbon credits for external financing
Capacity Building
Utilize existing facilities and training/awareness/ initiatives for CB of stakeholders encouraging collaborations and partnerships; roadshows for end-product market development; incubation centers for business skills development and financial literacy; innovation hubs for technology integration
Policy
Regulations for construction of composting facilities; Models with tariffs, waste fees and subsidies; CSR programs in partnership with facilities; Market development through integration of agriculture and horticulture; private sector tax exemptions and revenue sharing models; microfinance and development sector for project component financing; recruitment and work hours for GESI, source segregation
Research
Project Pipeline; Industry-academia partnerships for research on compost quality data collection and sharing for waste and soil; Stakeholder integration for market development; PPP viability and PFS/EIA/SIA using LCA
Technology Adoption & Scale-Up
0
1
2
3
4
5
6
7
8
9
10
Short Term
Long term

Aerobic Windrow Composting (TRL Level 5: Integrated Simulation)				
TECHNOLOGY ADOPTION & SCALE-UP				
Action Item	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify Stakeholders**
RESEARCH				
Short Term				
Project Pipeline Development	Develop initial project concepts, outlining the key components and potential benefits. Conduct in-depth technical and economic feasibility studies for each project concept, including cost-benefit analysis and risk assessments. Prioritize project proposals based on factors such as environmental impact, economic benefits, social impact, and technical feasibility.	0-1 yr	**Medium**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards NGOs PSF PCST

Initiate research and development programs with industry-academia partnership on identified technical, environmental and social issues for the technology.	Promote industry and academia collaborations to find innovative solutions to improve quality in terms of contamination and calorific value of compost to update status from 'soil nourishing amendment' to 'fertilizer'.	0-2 y	**High**	MoCC & EC MoST Provincial EPAs and EPDs Solid Waste Management Companies and Boards NGOs PSF PCST PARC/NARC Provincial Agricultural Departments HEC Academic Institutes
Facilitate development of central data base with clear data sharing protocols.	Integrate stakeholders, such as compost producers and buyers, through a central digital platform comprising of an accessible data base for operating facilities and buyers.	0-2 y	**High**	MoIT Solid Waste Management Companies and Boards
PPP Viability Study	Develop a financial model, and evaluate the economic viability of the PPP. Conduct financial and technical due diligence.	3-4yr	**High**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards NGOs PSF PCST

Gather and analyze waste and soil related data for the area being considered for technology adoption using waste modelling tools	Conduct waste composition analysis through detailed waste audits and sampling to acquire estimate of the organic material that is compostable in the waste stream Collect data for soil characteristics with a focus on soil organic matter and its depletion rate to promote compost as a soil nourishing amendment Utilize GIS and spatial analysis for site selection and project planning	0-1 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR
Conduct economic feasibility analysis and environmental/ social impact assessment using Life Cycle Assessment (LCA) approach for the selected technology or combination of technologies	Integrate data for surrounding agricultural land and/or horticulture activities to analyze application potential of produced compost Quantify baseline emissions and emission reduction potential to help pitch selected technology or combination of technologies to potential project proponents, prospective investors, interested donor fundings, and climate finance. Conduct an environmental impact assessment (EIA) and a social impact assessment (SIA) to	0.5-1 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR

	identify potential impacts and mitigation measures.			
POLICY				
Short Term				
Develop regulations for the construction of centralized composting facilities for cities.	Mandate **municipalities and city development authorities** to designate a sustainable waste management site within the city's premises. Establishment of model where city tariffs or waste fees are used to subsidize composting operations that could significantly promote sustainable waste management. Mandate CSR programs for large scale industrial, institutional and commercial producer executed through partnering with composting facilities.	0-1 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Provincial and City Development Authorities
Develop policy to improve market value of the compost	Enforce use of compost made from municipal solid waste in agriculture sector and horticulture as soil amendment starting with a mix of 20% with chemical fertilizers.	0-1 y	**Very High**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities

				Provinical Agriclture Departments Horticulture Authorites
Develop regulations that mobilize private sector for the implementation, operations and maintenance of composting facilities	Develop and implement public-private partnership (PPP) framework for composting facilities, via the identification of potential private sector partners, defining the most suitable PPP model, establishing a transparent procurement process, negotiating a comprehensive PPP agreement, and ensuring regulatory clarity and a robust monitoring framework. Incorporate private sector for an increased waste collection efficiency, wider adoption and less reliance on donor fundings through low interest loans, public private partnerships and impact bonds. Offer tax exemption and subsidies to companies investing in composting infrastructure in terms of land acquisition, purchasing composting machinery, managing operations etc.	0-1 y	**Very High**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities

	Provide long term concession agreements, revenue sharing models and public land leases offered to build and operate facilities.			
Develop regulations that mobilize finances other than private sector investment for the implementation, operations and maintenance of composting facilities	**Enable microfinance programs for applicable components of composting facilities, such as utility infrastructure.** Collaborate with development bank funding, grants and schemes to secure financial assistance at low-interest.	0-1 y	**Very High**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities Development Sector MicroFinance Banks and Institutes SMEDA
Develop regulations that ensure gender equality and social inclusion in implementation, and operation and maintenance of composting facilities	Gender responsive recruitment to include a percentage of women, youth and individuals from marginalized groups especially those belonging to the local community targeted for managerial positions and within governance structures. Ensure gender responsive workplace policies such as flexible workhours and antiharassment rules.	0-1 y	**Very High**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities

Long Term				
Mandating source segregation at household and commercial level through policy to achieve high quality steady supply of organic waste in the long run.	Develop infrastructure for source segregation system using separate bin system later on upgraded to smart bins	2-3 y	**Medium**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
CAPACITY BUILDING				
Short Term				
Utilise an existing fully functional model facility for demonstration of aerobic windrow composting technology, and as a benchmark for the monitoring and evaluation phase.	**Construction of a composting facility in provinical capitals, where the technology is absent as a prototype for wider and large-scale adoption.** **Ensure that training sessions are scheduled keeping in mind household responsibilities of women.**	0.5-1 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
Long Term				
Evaluate the existing knowledge of regulatory authorities and project proponents, and workers at facility, about composting and business management pertaining to composting facility and design	Conduct training sessions for regulatory authorities and project proponents, local engineers, technicians and facility operators to design, run and maintain facilities with a special focus on	Ongoing	**Medium**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards

awareness campaign accordingly.	managerial training for women, youth, informal sector and marginal groups. **Roadshow to organized to enhance stakeholder knowledge and capacity. This roadshow will focus on site visits, exhibitions, stakeholder consultation meetings. By bridging the knowledge gap, the roadshow will promote technology adoption and generate finances and a skilled workforce**			PCSIR Academic Institutes
Promote innovation hubs and business incubation centres to develop research and foster innovation along with business management skills for the technology	Develop knowledge and skills to prepare and develop business models, business plans, proposals and investor pitch for composting facilities to present business ideas to potential investors and to secure donor funding. Develop financial literacy covering topics of budgeting, cost control and revenue management especially targeting women and youth Research various combinations of practices, composting methods, feedstock, and integration with	Ongoing	**Medium**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR Academic Institutes SMEDA PITAC

	other technologies for optimization			
BUDGET				
Short Term				
Allocate an annual quota in the fiscal budget for development of waste management infrastructure	Allocation of budget with clear guidelines for utilization.	0-6 m	**Very High**	MoCC & EC MoF Provincial EPAs and EPDs Solid Waste Management Companies and Boards
Long Term				
Explore national and international climate finance options by establishing mechanisms	Facilitate access to green financing options, such as low-interest loans and green bonds, with a special focus on empowering youth, a vulnerable group disproportionately affected by climate change. Establish frameworks that enable initiatives to earn carbon credits for revenue generation from national and international carbon markets.	1-5 y	**Very High**	Provincial EPDs and EPAs Solid Waste Management Companies and Boards State Bank of Pakistan Pakistan Stock Exchange Multilateral financial institutions
GOVERNANCE				
Short Term				
Sustain business through planning with city authority for optimized operations and facility capacity	Secure reliable feedstock supply and allocate suitable land for the composting facility in coordination with the city authority.	1-2y	**Very High**	

Ensure policy implementation of public-private partnership for efficiency and upscaling and wider scale adoption of the technology.	Define roles and responsibilities, compliance requirements and accountability measures of all stakeholder including private sector, government agencies and local authorities Mandate compliance with waste management standards to be reported in terms of efficiency of composting facility operations, waste diversion rates and social inclusions metrics	1-3 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Public-Private Partnership Authority
Ensure policy implementation of gender equality and social inclusion in technology implementation and operations	Presence of women at managerial positions as per allocated quota Existence of women and youth led business initiatives	1-3 y	**Very High**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial Development Authorities
Long Term				
Integrate information technology for application of compost produced from municipal solid waste to develop markets	Create accessibility for final product from composting facility through digital platform Engage agriculture and horticulture to ensure end-product application	2-6 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority,

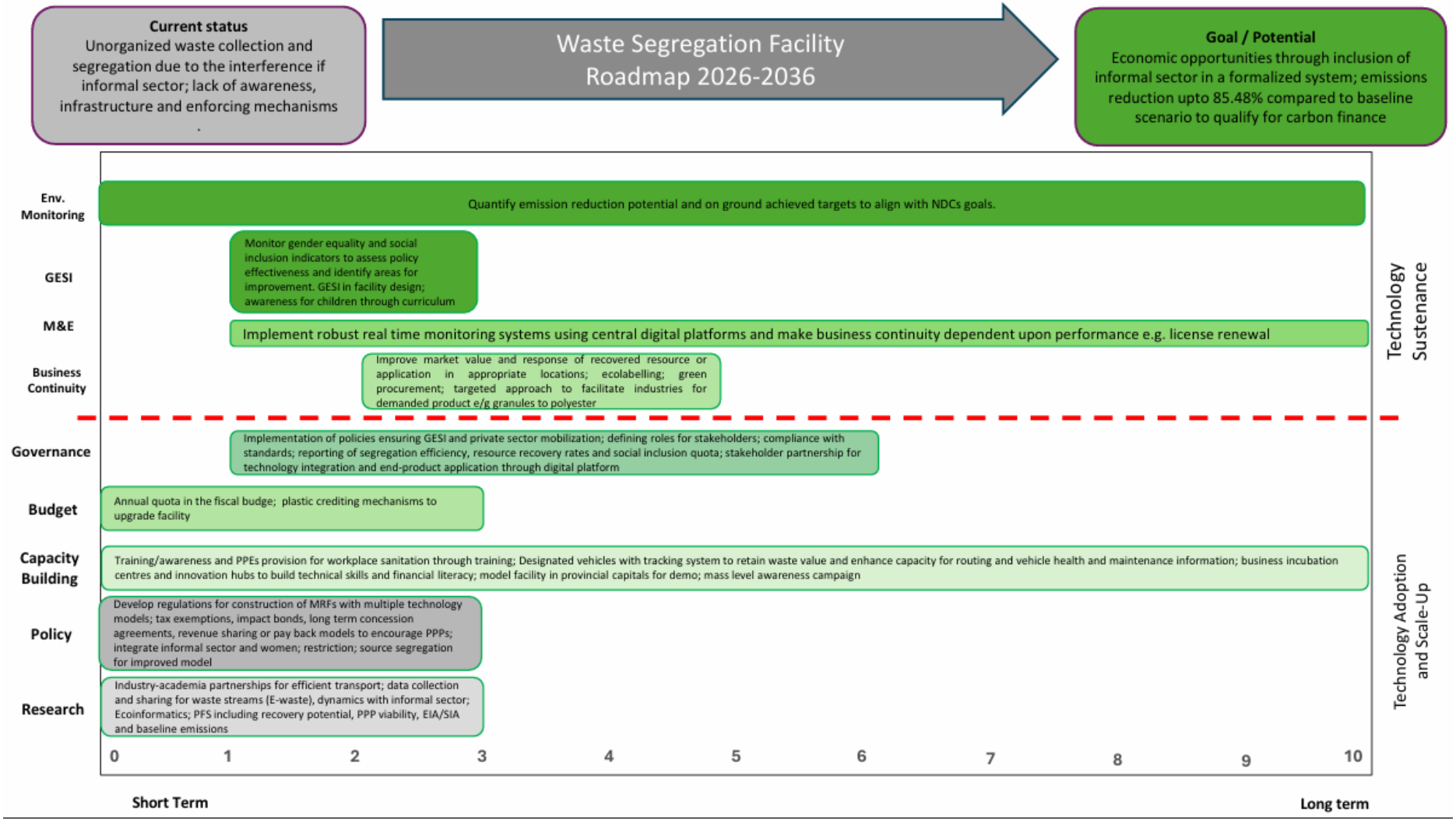
	Guidance available on the digital platform for waste producers to facilitate efficient compost production			Provincial and City Development Authorities MoIT PSEB P@sha Software Development Contractors Pakistan Horticulture Authority Agriculture Department and Extensions Landfill Sites
TECHNOLOGY SUSTENANCE				
Action Plan (short-term and long-term) and Milestones	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify stakeholders**
BUSINESS CONTINUITY				
Short Term				
Improve market value and response of produced compost or application in appropriate locations	Develop standards to ensure quality parameters such as nutrient content, pathogen level, plastic contamination etc. Engage chemical fertilizer companies to include compost made through technology adoption to add value and introduce in market.	2-5 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Agriculture Department and Extensions Municipalities

	Sale of compost as a nourishing soil amendment the agriculture sector or landscaping OR application of compost at landfill sites as daily biocover by municipalities. Diversion of agriculture and livestock waste into the technology process to improve quality of compost.			PARC
Research on integration of combination of practices and methods to enhance end-product quality	Integration of waste segregation technology to enable flow of homogenised organic compostable waste streams to compost facility Integration of windrow composting with vermicomposting to improve the quality of compost for better market value and revenue generation	3-5 y	**Medium**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Private Entities Research Institutes
MONITORING AND EVALUATION				
Short Term				
Leverage information technology for a robust monitoring and evaluation system engaging all stakeholder at a time	Utilize digital platform for reporting and real time monitoring for stakeholder engagement, performance and social inclusion	1-3 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City

				Development Authorities
Develop and implement balanced but vigilant monitoring and evaluation protocols	Stringent inspection of facilities to monitor compliance with waste handling standards and certification to ensure quality control.	1-5 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
Long Term				
Bring transparency to monitoring and evaluation system through integration of information technology	Generate lists on digital platform with rankings of private sector entities based on quality of compost produced, sorting efficiency achieved etc. for a transparent review that will drive private sector mobilization factors such as license renewal, incentive provision etc. Generate of a performance feedback system on the digital platform indicative of level of execution of the technology through operational private sector entities	Ongoing	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
GENDER EQUALITY AND SOCIAL INCLUSION				
Long Term				

Ensure that facility design is appropriate and accessible for women and all social groups	Ensure well-lit areas with surveillance especially if there are evening shifts. Provide PPEs for occupational health and safety of workers especially targeting unsanitary/hazardous conditions of incoming waste and noise in the facility. Flexible working hours should be allowed for women to accommodate.	Within 6 months of facility construction	**Medium**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial Development Authorities Municipalities Informal Sector
Ensure vigilant inspection of gender equality and social inclusion indicators to monitor policy implementation outcome and assessment of necessary revision in policy for achieving targets	Develop anonymous reporting platform for gender specific complaints Implementation of regular inspection and audits to assess relevant indicators.	1-3 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards MoHR NGOs Civil Societies IMO Capital Development Authority, Provincial Development Authorities Municipalities
ENVIRONMENTAL MONITORING				
Short Term				
Have a leachate collection system incorporated in the technology design to maintain groundwater quality	Monitor the efficiency of leachate collection system by regular testing of groundwater quality parameters	1-5 y	**High**	Provincial EPDs and EPAs Solid Waste Management

				Companies and Boards
Long Term				
Quantify emission reduction potential and on ground achieved targets to align with NDCs goals.	Implementation of carbon accounting protocols to quantify baseline scenario carbon emissions. Generation of yearly inventories to quantify achieved emissions reduction.	0-10 y	**Very High**	Provincial EPDs and EPAs Solid Waste Management Companies and Boards PCSIR


Current status
Unorganized waste collection and segregation due to the interference if informal sector; lack of awareness, infrastructure and enforcing mechanisms
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Waste Segregation Facility Roadmap 2026-2036
Goal / Potential
Economic opportunities through inclusion of informal sector in a formalized system; emissions reduction upto 85.48% compared to baseline scenario to qualify for carbon finance
Env. Monitoring
Quantify emission reduction potential and on ground achieved targets to align with NDCs goals.
GESI
Monitor gender equality and social inclusion indicators to assess policy effectiveness and identify areas for improvement. GESI in facility design; awareness for children through curriculum
M&E
Implement robust real time monitoring systems using central digital platforms and make business continuity dependent upon performance e.g. license renewal
Business Continuity
Improve market value and response of recovered resource or application in appropriate locations; ecolabelling; green procurement; targeted approach to facilitate industries for demanded product e/g granules to polyester
Governance
Implementation of policies ensuring GESI and private sector mobilization; defining roles for stakeholders; compliance with standards; reporting of segregation efficiency, resource recovery rates and social inclusion quota; stakeholder partnership for technology integration and end-product application through digital platform
Budget
Annual quota in the fiscal budge; plastic crediting mechanisms to upgrade facility
Capacity Building
Training/awareness and PPEs provision for workplace sanitation through training; Designated vehicles with tracking system to retain waste value and enhance capacity for routing and vehicle health and maintenance information; business incubation centres and innovation hubs to build technical skills and financial literacy; model facility in provincial capitals for demo; mass level awareness campaign
Policy
Develop regulations for construction of MRFs with multiple technology models; tax exemptions, impact bonds, long term concession agreements, revenue sharing or pay back models to encourage PPPs; integrate informal sector and women; restriction; source segregation for improved model
Research
Industry-academia partnerships for efficient transport; data collection and sharing for waste streams (E-waste), dynamics with informal sector; Ecoinformatics; PFS including recovery potential, PPP viability, EIA/SIA and baseline emissions
Technology Sustenance
Technology Adoption and Scale-Up
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Short Term
Long term

Waste Segregation (TRL Level 6: Prototype Demonstration)				
TECHNOLOGY ADOPTION & SCALE-UP				
Action Item	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify Stakeholders**
RESEARCH				
Short Term				
Initiate research and development programs with industry-academia partnership on identified technical, environmental and social issues for the technology	Conduct waste quantification and composition analysis for areas where such studies are lacking through detailed waste audits and sampling especially focused on E-Waste. Conduct a study on the dynamics of technology adoption and informal sector and explore solutions to integrate both to avoid threats to the economic viability of technology and social stability of informal sector. Engage industry and academia collaborations to find innovative solutions to maintaining the value of waste fractions during transport.	0-2 y	**High**	MoCC & EC MoST Pak, EPA Solid Waste Management Companies and Boards NGOs PSF PCST HEC Academic Institutes
Facilitate development of central data base with clear data sharing protocols.	Display of roles and responsibilities of stakeholders along with responsiveness to	0-2 y	**High**	MoIT Solid Waste Management

	performance parameters Enable engagement plans through this platform for improved collaborative approach to waste management Mass level awareness campaigns through this platform in addition to print, social and digital media on 3Rs, Zero Waste, Circular Economy and Source Segregation concepts			Companies and Boards
Ensure waste quantification and characterization before technology implementation.	Gather insights into the waste data studying their dynamics with social and behavioral factors. Integrate technology with ecoinformatics for appropriate site selection for facilities construction and route optimization	0-2 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR
PPP Viability Study	Develop a financial model, and evaluate the economic viability of the PPP. Conduct financial and technical due diligence.	0-1yr	**High**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards NGOs PSF PCST

Conduct economic feasibility analysis and environmental impact assessment using Life Cycle Assessment (LCA) approach for the selected technology or combination of technologies.	Select waste segregation facility adoption if lwaste streams have sufficient waste fractions with high economic value. Conduct an environmental impact assessment (EIA) and a social impact assessment (SIA) to identify potential impacts and mitigation measures. Quantify resource recovery potential through the implementation of waste segregation facility Quantify baseline emissions and emission reduction potential to help pitch selected technology or combination of technologies to potential project proponents, prospective investors, interested donor fundings, and climate finance.	2-3 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR
POLICY				
Short Term				
Develop and implement regulations for municipalities to ensure construction and operation segregation facility	Mandate municipalities to designate space for a material recovery facility (MRF) Provide multiple models, simple (conveyor belts) and complex (machinery	0-1 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards

	combinations) to suit scale, location scope of technology. Develop pay back systems for commercial, institutional and industrial entities for active participation.			Capital Development Authority, Provincial Development Authorities
Develop regulations that mobilize private sector for the implementation, operations and maintenance of waste segregation facilities	Incorporate private sector for wider adoption and less reliance on donor fundings through low interest loans, public private partner ships and impact bonds. Offer tax exemption and subsidies to companies investing in waste segregation infrastructure in terms of land acquisition, purchasing waste segregation machinery, managing operations etc. Provide long term concession agreements, revenue sharing models and public land leases offered to build and operate facility ~~Incentivize transport of recyclables to increase economic viability of the business model~~	0-1 y	**Very High**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority SECP Provincial Development Authorities SMEDA
Develop regulations that ensure gender equality and social inclusion in	Integrate informal sector through	0-1 y	**Very High**	MoCC & EC

implementation and, operation and maintenance of waste segregation facilities	ensuring registration and identification especially of migrants, formalizing through work permits and contracts creating inclusive job roles providing health and social benefits like PPEs, access to sanitation etc. Gender responsive recruitment to include a percentage of women, youth and individuals from marginalized groups especially belonging to the local community targeted for managerial positions and within governance structures Strict action to eliminate prevalent child labor in the informal waste sorting business Ensure gender responsive workplace policies such as flexible work hours and antiharassment rules.			Provincial EPDs and EPAs Provincial and City Development Authority, MoWR Solid Waste Management Companies and Boards NGOs Civil Societies IMO National Commission for Child Welfare and Development (NCCWD) ILO UNICEF
Long Term				
Mandating source segregation through policy to achieve high quality steady supply of organic waste in the long run.	Develop infrastructure for source segregation system using separate bin system later on upgraded to smart bins. Mandating source segregation through policy to avoid	2-3y	**Medium**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards

	contamination of waste fractions and maintain the value of recyclables.			Capital Development Authority, Provincial and City Development Authorities
CAPACITY BUILDING				
Short Term				
Implement vehicle tracking systems for efficient transport, optimized routing and reduced emissions	Integrate private sector in hiring of collection vehicles specifically designed to retain the quality and structure of waste fractions until it reached the Waste Segregation Facility Integrate private sector entities for vehicle tracking Develop stringent systems to ensure transparent tracking systems	0-1 y	**Very High**	Provincial EPAs and EPDs Provincial and City Development Authorities Solid Waste Management Companies and Boards
Provide an enabling environment for sanitary workers and waste collectors to ensure maintenance of quality of waste and human health	Provide PPEs to reduce health risks during waste segregation and transport.	0-1 y	**Very High**	Private sector entities CDA Provincial and City Development Authorities Provincial EPAs and EPDs Solid Waste Management Companies and Boards Informal Sector
Develop a fully functional model facility for demonstration of efficient waste segregation	Construction of model waste segregation plan utilizing machinery combinations in	1-2 y	**Very High**	Provincial EPAs and EPDs

operations as a benchmark for the monitoring and evaluation phase.	provincial capitals as prototypes for wider and large-scale adoption.			Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities Operational organizations and departments
Long Term				
Evaluate the existing knowledge of potential project proponents pertaining to technology and business management pertaining to facility and design an awareness campaign accordingly.	Utilize print and digital media for community awareness Conduct training sessions for local engineers, technicians and facility operators to design, run and maintain waste segregation facilities with a special focus on managerial training for women, youth, informal sector and marginal groups. Develop feedback mechanisms such as stickers for good and bad segregation for active community involvement	Ongoing	**Medium**	Provincial EPDs and EPAs Solid Waste Management Companies and Boards PCSIR Academic Institutes Informal Sector
Promote innovation hubs and business incubation centres to develop research and foster innovation along with business management skills for the technology	Develop knowledge and skills to prepare and develop business models, business plans, proposals and investor pitch for	Ongoing	**Medium**	Provincial EPDs and EPAs

	waste segregation facilities to present business ideas to potential investors and to secure donor funding. Develop financial literacy covering topics of budgeting, cost control and revenue management especially targeting women and youth Research various combinations of machinery and integration with other technologies such as RDF for optimization of resource recovery			Solid Waste Management Companies and Boards PCSIR Academic Institutes SMEDA PITAC
BUDGET				
Short Term				
Allocate an annual quota in the fiscal budget for development of waste management infrastructure	Allocation of budget with clear guidelines for utilization.	0-6 m		MoCC & EC MoF Provincial EPAs and EPDs Solid Waste Management Companies and Boards
Explore national and international climate finance options by establishing mechanisms and	Enable access to green financing options of low-interest loans and green bonds especially to youth as a vulnerable group to climate change impacts. Establish frameworks that enable initiatives to earn plastic credits and carbon credits for	1-3 y	**Very High**	MoCC & EC Provincial EPDs and EPAs Solid Waste Management Companies and Boards

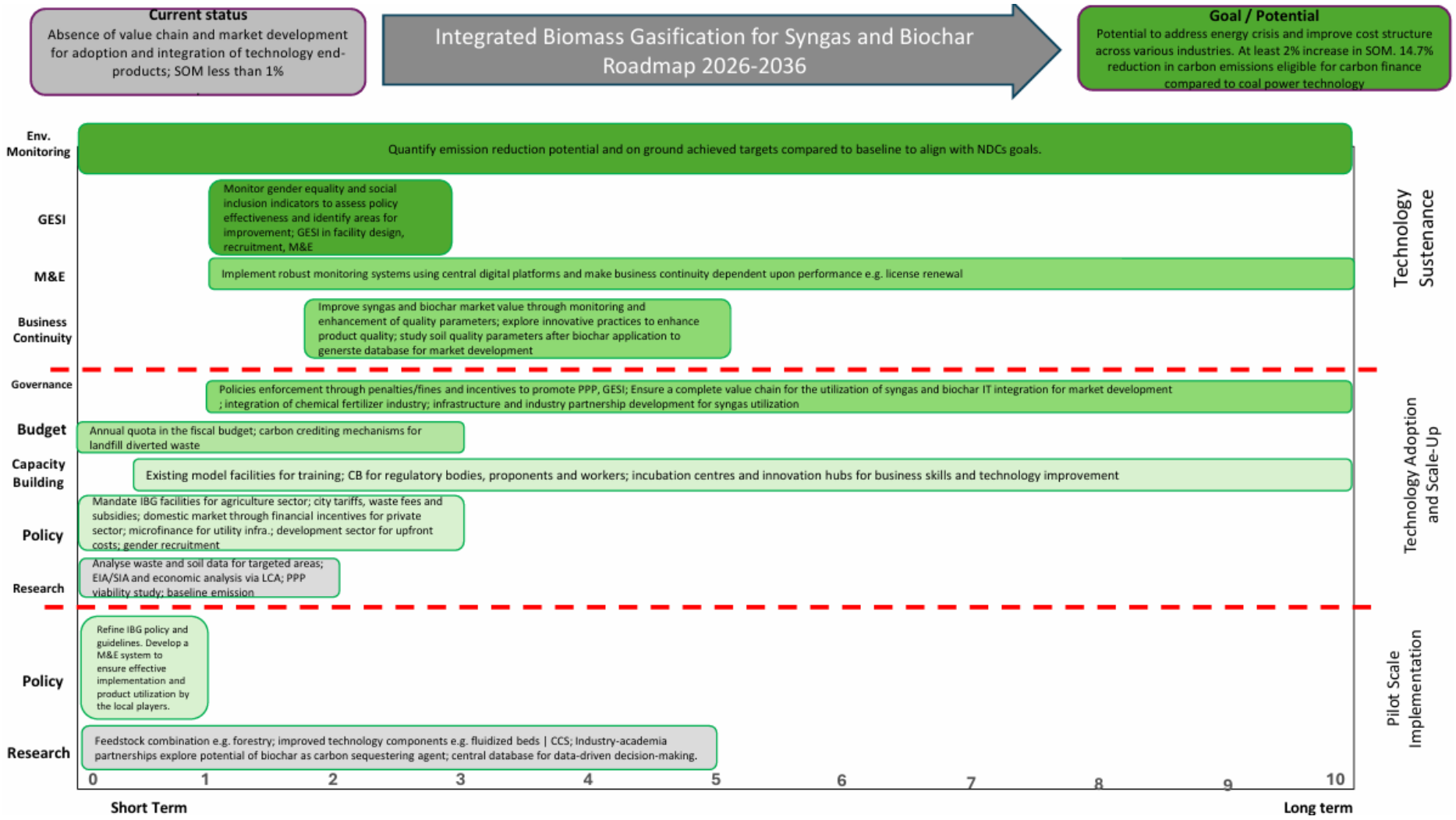
	revenue generation from national and international carbon markets for facility upgrade and sustenance			State Bank of Pakistan Pakistan Stock Exchange Multilateral financial institutions Plastic Crediting entities
GOVERNANCE				
Short Term				
Ensure policy implementation of public-private partnership for efficiency and upscaling and wider scale adoption of the technology.	Define roles and responsibilities, compliance requirements and accountability measures of all stakeholder including private sector, government agencies and local authorities Mandate compliance with waste management standards to be reported in terms of efficiency of waste segregation facility operations, resource recovery rates and social inclusions metrics	1-3 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Public-Private Partnership Authority IOM
Ensure policy implementation of gender equality and social inclusion in technology implementation and operations	Presence of women at managerial positions as per allocated quota Existence of women and youth led business initiatives	1-3 y	**Very High**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards

				Capital Development Authority, Provincial and City Development Authorities
Long Term				
Integrate stakeholders for efficient utilization of recovered resource through information technology	Integrate waste treatment and processing facilities with technology for conversion of recovered resource into a valuable and economically viable end-product by enabling an enabling environment for stakeholder engagement session, alliances and partnerships Guidance available on the digital platform for waste producers to facilitate stakeholder integration	2-6 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Provincial and City Development Authorities MoIT P@sha PPPA
TECHNOLOGY SUSTENANCE				
Action Plan (short-term and long-term) and Milestones	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify stakeholders**
BUSINESS CONTINUITY				
Short Term				
Improve market value and response of recovered resource or application in appropriate locations	Develop standards to ensure quality control and partner with environmental certification bodies for eco-labelling of recycled products	2-5 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards

	Develop industries for conversion of plastics into recycled raw material e.g granules to polyester Adoption of green public procurement through purchase of products made from recovered resource, Incorporate buy-back programs for recyclables to incentivize technology			Provincial Development Authorities Informal Sector
MONITORING AND EVALUATION				
Short Term				
Develop and implement balanced but vigilant monitoring and evaluation protocols	Stringent inspection of facilities to monitor compliance with waste handling standards and certification to ensure quality control	1-2 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
Leverage information technology for a robust monitoring and evaluation system engaging all stakeholder at a time	Utilize digital platform for reporting and real time monitoring for stakeholder engagement, performance and social inclusion	1-2 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities

Long Term				
Bring transparency to monitoring and evaluation system through integration of information technology	Generate lists on digital platform with rankings of private sector entities based on sorting efficiency achieved etc. for a transparent review that will drive private sector mobilization factors such as license renewal, incentive provision etc. Generate a performance feedback system on the digital platform indicative of level of execution of the technology through operational private sector entities	Ongoing	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
GENDER EQUALITY AND SOCIAL INCLUSION				
Long Term				
Ensure that facility design is appropriate and accessible for women and all social groups	Ensure well-lit areas with surveillance especially if there are evening shifts Provide PPEs for occupational health and safety of workers especially targeting unsanitary/hazardous conditions of incoming waste and noise in the facility Flexible working hours should be allowed for women to accommodate	Within 6 months of facility construction	**Medium**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial Development Authorities Municipalities Informal Sector

Ensure vigilant inspection of gender equality and social inclusion indicators to monitor policy implementation outcome and assessment of necessary revision in policy for achieving targets	Develop anonymous reporting platform for gender specific complaints Implementation of regular inspection and audits to assess relevant indicators. Facilitate underdeveloped areas by designating them as tax free-zones. Introduce waste awareness curriculum in schools Ensure that training sessions are scheduled keeping in mind household responsibilities of women	1-3 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards MoHR NGOs Civil Societies Capital Development Authority, Provincial Development Authorities Municipalities Informal Sector
ENVIRONMENTAL MONITORING				
Long Term				
Quantify emission reduction potential and on ground achieved targets to align with NDCs goals.	Implementation of carbon accounting protocols to quantify baseline scenario carbon emissions. Generation of yearly inventories to quantify achieved emissions reduction.	0-10y	**Very High**	Provincial EPDs and EPAs Solid Waste Management Companies and Boards PCSIR


Current status
Absence of value chain and market development for adoption and integration of technology end-products; SOM less than 1%
Integrated Biomass Gasification for Syngas and Biochar Roadmap 2026-2036
Goal / Potential
Potential to address energy crisis and improve cost structure across various industries. At least 2% increase in SOM. 14.7% reduction in carbon emissions eligible for carbon finance compared to coal power technology
Env. Monitoring
Quantify emission reduction potential and on ground achieved targets compared to baseline to align with NDCs goals.
GESI
Monitor gender equality and social inclusion indicators to assess policy effectiveness and identify areas for improvement; GESI in facility design, recruitment, M&E
M&E
Implement robust monitoring systems using central digital platforms and make business continuity dependent upon performance e.g. license renewal
Business Continuity
Improve syngas and biochar market value through monitoring and enhancement of quality parameters; explore innovative practices to enhance product quality; study soil quality parameters after biochar application to generste database for market development
Technology Sustenance
Governance
Policies enforcement through penalties/fines and incentives to promote PPP, GESI; Ensure a complete value chain for the utilization of syngas and biochar IT integration for market development ; integration of chemical fertilizer industry; infrastructure and industry partnership development for syngas utilization
Budget
Annual quota in the fiscal budget; carbon crediting mechanisms for landfill diverted waste
Capacity Building
Existing model facilities for training; CB for regulatory bodies, proponents and workers; incubation centres and innovation hubs for business skills and technology improvement
Policy
Mandate IBG facilities for agriculture sector; city tariffs, waste fees and subsidies; domestic market through financial incentives for private sector; microfinance for utility infra.; development sector for upfront costs; gender recruitment
Research
Analyse waste and soil data for targeted areas; EIA/SIA and economic analysis via LCA; PPP viability study; baseline emission
Technology Adoption and Scale-Up
Policy
Refine IBG policy and guidelines. Develop a M&E system to ensure effective implementation and product utilization by the local players.
Research
Feedstock combination e.g. forestry; improved technology components e.g. fluidized beds | CCS; Industry-academia partnerships explore potential of biochar as carbon sequestering agent; central database for data-driven decision-making.
Pilot Scale Implementation
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Short Term
Long term

Integrated Biomass Gasification for Syngas and Biochar (TRL Level 5: Integrated Simulation)				
PILOT SCALE IMPLEMENTATION				
Action Item	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify Stakeholders**
RESEARCH				
Short Term				
Initiate research and development programs with industry-academia partnership on identified technical, environmental and social issues for the technology.	Explore options to integrated other biomass waste sources e.g. forestry, to achieve feedstock optimization. Research on improving design for reactors, fluidized beds resulting in enhanced efficiency and better quality end-products. Additionally integrate technology with carbon, capture and storage (CCS) technologies for enhances carbon neutrality. Explore biochar applications as a carbon sequestering agent and syngas comparison to natural fuels to align with environmental goals of NDC.	0-5 y	**High**	MoCC & EC MoST MoE MNFSR Provincial EPAs and EPDs Solid Waste Management Companies and Boards NGOs PSF PCST PARC/NARC OGRA Provincial Energy and Agricultural Departments PPIB HEC Academic Institutes PARC/NARC
Facilitate development of central data base with clear data sharing protocols.	Utilise database platform for a transparent access to	0-2 y	**High**	MoIT

	integrated Biomass Gasification plants			Solid Waste Management Companies and Boards
POLICY				
Short Term				
Refine policy framework and develop clear guidelines for implementation of IBG and the utilization of products by the local players	Policy development and framework in place to mandate syngas and biochar utilization by local industry Tax exemption on biomass fuel consumtion	0-1 y	**Very High**	MoCC & EC MoST MoE MNFSR Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities OGRA PPIB National Institute for Soil and Fertility Industrial Sector
Develop policy for stringent monitoring and evaluation system and ensure enforcement	Develop policy for monitoring and evaluation of a safe and contamination free output. Develop policy to ensure application in local community, agriculture and horticulture	0-1 y	**Very High**	MoCC & EC MoE MoST MoE MNFSR Provincial EPAs and EPDs

				Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities OGRA PPIB National Institute for Soil and Fertility
TECHNOLOGY ADOPTION & SCALE-UP				
Action Plan (short-term and long-term) and Milestones	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify Stakeholders**
Research				
Short Term				
Gather and analyze waste related data for the area being considered for technology adoption using waste modelling tools.	Conduct waste composition analysis to determine if the waste has waste fractions suitable for biomass gasification process. Utilize GIS and spatial analysis for site selection and project planning	0-2 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR
PPP Viability Study	Develop a financial model, and evaluate the economic viability of the PPP. Conduct financial and technical due diligence.	0-1 y	**High**	

Conduct economic feasibility analysis and environmental impact assessment using Life Cycle Assessment (LCA) approach for the selected technology or combination of technologies	Quantify baseline emissions and emission reduction potential to help pitch selected technology or combination of technologies to potential project proponents, prospective investors, interested donor fundings, and climate finance. Conduct an environmental impact assessment (EIA) and a social impact assessment (SIA) to identify potential impacts and mitigation measures.	0-2 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR
POLICY				
Short Term				
Develop and implement regulations for the construction of integrated bioimass gasification plant for cities.	Mandate municipalities and city development authorities to designate a sustainable waste management site within the city's premises. Establishment of model where city tariffs or waste fees are used to subsidize biomass gasification operations that could significantly promote sustainable waste management.	0-1 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
Develop regulations that mobilize private sector for the implementation,	Incorporate private sector for stirring domestic market for	0-1 y	**Very High**	MoCC & EC

operations and maintenance of decentralized biomass gasification facilities	wider adoption and less reliance on donor fundings through low interest loans, public private partner ships and impact bonds. Offer tax exemption and subsidies to companies investing in biomass gasification infrastructure in terms of land acquisition, purchasing machinery, managing operations etc. Provide long term concession agreements, revenue sharing models and public land leases offered to build and operate facilities			Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
Develop regulations that mobilize finances other than private sector investment for the implementation, operations and maintenance of facilities	**Enable microfinance programs for applicable components facilities, such as utility infrastructure.** Collaborate with development bank funding, grants and schemes to secure financial assistance at low-interest	0-1 y	**Very High**	MoCC & EC MoE MoST MoE MNFSR Provincial EPDs and EPAs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities

				Development Sector MicroFinance Banks and Institutes SMEDA
Develop regulations that ensure gender equality and social inclusion in implementation and, operation and maintenance of facilities.	Gender responsive recruitment to include a percentage of women, youth and individuals from marginalized groups especially belonging to the local community targeted for managerial positions and within governance structures Ensure gender responsive workplace policies such as flexible workhours and antiharassment rules.	0-1 y	**Very High**	MoCC & EC MoE MoST MoE MNFSR Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
Long Term				
Mandating source segregation at household and commercial level through policy to achieve high quality steady supply of waste streams in the long run.	Develop infrastructure for source segregation system.	2-3 y	**Medium**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
CAPACITY BUILDING				

Short Term				
Utilise existing fully functional model facility for demonstration of integrated biomass facility, and as a benchmark for the monitoring and evaluation phase.	Where the facilites are not present, construction of model integrated biomass gasification facility in provincial capitals as prototypes for wider and large-scale adoption.	0.5-1 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities PARC/NARC
Conduct trainings, seminars, workshops etc. on site to disseminate sustainable waste management systems and their importance along with waste sorting protocols to ensure minimum contamination.	Conduct training sessions for regulatory authorities and project proponents, workers at facility, local engineers, technicians and facility operators to design, run and maintain facilities with a special focus on managerial training for women, youth, informal sector and marginal groups. Achieve 30% stakeholder engagement and accomplish 75% sorting efficiency in incoming waste streams for compostable fractions.	1-5 y	**Medium**	MoCC & EC MoE MoST MoE MNFSR Provincial Agriculture and Energy Departments Provincial EPAs and EPDs PCSIR PARC/NARC
Long Term				
Promote innovation hubs and business incubation centres to develop research and foster innovation along	Develop knowledge and skills to prepare and develop business models, business plans, proposals and	Ongoing	**Medium**	MoIP MoC

with business management skills for the technology	investor pitch for integrated biomass gasification facilities to present business ideas to potential investors and to secure donor funding. Develop financial literacy covering topics of budgeting, cost control and revenue management especially targeting women and youth. Research various combinations of practices, composting methods, feedstock, and integration with other technologies for optimization.			Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR Academic Institutes SMEDA PITAC PARC/NARC
BUDGET				
Short Term				
Allocate an annual quota in the fiscal budget for development of waste management infrastructure	Allocation of budget with clear guidelines for utilization.	0-6 m	**Very High**	MoCC & EC MoF MoE Provincial EPAs and EPDs Solid Waste Management Companies and Boards
Long Term				
Explore national and international climate finance options by establishing mechanisms and	Enable access to green financing options of low-interest loans and green bonds especially to youth as a vulnerable group to climate change impacts.	1-3 y	**Very High**	MoCC & EC MoF MoE Solid Waste Management Companies and Boards

	Establish frameworks that enable initiatives to earn carbon credits for revenue generation from national and international carbon markets			Provincial EPDs and EPAs and Energy Departments State Bank of Pakistan Pakistan Stock Exchange Multilateral financial institutions
GOVERNANCE				
Short Term				
Ensure policy implementation of public-private partnership for efficiency and upscaling and wider scale adoption of the technology.	Mandate compliance with waste management standards to be reported in terms of efficiency of facility operations, waste diversion rates and social inclusions metrics Regular inspections with reward and penalty system	1-3 y	**Very High**	Provincial Industries and Commerce Departments PPPA
Ensure a complete value chain for the utilization of syngas and biochar	Identify end user for syngas and biochar Identify a complete value chain with required infrastructure, human resource and budget. Develop infrastructure to provide syngas to 50 households in facility surroundings in the first year of operations	2-5 y	**Very High**	Provincial Agriculture and Energy Departments PIDC PPIB National Institute for Soil and Fertility

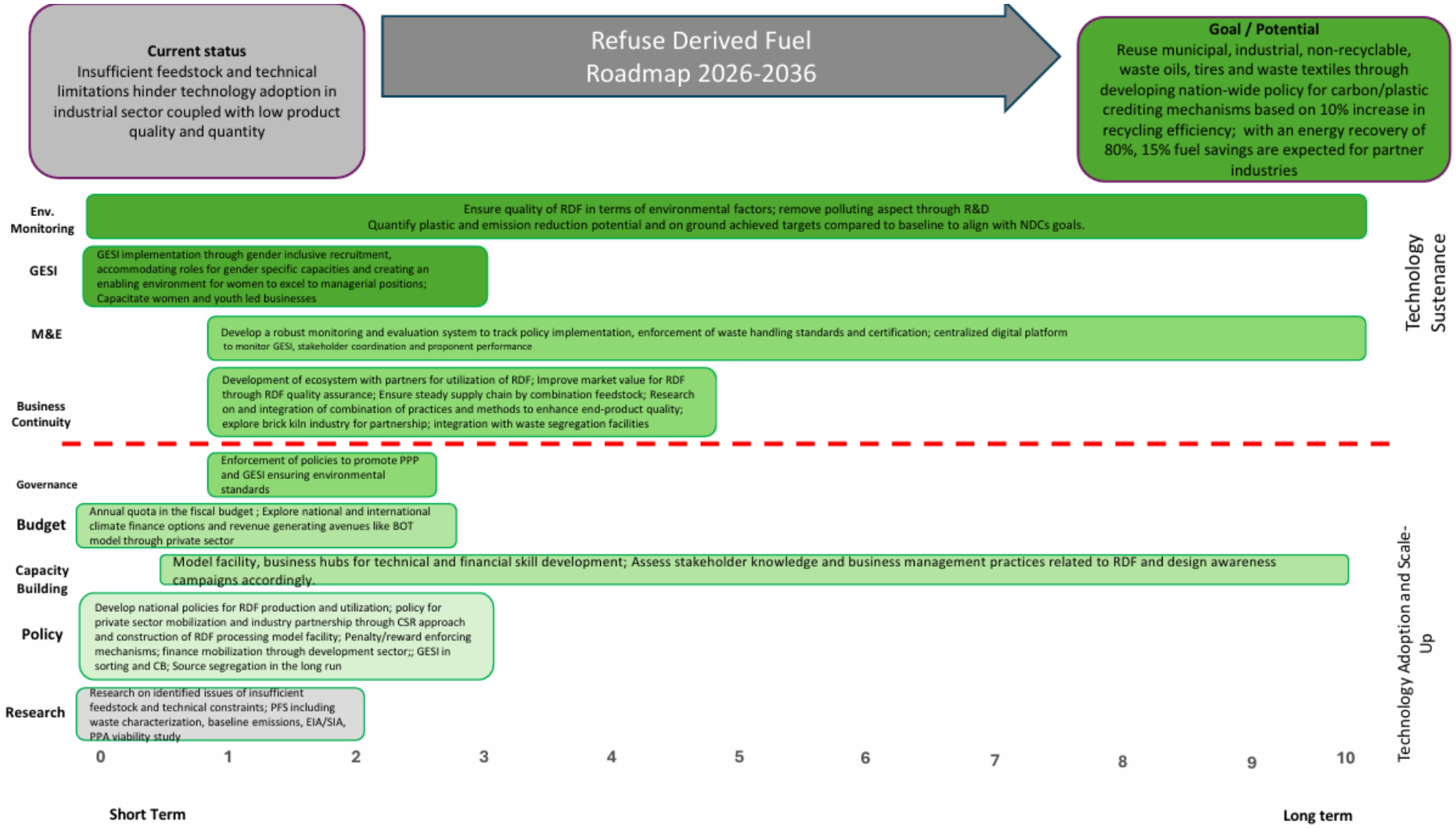
	Achieve 10% transition from chemical fertilizer to Biochar in the first year of operations and 25% in the third year. Ensure gender inclusivity especially for syngas utilization through training session with women for use and efficient management			
Long Term				
Integrate information technology for application of syngas and biochar produced from municipal solid waste to develop markets	Create accessibility for final product from facility through digital platform Engage farmers, agriculture and horticulture to ensure end-product application Guidance available on the digital platform for waste producers to facilitate efficient syngas and biochar production e.g statistic for product demand	Ongoing	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities MoIT PSEB P@sha Software Development Contractors Pakistan Horticulture Authority Agriculture Department and

				Extensions and farmers Landfill Sites
TECHNOLOGY SUSTENANCE				
Action Plan (short-term and long-term) and Milestones	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify stakeholders**
BUSINESS CONTINUITY				
Short Term				
Improve market value of produced syngas and biochar application	Develop standards to ensure quality parameters such as nutrient content, pathogen level etc, for biochar and calorific value etc. for syngas Sale of syngas as energy source and biochar as a nourishing soil amendment in the agriculture sector or landscaping Study and document improvement in soil quality including bulk density, porosity and soil organic matter to promote biochar.	2-5 y	**High**	MoE MNFSR Provincial EPAs and EPDs Solid Waste Management Companies and Boards Provincial Agriculture and Energy Department
MONITORING AND EVALUATION				
Short Term				
Develop and implement balanced but vigilant monitoring and evaluation protocols	Stringent inspection of facilities to monitor compliance with waste handling standards and certification to ensure quality control	1-2 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority,

				Provincial and City Development Authorities PARC/NARC
Ensure vigilant inspection of gender equality and social inclusion indicators to monitor policy implementation outcome and assessment of necessary revision in policy for achieving targets	Develop anonymous reporting platform for gender specific complaints Implementation of regular inspection and audits to assess relevant indicators.	1-2 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards MoHR NGOs Civil Societies IMO Capital Development Authority, Provincial Development Authorities Municipalities PARC/NARC
Leverage information technology for a robust monitoring and evaluation system engaging all stakeholder at a time	Utilize digital platform for reporting and real time monitoring for stakeholder engagement, performance and social inclusion	1-2 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities PARC/NARC
Long Term				
Bring transparency to monitoring and evaluation system through integration of information technology	Generate lists on digital platform with rankings of private sector entities based on quality of syngas and	Ongoing	**Very High**	Provincial EPAs and EPDs

	biochar produced for a transparent review that will drive private sector mobilization factors such as license renewal, incentive provision etc. Generate of a performance feedback system on the digital platform indicative of level of execution of the technology through operational private sector entities			Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities PARC/NARC
GENDER EQUALITY AND SOCIAL INCLUSION				
Short Term				
Ensure that facility design is appropriate and accessible for women and all social groups	Ensure well-lit areas with surveillance especially if there are evening shifts Provide PPEs for occupational health and safety of workers especially targeting unsanitary/hazardous conditions of incoming waste and noise in the facility Flexible working hours should be allowed for women to accommodate	Within 6 months of facility construction	**Medium**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial Development Authorities Municipalities Informal Sector
Ensure policy implementation of gender equality and social inclusion in technology implementation and operations	Presence of women at managerial positions as per allocated quota Existence of women and youth led business initiatives Ensure that training sessions are scheduled	1-3 y	**Very High**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards

	keeping in mind household responsibilities of women			Capital Development Authority, Provincial and City Development Authorities
ENVIRONMENTAL MONITORING				
Long Term				
Quantify emission reduction potential and on ground achieved targets to align with NDCs goals.	Implementation of carbon accounting protocols to quantify baseline scenario carbon emissions. Generation of yearly inventories to quantify achieved emissions reduction.	0-10 y	**Very High**	Provincial EPDs and EPAs Solid Waste Management Companies and Boards PARC/NARC PCSIR


Current status
Insufficient feedstock and technical limitations hinder technology adoption in industrial sector coupled with low product quality and quantity
Refuse Derived Fuel
Roadmap 2026-2036
Goal / Potential
Reuse municipal, industrial, non-recyclable, waste oils, tires and waste textiles through developing nation-wide policy for carbon/plastic crediting mechanisms based on 10% increase in recycling efficiency; with an energy recovery of 80%, 15% fuel savings are expected for partner industries
Env. Monitoring
Ensure quality of RDF in terms of environmental factors; remove polluting aspect through R&D
Quantify plastic and emission reduction potential and on ground achieved targets compared to baseline to align with NDCs goals.
GESI
GESI implementation through gender inclusive recruitment, accommodating roles for gender specific capacities and creating an enabling environment for women to excel to managerial positions; Capacitate women and youth led businesses
M&E
Develop a robust monitoring and evaluation system to track policy implementation, enforcement of waste handling standards and certification; centralized digital platform to monitor GESI, stakeholder coordination and proponent performance
Business Continuity
Development of ecosystem with partners for utilization of RDF; Improve market value for RDF through RDF quality assurance; Ensure steady supply chain by combination feedstock; Research on and integration of combination of practices and methods to enhance end-product quality; explore brick kiln industry for partnership; integration with waste segregation facilities
Governance
Enforcement of policies to promote PPP and GESI ensuring environmental standards
Budget
Annual quota in the fiscal budget ; Explore national and international climate finance options and revenue generating avenues like BOT model through private sector
Capacity Building
Model facility, business hubs for technical and financial skill development; Assess stakeholder knowledge and business management practices related to RDF and design awareness campaigns accordingly.
Policy
Develop national policies for RDF production and utilization; policy for private sector mobilization and industry partnership through CSR approach and construction of RDF processing model facility; Penalty/reward enforcing mechanisms; finance mobilization through development sector;; GESI in sorting and CB; Source segregation in the long run
Research
Research on identified issues of insufficient feedstock and technical constraints; PFS including waste characterization, baseline emissions, EIA/SIA, PPA viability study
Technology Sustenance
Technology Adoption and Scale-Up
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Short Term
Long term

Refuse-Derived Fuel (TRL Level 7: Operational Prototype)				
TECHNOLOGY ADOPTION & SCALE-UP				
Action Item	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify Stakeholders**
RESEARCH				
Short Term				
Initiate research and development programs with industry-academia partnership on identified technical, environmental and social issues for the technology and encourage development of central data base with clear data sharing protocols.	Identify problems being faced by industry specifically cement industry that are becoming barrier to wider adoption Explore options for stakeholder collaboration to resolve insufficient feedstock issues and non-optimized operational plants for RDF	0-2 y	**High**	MoCC & EC MoE MoST MoE MNFSR Provincial EPAs and EPDs Solid Waste Management Companies and Boards NGOs PSF PCST OGRA Provincial Energy Departments PPIB HEC Academic Institutes
Facilitate development of central data base with clear data sharing protocols.	Easy access to database showing successfully running projects to facilitate wide scale adoption	0-2 y	**High**	MoIT Solid Waste Management Companies and Boards

Long Term				
Gather and analyze waste related data for the area being considered for technology adoption using research tools	Conduct waste composition analysis to determine the amount of plastic that can be converted to RDF and the calorific value to assess end-product viability.	0-2 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR
Conduct economic feasibility analysis and environmental impact assessment using Life Cycle Assessment (LCA) approach for the selected technology or combination of technologies	Quantify baseline emissions and emission reduction potential to help pitch selected technology or combination of technologies to potential project proponents, prospective investors, interested donor fundings, and climate finance. Conduct an environmental impact assessment (EIA) and a social impact assessment (SIA) to identify potential impacts and mitigation measures.	0.5-1 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR
PPP Viability Study	Develop a financial model, and evaluate the economic viability of the PPP. Conduct financial and technical due diligence.	0-1yr	**High**	
POLICY				
Short Term				

Develop nation-wide policy and guidelines for the production and utilization of RDF	Develop policy and guidelines applicable nation-wide with an aim of improving plastic recycling potential by 10% in the second year	0-1 y	**Very High**	MoCC & EC MoE Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
Develop and implement regulations for municipalities to ensure construction and operation of refuse-derived fuel processing units	Encourage plastic producing commercial, institutional and industrial entities to include a refuse-derived fuel processing unit within their premises to provide energy to run their operations. Mandate CSR programs for large scale industrial, institutional and commercial producer executed through implementation of RDF plant or partnership with RDF producers	0-1 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
Develop regulations that mobilize private sector for the implementation, operations and maintenance of decentralized RDF facilities	Incorporate private sector for wider adoption and less reliance on donor fundings through low interest loans, public private partner ships and impact bonds.	0-1 y	**Very High**	MoCC & EC MoIP MoC Provincial EPDs and EPAs

	Offer tax exemption and subsidies to companies investing in RDF infrastructure in terms of land acquisition, purchasing RDF machinery, managing operations, utilization at site etc. Provide long term concession agreements, revenue sharing models and public land leases offered to build and operate facilities Partner with industrial consumers for utilization			Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
Develop regulations that mobilize finances other than private sector investment for the implementation, operations and maintenance of decentralized RDF facilities	**Enable microfinance programs for applicable components of facilities, such as utility infrastructure.** Collaborate with development bank funding, grants and schemes to secure financial assistance at low-interest	0-1 y	**Very High**	MoCC & EC MoE Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities Development Sector MicroFinance Banks and Institutes SMEDA

Develop regulations that ensure gender equality and social inclusion in implementation and, operation and maintenance of facilities	Gender responsive recruitment to include a percentage of women, youth and individuals from marginalized groups especially belonging to the local community targeted for managerial positions and capacity building initiative members	0-1 y	**Very High**	MoCC & EC Provincial EPDs and EPAs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
Long Term				
Mandating source segregation level through policy to achieve high quality steady supply of raw material for RDF	Develop infrastructure for source segregation system using separate bin system later on upgraded to smart bins	2-3y	**Medium**	MoCC & EC Provincial EPD EPAs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities Industrial partners
CAPACITY BUILDING				
Short Term				
Utilize existing fully functional model facility for demonstration of RDF facility, and as a benchmark for the monitoring and evaluation phase.	Construction of model RDF facility in provincial capitals where the technology is not present as prototypes for wider and large-scale adoption.	0.5-1 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards

				Capital Development Authority, Provincial and City Development Authorities
Long Term				
Evaluate the existing knowledge of regulatory authorities and project proponents, and workers at facility, about RDF and business management pertaining to RDF facility and design awareness campaign accordingly.	Conduct training sessions for regulatory authorities and project proponents, workers at facility, local engineers, technicians and facility operators to design, run and maintain facilities with a special focus on managerial training for women, youth, informal sector and marginal groups.	Ongoing	**Medium**	Provincial EPAs and EPDs, Solid Waste Management Companies and Boards Provincial Energy Departments PCSIR Academic Institutes
Promote business hubs and incubation centres to develop financial and business literacy	Develop knowledge and local skills to prepare and develop business models, business plans, proposals and investor pitch for facilities to present business ideas to potential investors and to secure donor funding. Develop financial literacy covering topics of budgeting, cost control and revenue management especially targeting women and youth	1-6 y	**Medium**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR Academic Institutes SMEDA

BUDGET				
Short Term				
Allocate an annual quota in the fiscal budget for development of waste management infrastructure	Allocation of budget with clear guidelines for utilization.	0-6 m		MoCC & EC MoF MoE Provincial EPAs and EPDs Solid Waste Management Companies and Boards
Explore national and international climate finance options and revenue generating models	Enable access to green financing options of low-interest loans and green bonds especially to youth as a vulnerable group to climate change impacts. Private sector for Build-Operate-Transfer models as a revenue generating avenue for city authorities	1-3 y	**Very High**	Provincial EPDs and EPAs Solid Waste Management Companies and Boards State Bank of Pakistan Pakistan Stock Exchange Multilateral financial institutions
GOVERNANCE				
Short Term				
Ensure policy implementation of public-private partnership for efficiency and upscaling and wider scale adoption of the technology.	Define roles and responsibilities, compliance requirements and accountability measures of all stakeholder including private sector, government agencies and local authorities	1-3 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Provincial and City

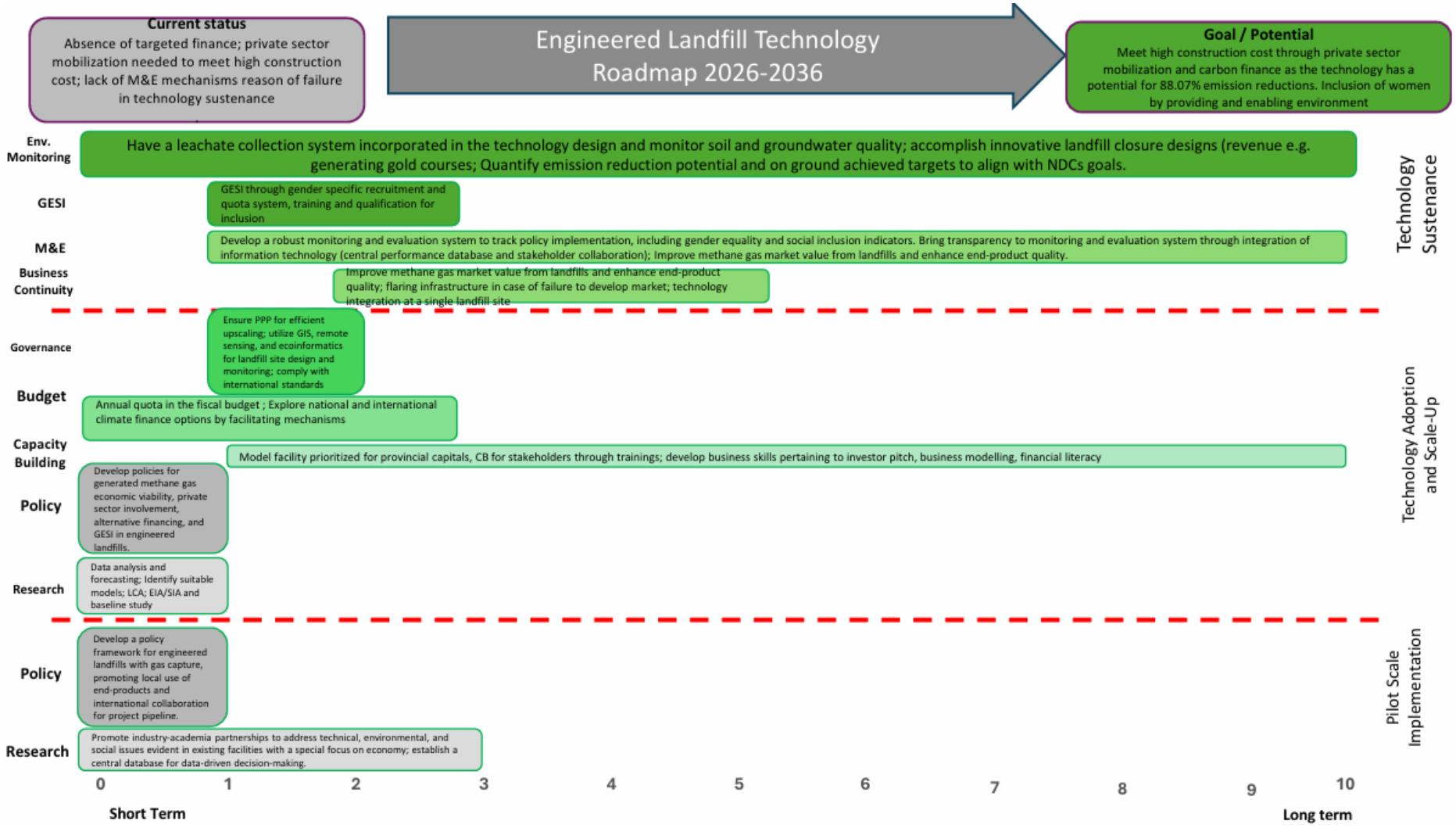
	Mandate compliance with waste management standards to be reported in terms of resource recovery and environmental impact of RDF facility operations, waste diversion rates and social inclusions metrics Ensure compliance with environmental standards through environmental monitoring			Development Authorities PPPA SMEDA
TECHNOLOGY SUSTENANCE				
Action Plan (short-term and long-term) and Milestones	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify stakeholders**
BUSINESS CONTINUITY				
Short Term				
Improve market value for RDF for economic viability of business model	Develop standards to ensure RDF quality including parameters such as calorific value, moisture content and pollutant content (chlorine, sulfur, heavy metals) Ensure supply chain for manufacturing units through diversion of waste from multiple sources such as municipal waste (especially commercial and institutional) and industrial waste.	2-5 y	**High**	MoIP MoC MoE Provincial EPAs and EPDs Solid Waste Management Companies and Boards Provincial Energy Departments PITAC
Develop a healthy ecosystem with Cement industry and other	Partnership with brick kilns after successful integration of cement	1- 3yr	**Very High**	MoIP MoC

industrial partners for utilization of RDF	industry to reduce environmental impacts caused by fuel burning.			Provincial EPAs and EPDs Solid Waste Management Companies and Boards Provincial Industries and Commerce Departments PIDC SMEDA
Research on and integration of combination of practices and methods to enhance end-product quality	Integration of waste segregation technology to enable flow of homogenised feedstock streams to RDF processing unit	1-3 y	**Medium**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Private Entities Academic/ Research Institutes
MONITORING AND EVALUATION				
Short Term				
Develop and implement balanced but vigilant monitoring and evaluation protocols	Stringent inspection of facilities to monitor compliance with waste handling standards and certification to ensure quality control	1-2 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development

				Authorities and Energy Departments
Leverage information technology for a robust monitoring and evaluation system engaging all stakeholder at a time	Utilize digital platform for reporting and real time monitoring for stakeholder engagement, performance and social inclusion	1-3 y	**High**	MoIT Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities and Energy Departments P@sha
Ensure vigilant inspection of gender equality and social inclusion indicators to monitor policy implementation outcome and assessment of necessary revision in policy for achieving targets.	Develop anonymous reporting platform for gender specific complaints. Implementation of regular inspection and audits to assess relevant indicators.	1-3 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards MoHR NGOs Civil Societies IMO Capital Development Authority, Provincial Development Authorities Municipalities
Long Term				
Bring transparency to monitoring and evaluation system through integration of information technology	Generate lists on digital platform with rankings of private sector entities based on quality of compost produced, sorting	Ongoing	**Very High**	MoIT Provincial EPAs and EPDs

	efficiency achieved etc. for a transparent review that will drive private sector mobilization factors such as license renewal, incentive provision etc. Generate of a performance feedback system on the digital platform indicative of level of execution of the technology through operational private sector entities.			Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
GENDER EQUALITY AND SOCIAL INCLUSION				
Short Term				
Ensure that facility design is appropriate and accessible for women and all social groups	Ensure well-lit areas with surveillance especially if there are evening shifts. Provide PPEs for occupational health and safety of workers especially targeting unsanitary/hazardous conditions of incoming waste and noise in the facility. Flexible working hours should be allowed for women to accommodate.	Within 6 months of facility construction	**Medium**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial Development Authorities Municipalities Informal Sector
Ensure policy implementation of gender equality and social inclusion in technology implementation and operations	Enabling environment for women to excel atmanagerial positions as per allocated quota through trainings and education Capacitate women and youth led business initiatives	1-3 y	**Very High**	MoCC & EC Provincial EPDs and EPAs Solid Waste Management Companies and Boards

	Ensure that training sessions are scheduled keeping in mind household responsibilities of women			Capital Development Authority, Provincial and City Development Authorities
ENVIRONMENTAL MONITORING				
Short Term				
Ensure quality of RDF in terms of environmental factors	Ensure monitoring of quality including parameters such as calorific value, moisture content and pollutant content (chlorine, sulfur, heavy metals) Research and innovation of polluting aspect of RDF production	1-5 y	**High**	Provincial EPDs and EPAs Solid Waste Management Companies and Boards PCSIR
Long Term				
Quantify plastic and emission reduction potential and on ground achieved targets to align with NDCs goals.	Implementation of plastic and carbon accounting protocols to quantify baseline scenario carbon emissions. Generation of yearly inventories to quantify achieved emissions reduction.	0-10 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Provincial and City Development Authorities and Energy Departments PCSIR Carbon and Plastic Crediting Entities


Current status
Absence of targeted finance; private sector mobilization needed to meet high construction cost; lack of M&E mechanisms reason of failure in technology sustenance
Engineered Landfill Technology Roadmap 2026-2036
Goal / Potential
Meet high construction cost through private sector mobilization and carbon finance as the technology has a potential for 88.07% emission reductions. Inclusion of women by providing and enabling environment
Env. Monitoring
Have a leachate collection system incorporated in the technology design and monitor soil and groundwater quality; accomplish innovative landfill closure designs (revenue e.g. generating gold courses; Quantify emission reduction potential and on ground achieved targets to align with NDCs goals.
GESI
GESI through gender specific recruitment and quota system, training and qualification for inclusion
M&E
Develop a robust monitoring and evaluation system to track policy implementation, including gender equality and social inclusion indicators. Bring transparency to monitoring and evaluation system through integration of information technology (central performance database and stakeholder collaboration); Improve methane gas market value from landfills and enhance end-product quality.
Business Continuity
Improve methane gas market value from landfills and enhance end-product quality; flaring infrastructure in case of failure to develop market; technology integration at a single landfill site
Technology Sustenance
Governance
Ensure PPP for efficient upscaling; utilize GIS, remote sensing, and ecoinformatics for landfill site design and monitoring; comply with international standards
Budget
Annual quota in the fiscal budget ; Explore national and international climate finance options by facilitating mechanisms
Capacity Building
Model facility prioritized for provincial capitals, CB for stakeholders through trainings; develop business skills pertaining to investor pitch, business modelling, financial literacy
Policy
Develop policies for generated methane gas economic viability, private sector involvement, alternative financing, and GESI in engineered landfills.
Research
Data analysis and forecasting; Identify suitable models; LCA; EIA/SIA and baseline study
Technology Adoption and Scale-Up
Policy
Develop a policy framework for engineered landfills with gas capture, promoting local use of end-products and international collaboration for project pipeline.
Research
Promote industry-academia partnerships to address technical, environmental, and social issues evident in existing facilities with a special focus on economy; establish a central database for data-driven decision-making.
Pilot Scale Implementation
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Short Term
Long term

Engineered Landfill Technology (TRL Level 3: Proof of Concept)				
PILOT SCALE IMPLEMENTATION				
Action Item	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify Stakeholders**
RESEARCH				
Short Term				
Initiate research and development programs with industry-academia partnership on identified technical, environmental and social issues for the technology.	Identify issues and reasons of lack of technology scale-up at existing landfill site (Lakhodair Landfill) Study the issues in balancing economies of scale for end product in landfill gas capture system in comparison to fossil fuels Study feasibility of international designs in local context	0-3 y	**High**	MoCC & EC MoE MoST MoE MNFSR Provincial EPAs and EPDs Solid Waste Management Companies and Boards NGOs PSF PCST OGRA Provincial Energy Departments PPIB HEC Academic Institutes
POLICY				
Short Term				
Develop policy framework for implementation of Engineered Landfills with	Development of policy, and framework in place to mandate	0-1 y	**Very High**	MoCC & EC MoE

Landfill Gas Capture Technology and the utilization of end-products by the local community	captured methane utilization by local community Design policy to implement infrastructure for captured methane utilization			Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities and Energy Departments PPIB OGRA PARC/NARC
Incorporate international collaborations for technology implementation	Develop international collaborations to utilize knowledge and skills in design, development, implementation, operations and monitoring of sites	0-1 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards International Solid Waste Association (ISWA) International experts
TECHNOLOGY ADOPTION & SCALE-UP				
Action Plan (short-term and long-term) and Milestones	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify Stakeholders**
Research				
Short Term				

Gather and analyze waste related data for the area being considered for technology adoption using waste modelling tools	Conduct waste composition analysis through detailed waste audits and sampling for assessing the potential of landfill gas generation. Identify potential international designs that will be successful in indigenous context. Forecast waste generation for the next 20-30 years considering local demographic, economic and behavioural factors to assess technology sustenance in the long run. Utilize ecoinformatics using GIS and spatial analysis for site selection and project planning.	0-1 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR
PPP Viability Study	Develop a financial model, and evaluate the economic viability of the PPP. Conduct financial and technical due diligence. b	0-1yr	**High**	
Conduct economic feasibility analysis and environmental impact assessment using Life Cycle Assessment (LCA) approach for the selected technology or combination of technologies	Quantify baseline emissions and emission reduction potential to help pitch selected technology or combination of technologies to potential project proponents, prospective investors,	0-1 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR

	interested donor fundings, and climate finance. Conduct an environmental impact assessment (EIA) and a social impact assessment (SIA) to identify potential impacts and mitigation measures.			
POLICY				
Short Term				
Develop a policy to ensure economic viability of captured methane gas in comparison with natural gas and other renewable energy options	Economic feasibility of operations in terms of price of captured methane must be incentivized through subsidies and alignment of economies of scale	0-1 y	**Very High**	MoE MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards PPIB AEDB
Develop regulations that mobilize private sector for the implementation, operations and maintenance of engineered landfills	Incorporate private sector for wider adoption and less reliance on donor fundings through low interest loans, public private partner ships and impact bonds. Offer tax exemption and subsidies to companies investing in engineered landfill technology infrastructure in terms of land acquisition, purchasing machinery, managing operations etc. Provide long term concession	0-1 y	**Very High**	MoCC & EC MoIP MoC Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities

	agreements, revenue sharing models and public land leases offered to build and operate facilities Revenue generating mechanisms through sale of captured methane			
Develop regulations that mobilize finances other than private sector investment for the implementation, operations and maintenance of engineered landfills	Collaborate with development bank funding, grants and schemes to secure financial assistance at low-interest	0-1 y	**Very High**	MoCC & EC MoF Provincial EPDs and EPAs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities and Energy Departments Development Sector SMEDA
Develop regulations that ensure gender equality and social inclusion in implementation and, operation and maintenance of engineered landfills	Integration of the informal sector scavengers in the project via decent employment opportunities Gender responsive recruitment to include a percentage of women, youth and individuals from marginalized groups	0-1 y	**Very High**	MoCC & EC Provincial EPDs and EPAs Solid Waste Management Companies and Boards

	especially belonging to the local community targeted for managerial positions and within governance structures Ensure gender responsive workplace policies such as flexible workhours and antiharassment rules.			Capital Development Authority, Provincial Development Authorities
CAPACITY BUILDING				
Short Term				
Utilize existing fully functional model facility for demonstration of Engineered Landfill, and as a benchmark for the monitoring and evaluation phase.	Leverage existing facilities for technical training and prioritize construction of Engineered Landfill in provincial capitals where the technology is not present as prototypes for wider and large-scale adoption and to accommodate metropolitan cities	1-3 y	**Very High**	Capital Development Authority, Provincial and City Development Authorities
Long Term				
Evaluate the existing knowledge of regulatory authorities and project proponents, and workers at facility, about business management pertaining to engineered landfill facility and design awareness campaign accordingly.	Conduct training sessions for regulatory authorities and project proponents, workers at facility, local engineers, technicians and facility operators to design, run and maintain facilities with a special focus on managerial training for women, youth, informal sector and marginal groups. Ensure that training sessions are scheduled keeping in mind household	Ongoing	**Medium**	MoCC & EC MoE MoIP MoC Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR Academic Institutes

	responsibilities of women.			
Promote innovation hubs and business incubation centres to develop research and foster innovation along with business management skills for the technology	Develop knowledge and skills to prepare and develop business models, business plans, proposals and investor pitch for engineered landfill facilities to present business ideas to potential investors and to secure donor funding. Develop financial literacy covering topics of budgeting, cost control and revenue management especially targeting women and youth Research various combinations of engineered landfill designs and integration with other technologies like composting, gasification for optimization	Ongoing	**Medium**	MoIP MoC Provincial EPAs and EPDs Solid Waste Management Companies and Boards PCSIR Academic Institutes SMEDA PITAC
BUDGET				
Short Term				
Allocate an annual quota in the fiscal budget for development of waste management infrastructure	Allocation of budget with clear guidelines for utilization.	0-6 m	**Very High**	MoCC & EC MoF
Explore national and international climate finance	Enable access to green financing options of low-interest loans and green bonds especially to youth as a vulnerable group to climate change impacts.	1-3 y	**Very High**	Provincial EPDs and EPAs Solid Waste Management Companies and Boards

	Establish frameworks that enable initiatives to earn carbon credits against methane gas capture for revenue generation from national and international carbon markets			State Bank of Pakistan Pakistan Stock Exchange Multilateral financial institutions
GOVERNANCE				
Short Term				
GIS, remote sensing and ecoinformatics application is designing and monitoring of landfill site	Landfill site selection considering all environmental and social factors GIS mapping of effectiveness of landfill sites for long term utilization	1-2 y	**High**	MoCC&EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards
Ensure policy implementation of public-private partnership for efficiency and upscaling and wider scale adoption of the technology.	Define roles and responsibilities, compliance requirements and accountability measures of all stakeholder including private sector, government agencies and local authorities Mandate compliance with waste management standards to be reported in terms of efficiency of facility operations, sustainable waste disposal rates and social inclusions metrics	1-2 y	**Very High**	MoIP MoC Provincial EPAs and EPDs Solid Waste Management Companies and Boards Public-Private Partnership Authority SMEDA
TECHNOLOGY SUSTENANCE				
Action Plan (short-term and long-term) and Milestones	**Milestones/Targets**	**Deadline**	**Priority Level**	**Identify stakeholders**

BUSINESS CONTINUITY				
Short Term				
Improve market value of captured methane gas from engineered landfills	Develop infrastructure for flaring or the utilization of methane gas captured to surrounding communities	2-5 y	**High**	MoE Provincial EPAs and EPDs Solid Waste Management Companies and Boards Provincial Energy Department
Integration of combination of practices and methods to enhance end-product quality	Use and improve initial research on economic viability through LCA of technology combination to develop lucrative combination designs Integration of Engineered Landfills with facilities for waste segregation, composting, biomass gasification and RDF technology.	2-5 y	**Medium**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Private and Public Project Owners Research Institutes
MONITORING AND EVALUATION				
Short Term				
Develop and implement balanced but vigilant monitoring and evaluation protocols	Stringent inspection of facilities to monitor compliance with waste handling standards and certification to ensure quality control in operations.	1-2 y	**Very High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority,

				Provincial and City Development Authorities
Ensure vigilant inspection of gender equality and social inclusion indicators to monitor policy implementation outcome and assessment of necessary revision in policy for achieving targets	Develop a responsive digital platform for gender specific complaints that maintain the anonymity of the complainant Implementation of regular inspection and audits to assess gender and social inclusion indicators.	1-2 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards MoHR NGOs Civil Societies IMO Capital Development Authority, Provincial and City Development Authorities Municipalities
Leverage information technology for a robust monitoring and evaluation system engaging all stakeholder at a time	Utilize digital platform for reporting and real time monitoring for stakeholder engagement, performance and social inclusion	1-3 y	**High**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
Long Term				
Bring transparency to monitoring and evaluation system through integration of information technology	Generate lists on digital platform with performance-based rankings of private sector enabling increase in cliental, license renewals,	Ongoing	**Very High**	Provincial EPAs and EPDs Solid Waste Management

	incentive provision etc. Generation of performance feedback system on the digital platform indicative of level of execution of the technology			Companies and Boards Capital Development Authority, Provincial and City Development Authorities
GENDER EQUALITY AND SOCIAL INCLUSION				
Short Term				
Ensure that facility design is appropriate and accessible for women and all social groups	Ensure well-lit areas with surveillance especially if there are evening shifts Provide PPEs for occupational health and safety of workers especially targeting unsanitary/hazardous conditions of incoming waste and noise in the facility Flexible working hours should be allowed for women to accommodate	Within 6 months of facility construction	**Medium**	Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial Development Authorities Municipalities Informal Sector
Ensure policy implementation of gender equality and social inclusion in technology implementation and operations	Presence of women at managerial positions as per allocated quota.	1-3 y	**Very High**	MoCC & EC Provincial EPAs and EPDs Solid Waste Management Companies and Boards Capital Development Authority, Provincial and City Development Authorities
ENVIRONMENTAL MONITORING				

Short Term				
Have a leachate collection system incorporated in the technology design to maintain groundwater quality	Monitor the efficiency of leachate collection system by regular testing of groundwater quality parameters	1-3 y	**High**	Provincial EPDs and EPAs Solid Waste Management Companies and Boards
Long Term				
Quantify emission reduction potential and on ground achieved targets to align with NDCs goals.	Implementation of carbon accounting protocols to quantify baseline scenario carbon emissions. Generation of yearly inventories to quantify achieved emissions reduction.	0-10 y	**Very High**	Provincial EPDs and EPAs Solid Waste Management Companies and Boards Provincial Energy Departments PCSIR
Manage landfill closure through creative and environmental friendly startegies	Convert fully utilized landfill sites for activities such as recreational parks, golf courses etc after ensuring that the site is free of any environmental hazard	Landfill closure onwards	**High**	Provincial and City Development Authorities Provincial EPAs and EPDs Solid Waste Management Companies and Boards

6.4 Immediate Action Plan

The existing waste management landscape in Pakistan calls for an integrated solid waste management system to improve efficiency. The zero waste concept sitting at the very core of such a system requires a sustainable and circular approach through adequate management of waste output diverted from landfills back into the economy for utilization of extracted resources and reduction of burden on virgin materials. Such a system has a significant potential to reduce greenhouse gas emissions coming from burning of fossil fuels in the transport of waste from source and from the decay of organic waste undergoing decomposition at the disposal site. Moreover, an efficient and integrated solid waste management system can provide improved sanitation to the community, avoiding environmental hazards caused by mismanagement. Therefore, all technologies that offer a solution and prevent waste from going into landfills need to be included in the immediate plan.

It is also to be noted that all pre-disposal technology options may be supported by the existing scenario of all provinces with Punjab being more advanced than others. They cannot be utilized all at the same time as the feedstock for two technologies might be the same. Therefore, to optimize capacities of plants, selection of the appropriate technology should be a well-informed decision based on the quantities and characteristics of the generated waste of that area for which an initial phase of research is essential. This study can be conducted by EPAs and PCSIR which must include reaching rates of current waste generation, physical characteristics of this waste distinguishing between various waste fractions and future projections that are driven by integration of relevant growth rates like population, income etc.

At the same time capacity building and awareness of the community goes hand in hand in preliminary research before establishing a facility. This step may include assessing the current awareness level of residents in domestic setups and current responsibilities of waste producers in commercial and industrial sectors. It may also include integrating awareness campaigns during the research and conveying and implementing future expectations after facilities are in place.

6.4.1 Aerobic Windrow Composting

For aerobic windrow composting technology deployment, waste quantification and characterization studies should exhibit high organic compostable waste content as well. Therefore, conducting the research on these parameters should be the immediate action in order to make informed decisions in selection of technology, design optimised and adaptable infrastructure and incorporate indigenous social and cultural factors. One of the major barriers that prevents wider adoption of this technology is the application of compost as there is underdeveloped domestic market for the end-product of composting. To facilitate this, capacity building programs, financial incentives and awareness amongst the agriculture sector through the mobilization of Agriculture Departments and Extensions pertaining to the benefits of compost and its soil enhancing properties in comparison to the chemical fertilizers and their impact on the environment is essential.

6.4.2 Waste Segregation Facility

After stakeholder consultation on this sector, successful public-private models were seen to be implemented by Punjab, Sindh and KPK. Similar model for waste segregation facility would distribute responsibilities among management companies and bring efficient, responsive and well monitored systems for adoption. The immediate plan for a waste segregation facility should be the incorporation of the informal sector into the formalized system as formalised and trained workers, preventing social and/or economic exclusion that plagues the informal sector. This will organize the waste sector, ensuring systemized operations and providing a respectable working environment to these groups that will improve their living standards as compared to previous setup. With the provision of better and systemized income opportunities, this system is also likely to eradicate child labor in this sector where the families rely heavily on each member (children earning between Rs 200 to 500 per day (ILO, 2023) working to generate income for the household regardless of their age. The approach will lead to further improvement in living standard as a result underaged workers being engaged in education rather than child labor. NGOs and civil society organizations can be partnered with for a more informed strategy planning. Furthermore, waste segregation action should always lead to source segregation goals which should immediately be incorporated as a vision into the policy. Collection vehicles specifically designed to retain the quality and structure of various waste fractions that are to be segregated. A vehicle tracking system improved the efficiency of the transportation of waste and must also be focused. To improve the viability of facilities locations should be chosen near the generation points to reduce cost of transport and chances of waste contamination caused by mixing. The system should be backed by a mass level campaign incentivized by laws and regulations.

6.4.3 Refuse-Derived Fuel

Significant integration with industries that can utilize the end product is essential. While current regulations have recognized the use of RDF in the cement industry, additional opportunities should be explored. Engaging industry stakeholders will be critical to ensuring the market viability of the technology's outcomes. The Pakistan Industrial Development Corporation (PIDC) and SMEDA can play key roles in facilitating this integration within the industrial sector.

6.4.4 Integrated Biomass Gasification for Syngas and Biochar

The immediate action needed for this technology is to achieve an economic balance that ensures Syngas and Biochar are cost-effective alternatives both as energy sources and as soil amendments, compared to conventional options. Policy and regulation will play an important part in this while climate finance must also be incorporated to bear the cost of infrastructure development. Since syngas and biochar applications are products of processing agricultural waste, relevant departments and extensions are responsible to ensure application and utility.

Mobilizing the private sector is essential for all identified technologies that need immediate action as decentralized waste management system requires an approach that distributes responsibilities across levels such as that of a housing society as a unit and achieves robust operations and monitoring system for waste that needs daily monitoring. Ensuring participation of women and

vulnerable groups is essential in all stages of technology implementation to ensure that the positive outcomes are also received by women and other vulnerable groups. Women who informally play a major role in waste management activities such as reusing, recycling and segregation must be formally incorporated into the system to ensure equitable participation in the waste sector.

Another immediate action should be the integration of information technology for easier access of information for all stakeholders. This will involve stakeholder like P@sha, MoITT and PSEB to play their role in development of a digital platform for sharing of information like approved waste segregation protocols, compost application, waste collection schedules and complaint platform along with a list of high performing entities in the private sector can help make the system more accessible for the end users.

Last but not the least, keeping the NDCs targets in mind and achieving climate finance goals, it is mandatory to measure baseline scenarios on the basis of which emissions reduction can be calculated and verified. MoCC&EC, State Bank of Pakistan and PSX are responsible for this task where all these actions will put wheels under a well-informed, systematic and integrated solid waste management system with a clear focus on quantifying its impact on climate change. Such a design will initially need support but will eventually run on its own only requiring vigilant monitoring and evaluation systems.

7 Conclusion & Way Forward

The NDC Technology Roadmap for the Water and Waste sectors aims to leverage the opportunities offered by technological innovations and work towards the attainment of Pakistan's NDC goals, ensuring efficient, equitable and sustainable management and delivery of the water and waste sectors goals. Cognizant of Pakistan's ambitions set forth in its NDCs, the Roadmap development process adopts a detailed assessment and methodological approach designed to meet the sector and time specific NDCs targets including goals such as renewable energy mix, improved water resource management and greenhouse gas emission reduction.

Through a data-driven, informed and collaborative process composed of extensive data analyses, stakeholder consultations, technological assessments, and more, this document has presented a time-bound action plan consisting of short- and long-term milestones categorized by priority level and identified stakeholders. The action plans propose strategic and informed measures across key categories: policy, capacity-building, budget, governance, business continuity, monitoring and evaluation, gender equality and social inclusion, and environmental monitoring. The Action Plan embraces the vision of the proposed NDC Technology Roadmap and aims to guide the way forward for technology adoption and integration into Pakistan's water and waste sectors.

7.1 Water Sector

The action plan identifies the way forward for the development of the identified technologies in the water sector. For the water sector emphasis has been placed on the technologies that exist at deployment stage in the readiness level chart. Rainwater Harvesting, Run of the River Plants and Micro and Small Hydro Powerplants are seen to be at operational deployment as the technologies are fully developed and functioning in several suitable locations. Priority should be given to mobilization of financing and private sector engagement to diversify their scope and scale. Simultaneously the integration of information technology is also seen as a means of scaling-up existing technologies like solar water pumping for a more efficient and improved system. To sustain the technologies proposed in the action plan, continuous upscaling mechanisms and opportunities need to be supported and funded by the authorities. The aim should be to keep improving the performance of technologies such as IoT for Solar Based Pumps and GIS and remote sensing through upgrading tools and machinery for over all sustainable water management and invest in the maintenance of existing projects through subsidies and climate finance. It is also vital to provide intermittent capacity building programs that help promote wider adoption through demonstrating the success of existing projects and transferring technical skills through personnel working in these projects. Policy must also be subjected to continuous review and revision where opportunities to explore scope expansion must be prioritized.

7.2 Waste Sector

On the other hand, waste sector calls for redesigning waste management infrastructure into decentralized facilities punched within cities for a more efficient and carbon free system. This

system should follow the principles of integrated waste management and zero waste and design an array of technologies to work in harmony towards diverting waste from landfills/dumpsites. These facilities are to be facilitated by the incorporation of information technology by designing a web portal that brings all stakeholders on one platform. However, the true potential of redesigning the waste management system lies in the opportunity for social inclusion, entrepreneurship and resource recovery. Currently, the materials like recyclables with economic value and organics with energy and soil amendment potential that are discarded as waste, if recovered from waste streams, can create new business opportunities that can provide employment and environmental wellbeing to the society. Further research activities are recommended in developing sustainable composting methods along with a focus on biochar production and distribution from integrated biomass gasification. Engineered Landfill Technology is also a technology implemented in Pakistan facing issues that can be addressed through research and innovation in design, construction and monitoring.

The action plan recognizes the potential opportunities and aims to work towards their actualization by outlining the necessary key steps to ensure improvement through the utilization of identified technologies in Pakistan's water and waste sector, working towards the attainment of its NDC goals. It is, however, vital to note that implementation of action items that are related to market development for end-products of technology along with mobilizing the private sector and finances are crucial for a successful implementation. Since these are the main barriers to wide scale adoption of fully developed technologies, a focused approach to providing an enabling environment is the crux of this roadmap. In addition, including gender equality and social groups along with capacity building programs can further enhance the efficiency and outcome of the action plan ensuring a sustainable technology intervention in the water and waste sector.

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Annex 1

WATER SECTOR

Assessment Criteria	Technologies	Existing				Emerging	
		Drip Irrigation Systems **Score** **Legal: 15** **Eco. & Tech.: 27** **Social & Env.: 22** **Total: 64**	**Run Off River Plants** **Score** **Legal: 12** **Eco. & Tech.: 23** **Social & Env.: 22** **Total: 57**	**Micro & Small Hydropower Plants** **Score** **Legal: 13** **Eco. & Tech.: 23** **Social & Env.: 20** **Total: 56**	**Rainwater Harvesting** **Score** **Legal: 10** **Eco. & Tech.: 25** **Social & Env.: 18** **Total: 53**	**IoT based Solar Pump & Storage System** **Score** **Legal: 8** **Eco. & Tech.: 20** **Social & Env.: 18** **Total: 46**	**AI Integrated GIS and Remote Sensing for Water Management (Second Emerging)** **Legal: 7** **Eco & Tech: 14** **Social & Env: 12** **Total: 33**
	Description of Technology	Referred to as trickle irrigation or micro irrigation, involves delivering water slowly to plant roots either onto the soil surface or directly to the root zone via a network of valves, pipes, tubing, and emitters. directly to the plant base (ICIDCIID, n.d.).	It is a form of hydroelectric power generation characterized by minimal or no water storage.	These projects harness the kinetic energy of water flow to power turbines, ultimately generating electricity. Installations are below 25 MW, further subdivided into micro (up to 100 kW) category. (CTCN, n.d.)	Defined as direct collection of rainwater from rooftops and its storage in reservoirs for direct use or to be recharged into the groundwater by different suitable techniques through feasible structures.	Utilizes solar energy to power water pumps. Integrating IoT enhances the automation to turn the water pump on and off based on set conditions. Sensors like humidity gauges and solar panels help the system adjust watering schedules by itself, reducing manual work, saving time, and making irrigation more efficient.	RS and GIS provide valuable data on water sources, flow patterns, and environmental impacts. This information is crucial for selecting hydropower plant locations, predicting water availability, and minimizing environmental damage. AI algorithms can analyze vast amounts of RS data much faster than humans, automating tasks and identifying trends. This allows experts to focus on strategic decision-making.
Legal and Financial Framework	**Policies and Frameworks**	Supported by The National Water Policy of 2018 ANSI/ASAE and ISO standards in Pakistan define standards and specifications. Clear mechanism for implementation and installation of High Efficiency Irrigation systems include drip Irrigation. Clear financial guidelines developed by State bank of Pakistan. 80% subsidy provided in Punjab.	The country targets 10% renewable energy mix from hydropower. National Water Policy 2018 regulate development of hydropower projects. Dams installation is supported by Hydropower Policy 1995, The Punjab Irrigation and Drainage and Rivers	The country targets 10% renewable energy mix from hydropower. National Electric Power Regulatory Authority (NEPRA) provides clear guidelines, sets regulations for integration with national grid and encourages private sector engagement and PPPS Provincial policies focus on providing framework for project execution. Foreign joint programs for grants enable wide adoption.	Pakistan's National Water Policy 2018 and the National Water Conservation Strategy 2023 provide supportive legal environment. CDA implemented policies to promote rainwater harvesting through clause 5.6.6 of building and zoning regulations 2014	National Water Policy 2018 and subsidy regulations for the import of solar instruments No specific national policy National Water Policy 2018 is evolving for solar pumps and advises transition through subsidies. regulations for the import of solar	Supported by National Space Policy. National Water Policy 2018 and the Water Conservation Strategy 2023 highlight the importance of GIS and remote sensing technologies for water resource management. The Surveying and Mapping Act 2014 further promotes research activities and collaboration in the

			Act 2023. Provincial policies focus on providing framework for project execution. WAPDA acts as regulatory body and National Electric Power Regulatory Authority (NEPRA) provides clear guidelines, sets regulations for integration with national grid and encourages private sector engagement and PPPS. Supported by foreign investment such as China Silk Road Infrastructure Fund, World Bank Investment Forum, and IFC but financial uncertainties remain unaddressed	Initiatives by Pakistan Council of Renewable Energy Technology (PCRET) and Sarhad Rural Support Program (SRSP) facilitate installation	Absence of clear guidelines and official data on installment and use hinder development.	instruments. National Electric Power Regulatory Authority (NEPRA) provides clear guidelines, sets regulations for integration with national grid. No direction, guideline, regulation on IoT integration. Absence of national policy and guidelines specifically for groundwater pumping in agriculture. Subsidies in Khyber Pakhtunkhwa for Solar Irrigation Pumps (SIPs) 11 schemes in 2017 to introduce solar-powered tube wells and pumping stations without IOT Rapidly evolving financial landscape through Free Solar Pump Scheme and subsidies in KPK for Solar Irrigation Pumps.	field of remote sensing and GIS. Available in Pakistan through government departments such as Planning and Development (P&D), with notable examples like the GIS Lab in P&D, and NGOs like WWF and University of Punjab
Economical and Technical Feasibility	**Capital Cost/Total Investment**	Capital expenditure: Rs. 34,392 to Rs. 81,059 per farm PKR 200,000 – 300,000 per acre. (Khan, 2022) Base Case Cost: 522.5 USD + (2% operation and maintenance cost) NPV: USD 3,431 IRR: 83% Payback Period: 1.2 y	Gorkin Maltiltan Hydropower Plant The cost of project is estimated 20,722 million rupees (PEDO, n.d.), having the capacity of generating 84MW of electricity, Base Case Kari Muskhur Hydropower Project (495MW) (PEDO, Feasibility Report Kari Muskhur Hydropower Project	An example of project in Pakistan , Jukhtai (Swat) (Ebrahim, 2018) Base Case Cost: Rs. 151,547 USD NPV: 301,429 USD IRR: 34% Payback period: 2.9 y	For individual buildings rainwater harvesting system cost PKR 150,000Rs (Zaman, 2020) with capacity of 3,200 liters of water capture in one hour after 25 mm of rain (Zaman, 2020) Base Case PKR 150 million (USD 920,000) (Zaman, 2020), for community system which can hold 6.4 million liters of water (Zaman, 2020), serving a catchment	The cost of solar pumps ranges from PKR 200,000 to PKR 500,000 (Alpha Solar, 2024), cost of 750 gallons water tank ranges from 30-40k (Saleem, Ashraf, & Fripp, 2015), while integrating the IoT SMART system will cost around Rs 200,000 (Hamied, Mellit, Benghanem, & Boubaker, 2023)	Estimates not available, as it is complex to quantify the cost of GIS software's used for the application. Similarly, the expert human resources and skills required for the Application of AI can vary case to case. Based on study: Setting up a GIS lab for hydropower plants Cost: Assumptions from GIS lab setup

			(495MW) District Chitral, n.d.) NPV: 1,546 USD million IRR: 15.69% Benefit Cost Ratio: 2.71		area of 25 acres (Zaman, 2020). NPV: USD 288,054 IRR: 12% Payback period: 7.5 y	Base Case (Sharma, Tyagi, & Sundararagavan, 2024) For Companies Investment: 579.13 million USD NPV: 857.82 million USD at a 7% discount rate IRR: 27.7% (Sharma, Tyagi, & Sundararagavan, 2024) Payback period: 17 m For Farmers Investment: 86.48 million USD NPV: USD 1,478.03 at 7% discount million at a 7% IRR: 38.7% Payback period: 1.09 m	USD 88,333+ additional cost USD 232,995) with 10% increase for benefits (USD 59,743) NPV: USD 262,395 IRR: 23% Payback period: 4.3
Social Inclusivity and Climate Impact	**Climate Impact**	Water usage reduction: 60% (CFP, n.d.) % reduction in fertilizer usage, 50% (CFP, n.d.) Water-saving potential: 30% to 70% (CFP, n.d.), Drip irrigation, combined with optimized irrigation scheduling, can lead to reductions in emissions of CO2, N2O, and NO by up to 62%. (Andrews, Homyak, Oikawa, Wang, & Jenerette, 2022)	Karot power plant in Pakistan generates 3.2 billion kilowatt (Power Technology, 2022) hours of clean energy annually. Karot plant helps reduce 3.5 million tons (Mt) of carbon dioxide emissions annually and decreases the use of 1.4 Mt of coal equivalent per year.	Mitigation potential of 100 billion tons of carbon dioxide have been saved in the last 50 years (Paradigm Shift, 2023). Sarhad Rural Support Program produced 29 MW of energy. (Paradigm Shift, 2023) Tend to prevent deforestation enhancing climate resilience. (Paradigm Shift, 2023)	Stabilizes groundwater levels, reduces land erosion and mitigates flood inflow to major rivers. (GoP G. o., TECHNOLOGY NEEDS ASSESSMENT FOR CLIMATE CHANGE ADAPTATION, 2016)	Reductions in energy costs for farmers by up to 70% (Goel & Sharma, 2020). With 50%(Hussain, 2023) conversion of diesel- and electric-operated pumps solar, could lead to a substantial reduction of 4200 MW(Hussain, 2023). The conversion of diesel tube wells to solar-powered ones could offset around 5.025 million metric tons(Hussain, 2023) of CO2 emissions annually	Can provide major support to projects with emissions reduction potential e.g. 9% of global annual CO2 emissions**.** (IEA50, 2022)

	Gender Equality and Social Inclusion	Women who utilized solar-powered drip irrigation systems in Nepal spent 50 per cent less time tending to their plots compared to traditional methods of hand watering. (Shrestha, Labisha, Manohara, & Mukherji, 2023)	Karot project employed over 4,000 people(Power Technology, 2022) and benefitted approximately five million people. Opportunities for women in decision making.	Better lighting allows for extended study hours for girls/boys and allows time saving for women along with improved quality of life. 927,495 people benefitted from Sarhad Rural Support. Installation of technology creates job opportunities for youth. Enhanced economic activity	Reduced dependency on municipal water supplies, (Hassan, 2016)	Automating pump operation can dramatically reduce the reliance on manual labor, freeing up farmers' time and resources	Underrepresentation of women in the remote sensing community, may hinder inclusive development efforts. AI can analyze social and economic data along with environmental data.

WASTE SECTOR

Assessment Criteria	Technology	Existing				Emerging
		Aerobic Windrow Composting **Score** **Legal: 12** **Eco. & Tech.: 24** **Social & Env.: 18** **Total: 54**	**Waste Segregation** **Score** **Legal: 9** **Eco. & Tech.: 21** **Social & Env.: 22** **Total: 52**	**Refuse-Derived Fuel** **Score** **Legal: 11** **Eco. & Tech.: 21** **Social & Env.: 17** **Total: 49**	**Engineered Landfill Technology** **Score** **Legal: 13** **Eco. & Tech.: 18** **Social & Env.: 15** **Total: 46**	**Integrated Biomass Gasification for Syngas and Biochar** **Score** **Legal: 8** **Eco. & Tech.: 19** **Social & Env.: 21** **Total: 48**
	Description of Technology	Composting breaks down organic waste aerobically using microorganisms, producing nutrient-rich compost.	Waste segregation categorizes waste at the source for recycling, composting, or disposal efficiency.	Refuse Derived Fuel (RDF) converts non-recyclable plastic waste into a uniform fuel source, suitable for burning in industrial furnaces or power plants, through shredding, washing, and processing.	Engineered landfills capture methane from decomposing waste using liners and gas collection systems, which can be repurposed for electricity generation or heat.	Integrated Biomass Gasification is a thermochemical process that converts biomass into syngas and biochar via gasification.
Legal and Financial Framework	**Policies and Frameworks**	Guidelines are present as (Draft) Guidelines for Solid Waste Management in Pakistan 2005 by EPA The Solid Waste Sector Reform Roadmap by ADB (2022) indicates operational small scale plants Absence of well-defined monitoring and evaluation framework, financial instruments and private sector mobilization	Guidelines are present as (Draft) Guidelines for Solid Waste Management in Pakistan 2005 by EPA National Hazardous Waste Policy of Pakistan 2022 and Asian Development Bank's reform roadmap 2022 Fails in providing supportive infrastructure and enforcement mechanisms. Financial constraints and informal sector are not addressed.	Regulatory support provided by Guidelines for Processing and Using Refuse-Derived Fuel formulated in 2012 for its use in the cement industry only. Absence of nation-wide policy and regulations. Infrastructure development hindered by financial constraints. Private sector potential remains untapped.	Regulatory support outlined in National Hazardous Waste Management Policy of Pakistan 2022 and the Asian Development Bank's reform roadmap 2022 Absence of targeted financial mechanisms Scalability hindered by limited expertise and lack of monitoring and evaluation framework	Policy on biomass energy technology submitted to UNIDO for advice Lack of clear regulations and standards, limited access to financing and absence of robust monitoring and evaluation frameworks
Economical and Technical Feasibility	**Cost Savings**	Composting can manage the waste of a household for 25 USD saving up to USD 60, whereas normal waste management cost will be 85 USD	N/A	RDF cost was told to be PKR 1/kg (LWMC) 1kg of Coal is around PKR 250	Normal Waste Excavation or clean fill/management costs around USD 400,000, but in engineered landfills the cost is reduced to USD 117,720.	The production cost of electricity through gasification is 0.09-0.16 USD/kWh, which is lower than that of diesel-fueled engine

	Capital Cost/Total Investment	Base Case Investment: 37.1 million USD with 20% running cost) and 1000 TPD NPV: USD 138.8 million IRR: 27% Payback Period: 3.7 years	150,000 INR per segregation belt, capacity 50-100kg per foot (~PKR 500,000) Base Case Capital cost USD 555,712 (Al-Athamin, et al., 2021) NPV: 1.7 million USD IRR: 56% Payback Period: 1.4 y	PKR 300M, Capacity 12 TPH, replaces 170 tons of coal/day Base Case Investment 26.1 million USD deduced from study (CDM, 2017) with 3% O&M NPV: USD 10.6 million IRR: 15% Payback Period: 6.4	Lakhodair managing up to 2000-2500 TPD Base Case Lakhodair Project Capital Cost 11,036 USD (Urban Unit, n.d.) Landfill Gas Capture Cost: USD 16,554 O&M: USD 1655.4 NPV: 7.08 million USD IRR: 34% Payback Period: 0.02 y	INR 1,500,000, 7.5 TPD Capacity (~ PKR 5M) Base Case For a USD 56,882 (Qamar, javed, Liaquat, & hassan, 2021) investment plant with 100-kW using corner stove NPV: - IRR: 35.2% Payback Period: -
Social Inclusivity and Climate Impact	**Climate Impact**	50% emissions reduction	85.48% emissions reduction based on a Chinese model	54.8% CO2e emissions reduction	88.07% reduction in emissions based on a Chinese model	14.7% reduction in carbon emissions
	Gender Equality and Social Inclusion	Social reservations especially for women. More potential for job creation as compared to landfills and incineration facilities.	Resistance of informal sector. Improper segregation by residents. Limited space in densely populated areas. Economic and employment opportunities in formalizing the sector.	Women at lowest strata in value chain. Reluctance from industry partners due to technical difficulties.	Absence of women in value chain. Community resistance and site selection difficulties. Likely to improve safety and environmental well-being.	Potential to provide access to electricity, job creation and economic opportunities especially for women.