Republic of Kazakhstan



TECHNOLOGY NEEDS ASSESSMENT FOR CLIMATE CHANGE MITIGATION

REPORT I
TECHNOLOGY PRIORITISATION

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TNA TECHNOLOGY NEEDS ASSESSMENT

AIIB ASIAN INFRASTRUCTURE INVESTMENT BANK

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Table of contents

List of Tables iii
List of Figures iii
Abbreviations and acronyms iv
EXECUTIVE SUMMARY vi
Chapter 1 TNA process and the national context 1
1.1 Introduction 1
1.2 TNA process in Kazakhstan 2
1.2.1 Sector selection 2
1.2.2 Organisational structure 3
1.3 Summary of the national context 3
Chapter 2 Technology prioritisation for Energy sector 6
2.1 Technology options in Energy sector 7
2.1.1 Process of identifying technologies 8
2.1.2 Long list of technology options 9
2.2 Technology prioritisation process 10
2.2.1 Setting criteria 10
2.2.2 Assigning weights 10
2.2.3 Scoring 11
2.3 Prioritised technologies for Energy sector 12
2.3.1 Combining scores and weights 12
2.3.2 Result examination and sensitivity analysis 12
Chapter 3 Technology prioritisation for Waste sector 16
3.1 Technology options in Waste sector 16
3.1.1 Process of identifying technologies 19
3.1.2 Long list of technology options 20
3.2 Technology prioritisation process 21
3.2.1 Setting criteria 21
3.2.2 Assigning weights 22
3.2.3 Scoring 23
3.3 Prioritized technologies for Waste sector 24
3.3.1 Combining scores and weights 24
3.3.2 Result examination and sensitivity analysis 24
Chapter 4 Summary and Conclusions 26
References 28
Annex 1: Extended list of technologies (energy sector) 30
Annex 2: Technology Factsheets for selected technologies (energy sector) 32
Annex 3: Performance, Scoring and Decision Matrices for MCA (energy sector) 72
Annex 4: List of stakeholders involved (energy sector) 75
Annex 5: Extended list of technologies (waste sector) 76
Annex 6: Technology Factsheets for selected technologies (waste sector) 78
Annex 7: Scoring and Decision Matrices for MCA (waste sector) 125
Annex 8: Sensitivity Analysis Results for MCA (waste sector) 127
Annex 9: List of stakeholders involved (waste sector) 130

List of Tables

Table 2.1. The long list of energy technologies 9
Table 2.2. Criteria and weights for the Simple MCA Tool 11
Table 2.3. Final technology scores based on decision matrix 13
Table 2.4. Final top-ranked technologies for the Energy Sector 15
Table 3.1. The long list of waste technologies 20
Table 3.2. Criteria for the Simple MCA Tool. 21
Table 3.3. MCA criterion weights 23
Table 3.4. Top-ranked technologies for the Waste sector and the sensitivity analyses ..24
Table 4.1. Short list of technologies for energy sector in Kazakhstan 27
Table 4.2. Short list of technologies for waste sector in Kazakhstan 27

List of Figures

Figure 1.1 Steps in a TNA process: from priorities to action (UNEP-CCC, 2024) 1
Figure 2.1. Seven steps in the technology prioritisation process (UNEP-CCC, 2024) ... 6
Figure 2.2. Sensitivity analysis results for three scenarios in energy sector 14
Figure 3.1. Normalized total scores of waste sector technologies 25

Abbreviations and acronyms

AIIB	Asian Infrastructure Investment Bank
BAEF	Barrier Analysis and Enabling Framework
BESS	Battery Energy Storage System
BTR	Biennial Transparency Report
C&D	Construction & Demolition
CAPEX	Capital Expenditure/Capital Cost
CCGT	Combined-Cycle Gas Turbine
CCUS	Carbon Capture, Utilization, and Storage
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
EPR	Extended Producer Responsibility
EST	Environmentally Sound Technologies
ETS	Emissions Trading System
EUR	Euro
EV	Electric Vehicle
GCF	Green Climate Fund
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GPS	Global Positioning System
IEA	International Energy Agency
IGTIPC	International Green Technologies and Investment Projects Center
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
JSC	Joint-stock Company
KEGOC	Kazakhstan Electricity Grid Operating Company
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Energy
LNG	Liquified Natural Gas
MENR	The Ministry of Ecology and Natural Resources of the Republic of Kazakhstan
MCA	Multi-Criteria Analysis
MSW	Municipal Solid Waste
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
OECD	Organisation for Economic Co-operation and Development
OPEX	Operating Expenditure/Operational Expense
PPP	Public-private Partnership
PSC	Project Steering Committee
PV	Photovoltaic
RDF	Refused Derived Fuel
RES	Renewable Energy
SWG	Sectoral Working Groups

TAP	Technology Action Plans
TFS	Technology Fact Sheet
TNA	Technology Needs Assessment
TRL	Technology Readiness Level
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNEP-CCC	UNEP Copenhagen Climate Centre
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
WtE	Waste-to-Energy

Units

GW	Gigawatt
GWh	Gigawatt-hour
kWh	Kilowatt-hour
Mt	Million tonnes
MW	Megawatt
MWh	Megawatt-hour
tCO_2e	Tonnes of Carbon Dioxide Equivalent
TWh	Terawatt-hour

EXECUTIVE SUMMARY

The Technology Needs Assessment (TNA) Report presents the results of the prioritisation of climate change mitigation technologies for the Republic of Kazakhstan. The TNA is a country-driven process conducted under the United Nations Framework Convention on Climate Change (UNFCCC) to support developing countries and economies in transition in identifying, evaluating, and accelerating the deployment of environmentally sound technologies. The outputs of the TNA process form the basis for Technology Action Plans (TAPs), which provide national roadmaps for the implementation, financing, and scale-up of priority climate technologies.

This TNA represents Kazakhstan's second national Technology Needs Assessment, building on the first TNA approved by the Government in 2010 and implemented from 2014 to 2017 under the Green Economy framework. The following TNA is being conducted at a pivotal moment, following the submission of Kazakhstan's enhanced Nationally Determined Contribution (NDC 3.0) in November 2025. This updated NDC represents a significant increase in national ambition and transparency and aligns the country's development pathway with its long-term objective of achieving carbon neutrality by 2060. The TNA is fully aligned with NDC 3.0, which commits Kazakhstan to reducing national net greenhouse gas (GHG) emissions by 17 percent below 1990 levels by 2035 (unconditional target), and with the Strategy for Achieving Carbon Neutrality by 2060.

The TNA follows the three-step methodology endorsed by the UNFCCC (UNEP-CCC, 2024):

1. Technology identification and prioritisation;
2. Barrier Analysis and Enabling Framework (BAEF); and
3. Technology Action Plan (TAP) development.

This report covers the first step of the process and establishes the analytical and stakeholder-based foundation for the development of enabling policies, investment frameworks, and implementation roadmaps.

For the 2025 TNA cycle, Kazakhstan prioritised three sectors based on national emission trends, mitigation potential, and policy relevance:

- **Mitigation:** Energy and Waste sectors
- **Adaptation:** Agriculture sector

The Energy sector was selected as the highest mitigation priority because it accounts for nearly 80 percent of Kazakhstan's total GHG emissions, reflecting the country's strong dependence on fossil fuels, particularly coal.

In the Energy sector, coal-fired power generation still represents about 68 percent of electricity production. Kazakhstan has set ambitious targets for 2035, including increasing the share of low-carbon electricity generation to at least 35 percent, increasing renewable energy to 20 percent, and reducing the energy intensity of GDP by 20 percent.

The Waste sector was selected as a secondary mitigation priority due to rising methane emissions and the adoption of the Concept for the Management of All Types of Waste for 2026–2030, which establishes ambitious targets for waste reduction, recycling, and methane mitigation.

Based on a multi-criteria assessment of economic, environmental, climate, technological and policy factors, the TNA identified the following technologies as the highest-priority options for decarbonising the energy system:

- **Large-scale on-grid solar farms (0.1–1 GW)**
- **Large-scale on-grid wind farms (0.1–1 GW)**
- **Small hydropower (<10 MW) in south and north-east Kazakhstan**

These technologies directly address both supply-side decarbonisation and demand-side efficiency, allowing Kazakhstan to reduce coal dependence, improve system flexibility, and achieve rapid and cost-effective emissions reductions across the power and building sectors.

In line with Kazakhstan's new waste management policy and circular economy objectives, the TNA prioritised the following technologies as having the highest mitigation and development impact:

- **Multi-stream waste separation**
- **Anaerobic digestion of sewage sludge**
- **Sanitary landfills with methane recovery**

These technologies enable systematic methane reduction while improving waste collection, recycling, and resource recovery, and generating co-benefits in public health, environmental quality, and renewable energy production.

The prioritisation was carried out using a structured, multi-criteria decision-making approach aligned with TNA guidelines and adapted to Kazakhstan's national context through expert analysis and stakeholder consultations. The resulting set of prioritised technologies provides a strong evidence-based foundation for the next stages of the TNA process.

The outcomes of this report will feed directly into the Barrier Analysis and Enabling Framework and the Technology Action Plans, supporting Kazakhstan in mobilising investment, strengthening institutions, and accelerating the deployment of high-impact mitigation technologies in line with its NDC 3.0 and carbon-neutrality pathway.

Chapter 1 TNA process and the national context

1.1 Introduction

The TNA process is a comprehensive, country-driven, and participatory effort that is critical to implementing both mitigation and adaptation actions under the global climate regime. It is aimed at identifying, selecting, and planning for the effective transfer, adoption, and diffusion of climate technologies to reduce greenhouse gas (GHG) emissions (mitigation) and/or increase resilience to the adverse effects of climate change (adaptation).

The importance of widespread technological change was directly referenced in the Paris Agreement, building on earlier mandates from the United Nations Framework Convention on Climate Change (UNFCCC). Multilateral support for conducting effective TNAs and implementing Technology Action Plans (TAPs) is channeled through the GEF or AIIB funded TNA project, in partnership with UN Environment Programme (UNEP) and UNEP Copenhagen Climate Centre (UNEP-CCC).

The TNA process involves three distinct and sequential steps:

1. Technology Identification and Prioritisation: The focus of this TNA Report.
2. Barrier Analysis and Enabling Framework (BAEF).
3. Technology Action Plan (TAP) Development.

The steps build upon each other, resulting in TAPs that serve as national roadmaps. These roadmaps are designed to be integrated into government planning and to create a pipeline of bankable programmes and projects targeted at specific sources of multilateral (e.g., Green Climate Fund - GCF) and private finance.

The main objectives of the TNA project are:

- To identify and prioritise technologies that contribute to the country's mitigation and adaptation goals, while meeting national sustainable development goals and priorities.
- To identify and analyse barriers hindering the acquisition, deployment, and diffusion of these prioritised technologies.
- To develop Technology Action Plans (TAPs) specifying activities and enabling frameworks to overcome these barriers and facilitate technology transfer.

Ultimately, the TNA process enhances the country's capacity to mainstream climate change and leverages international climate finance to adopt environmentally sound technologies (ESTs) for a low-carbon, climate-resilient development pathway. The process steps, moving from priorities to implementation, are illustrated in Figure 1.1 below.



1.2 TNA process in Kazakhstan

This Technology Needs Assessment (TNA) is conducted in the context of the Republic of Kazakhstan's fundamental and long-term commitment to a sustainable, low-carbon, and climate-resilient economy.

Kazakhstan's engagement in the global climate change agenda is demonstrated by its adherence to key international frameworks. Following its independence, the nation became a Party to the United Nations Framework Convention on Climate Change (UNFCCC) in 1995, reinforced by the ratification of the Kyoto Protocol in 2009 and the Paris Agreement in 2016. Recognizing the urgent need for transformative action, the country has adopted the Strategy for Achieving Carbon Neutrality by 2060, which represents the country's decisive long-term climate policy. This strategy integrates comprehensive measures to decarbonize key economic sectors and promotes sustainable development in line with the country's updated Nationally Determined Contribution (NDC).

The foundation for this process was laid by the first TNA project, approved by the Government in late 2010 and carried out in 2014-2017. This initial effort, implemented by the Ministry of Environment and Water Resources of Kazakhstan, Ministry of Energy of Kazakhstan and the Climate Change Coordination Centre (CCCC) with support from the GEF, UNEP Risø Centre (URC), and AIT Bangkok, focused on technology identification under the framework of the Concept for the Transition to a "Green Economy" (approved May 2013).

The key output of the first TNA was the prioritisation of specific technologies across four critical sectors:

- **Mitigation:** For the Energy (Power Production) and Industry (Cement Production) sectors, priority technologies included Pulverized Coal Combustion with higher efficiency (to address reliance on fossil fuels), Small Hydropower, and measures such as energy efficiency and the change from wet to dry production technology for cement.
- **Adaptation:** For the highly climate-sensitive Agriculture and Water Resources sectors, priority technologies included Drip Irrigation and Water Metering (to improve water use efficiency), Diversification of crop production, and the development of grazing and stabling systems on an industrial basis.

These results led to the development of the first National Technology Action Plans (TAPs), which provided detailed roadmaps designed to inform and support subsequent climate policy and project development.

The current TNA exercise (2025) is designed to build upon this foundational technical work. It updates and refines the country's technological pathways, ensuring they are fully aligned with the 2060 Carbon Neutrality Strategy. The priority sectors selected for this TNA—**Energy** and **Waste** sectors for mitigation and **Agriculture** for adaptation—reflect the current strategic focus on deep decarbonization and investment required to meet the long-term national climate goals.

1.2.1 Sector selection

The selection of priority sectors for this TNA was conducted through a comprehensive assessment process, guided by the country's strategic documents, the latest national GHG inventory data, and consultation with key stakeholders and relevant national authorities. To ensure maximum impact and alignment with the Carbon Neutrality by 2060 Strategy, the TNA focuses on a total of three sectors: two for mitigation and one for adaptation.

The foundation for the mitigation selection is the GHG emissions trend reported in the First Biennial Transparency Report of the Republic of Kazakhstan (UNDP, 2025). This data confirms that the Energy sector overwhelmingly dominates the national emissions profile, accounting for 79.9% of the total GHG emissions in 2022. Following this, Agriculture contributed 9.3%, Industrial Processes 7.7%, and Waste 2.0% of the total net emissions.

The Ministry of Ecology and Natural Resources of Kazakhstan determined the following three sectors to be the highest priority for the current assessment: Energy and Waste for mitigation, and Agriculture for adaptation.

For Mitigation, the Energy sector was selected as the highest priority due to its overwhelming dominance of the national emissions profile, accounting for almost 80% of total GHG emissions. Addressing this sector is non-negotiable for achieving the long-term Carbon Neutrality by 2060 goal, requiring a deep assessment of low-carbon generation and energy efficiency technologies. The Waste sector was selected as the secondary mitigation focus due to a strong policy driver: the approval of the Concept for the Management of All Types of Waste for 2026–2030 (The Press Service of the Government of the Republic of Kazakhstan, 2025) in 2025. This new policy provides a vital window for improved regulations for managing all types of waste.

1.2.2 Organisational structure

The TNA process operates within a robust governance framework designed to bridge high-level political objectives with operational excellence. This structure ensures that technical assessments align seamlessly with national strategic priorities.

1. National Leadership and Political Oversight
   - Host Entity: The Ministry of Ecology and Natural Resources (MENR) serves as the National Focal Point. The Ministry ensures the TNA project remains strictly aligned with Kazakhstan's Strategy on Achieving Carbon Neutrality by 2060 and NDC 3.0.
   - Strategic Direction: The National TNA Project Steering Committee (PSC) provides high-level guidance and grants final approval on all reports. Comprising representatives from key ministries (Energy, Agriculture, National Economy), the PSC ensures cross-sectoral buy-in and policy coherence.
2. International Framework and Strategic Finance
   - Methodology & Support: UNEP and UNEP-CCC provide the global methodological framework, while Regional Centres offer technical backstopping to ensure national analysis meets international standards.
   - Strategic Funding: The project is reinforced by dedicated funding from the Asian Infrastructure Investment Bank (AIIB). This partnership ensures the TNA moves beyond theoretical assessment to generate bankable, investment-ready climate projects suitable for future infrastructure financing.
3. The National TNA Team
   - The execution of the project is driven by a unified national team responsible for translating policy mandates into technical analysis.
   - Coordination: The International Green Technologies and Investment Projects Center (IGTIPC) acts as the National TNA Coordinator, managing day-to-day operations and stakeholder engagement.
   - Technical Analysis: National Consultants serve as the project's analytical engine, conducting data collection, market analysis, and drafting technical reports.
   - Validation: Sectoral Working Groups (SWGs) validate the consultants' findings. These groups represent a broad spectrum of stakeholders—including industry, finance, and end-users—ensuring that identified technologies are feasible and grounded in local reality.

1.3 Summary of the national context

The TNA is being conducted at a pivotal moment, following the submission of the enhanced Nationally Determined Contribution (NDC 3.0) (Ministry of Ecology and Natural Resources, 2025) in November 2025. This NDC 3.0 reflects a significant step-up in national

ambition and transparency, aligning Kazakhstan's development trajectory with the long-term goal of achieving Carbon Neutrality by 2060 (The Government of Kazakhstan, 2023).

The NDC 3.0 sets an unconditional target to reduce national net greenhouse gas (GHG) emissions by 17 percent below 1990 levels by 2035, and up to 25 percent with predictable, concessional, and technology-oriented international support. This commitment spans the 2026–2035 timeframe and covers all IPCC sectors and gases, with progress tracked against the most recent reported net emissions in the First Biennial Transparency Report (BTR). This commitment operationalizes national strategies—such as the Strategy on Achieving Carbon Neutrality by 2060 and the Action Plan for the Transition to a Green Economy—by establishing measurable sectoral targets and investment priorities. Kazakhstan's long-term climate policy is guided by the Strategy on Achieving Carbon Neutrality by 2060, which defines the national decarbonisation trajectory, outlining sectoral pathways and investment needs estimated at USD 610 billion to 2060. Indicative investment needs for climate action in the 2026–2035 period are estimated at about USD 175.6 billion (USD 128.5 billion for mitigation and USD 47 billion for adaptation), underscoring the TNA's critical role in identifying growth through innovation and modernization.

The TNA is directly aligned with a comprehensive "whole-of-government" approach to climate policy, supported by the following strategies and plans:

I. Foundational International Commitments

1. United Nations Framework Convention on Climate Change (UNFCCC) (Joined 1995)
2. Kyoto Protocol (Ratified 2009)
3. Paris Agreement (Ratified 2016)

II. Overarching National Strategies and Initiatives

1. **Strategy on Achieving Carbon Neutrality by 2060** (Approved February 2023): The decisive long-term climate policy.
2. **Roadmap for the Strategy on Achieving Carbon Neutrality by 2060**: The implementation plan detailing milestones and actions to achieve the 2060 goal. The roadmap is currently under development.
3. **Enhanced Nationally Determined Contribution (NDC 3.0)** (Submitted 2025): Sets the **17% unconditional** and **25% conditional** GHG emission reduction targets by 2035 (relative to 1990 levels) and integrates adaptation, loss and damage, and just transition principles.
4. **Concept for the Transition to a Green Economy** (Approved May 2013) **and its subsequent update under Presidential oversight**: The foundational concept guiding sectoral reforms towards sustainable development and resource efficiency (The Government of Kazakhstan, 2013).
5. **National Adaptation Plan (NAP)** (Forthcoming / Currently under Drafting): A crucial document that will define specific, long-term actions for climate resilience across four key sectors.
6. **National Development Plan to 2029**: Provides the medium-term economic and development planning context, to which the **NDC 3.0** and TNA are linked. The Action Plan for Transition to a Green Economy 2024–2030.

III. Core Regulatory and Sectoral Plans

1. **Environmental Code** (Updated in 2021): Provides the unified legal framework for environmental protection, emission regulation, and climate change adaptation mechanisms.

2. **Concept for the Management of All Types of Waste for 2026–2030** (Approved November 2025): The specific policy driving the shift to a circular economy and advanced waste processing technologies (The Government of Kazakhstan, 2025).
3. **Emissions Trading System (ETS)**: The domestic carbon market mechanism, central to achieving mitigation targets.
4. **Green Finance Programs**: Mechanisms supporting climate investments through green bonds, green loans, and other financial instruments, essential for mobilizing the estimated USD 175.6 billion investment needs for 2026–2035.

Energy Sector

According to the latest BTR (UNDP, 2025), the energy sector remains the dominant source of national GHG emissions due to Kazakhstan's continued reliance on fossil fuels. In 2022, it generated approximately 281.9 Mt CO_2e, representing the largest share of total emissions. This was 12.1% higher than in 2021, reflecting post-COVID economic recovery, but still 12.5% below 1990 levels.

Within the sector:

- Energy industries (electricity and heat generation) accounted for 44.7% (about 126 Mt CO_2e).
- Manufacturing industries and construction contributed 9.9% (about 27.8 Mt CO_2e), marking a sharp decline from the 2021 peak.
- Transport represented 9.92% (around 28 Mt CO_2e), continuing its upward trend due to rapid growth in the vehicle fleet.
- Fugitive emissions from oil, gas, and solid fuel extraction and transport remain significant, although they have declined since 1990 as a result of improved technologies and monitoring.

The greatest mitigation potential lies in transforming the power and heat generation mix and improving energy efficiency. Under NDC 3.0, the share of low-carbon electricity generation (including renewables, nuclear, hydropower, and gas with carbon capture and transitional fuels) is required to reach at least 35% by 2035. In particular, renewable energy is targeted to increase from 7.2% to 20% over the same period. In parallel, energy intensity of GDP is to be reduced by 20% by 2035 (relative to 2021). Accordingly, the mitigation TNA prioritizes low-carbon power and heat generation and energy-efficiency technologies that are critical for achieving these national targets.

Waste Sector

According to the latest First BTR (UNDP, 2025), in 2022, the waste sector emitted 6.9 Mt CO_2e, representing a 74.2% increase compared to 1990, largely driven by population growth and rising waste generation. Methane dominates the sector's emissions, accounting for 94% of the total. Wastewater treatment and effluent discharge contributed 51% (about 3.5 Mt CO_2e), while solid waste landfills accounted for 48% (around 3.3 Mt CO_2e).

The TNA directly supports the Concept for the Management of All Types of Waste for 2026–2030 by prioritizing methane capture, waste treatment, and recycling technologies, which are essential for the transition toward a circular economy.

Chapter 2 Technology prioritisation for Energy sector

As part of Task 1 of the Kazakhstan Technology Needs Assessments (TNA) Project being led by the United Nations Framework Convention on Climate Change (UNFCCC), we followed a systematic process to identify priority technologies for the energy sector. This process was guided by the methodology outlined in the TNA Step by Step Guidebook (UNEP-CCC, 2024), which consists of seven component steps (Figure 2.1). The first of these steps (Step 1.1) involves a comprehensive review of Kazakhstan's energy sector to establish a context for decision-making, addressing key issues, existing policies, infrastructure, long-term national goals, greenhouse gas (GHG) emissions, and environmental impacts.

To establish this context, we conducted an extensive desk review of national-level documents relevant to climate change mitigation and Kazakhstan's energy sector. This review covered Kazakhstan's Nationally Determined Contributions (NDCs), aiming for carbon neutrality by 2060, with targets to cut emissions by 15% (unconditional) and up to 25% (conditional on international support) by 2030 vs. 1990 levels, focusing on renewables, energy efficiency; and the National Communications to the UNFCCC, which provide information on energy-related emissions and mitigation actions reported in the past. In addition, the documents from the previous TNA project for Kazakhstan (The Ministry of Environment and Water Resources of Kazakhstan, 2013) (Ministry of Energy of the Republic of Kazakhstan, 2016) (Ministry of Energy of the Republic of Kazakhstan, 2017) have been examined to identify technologies that were previously prioritized, to evaluate the extent of their implementation, and to determine whether new or updated technologies are required in response to evolving national advancements and Energy strategy and policies (UNECE, 2025).

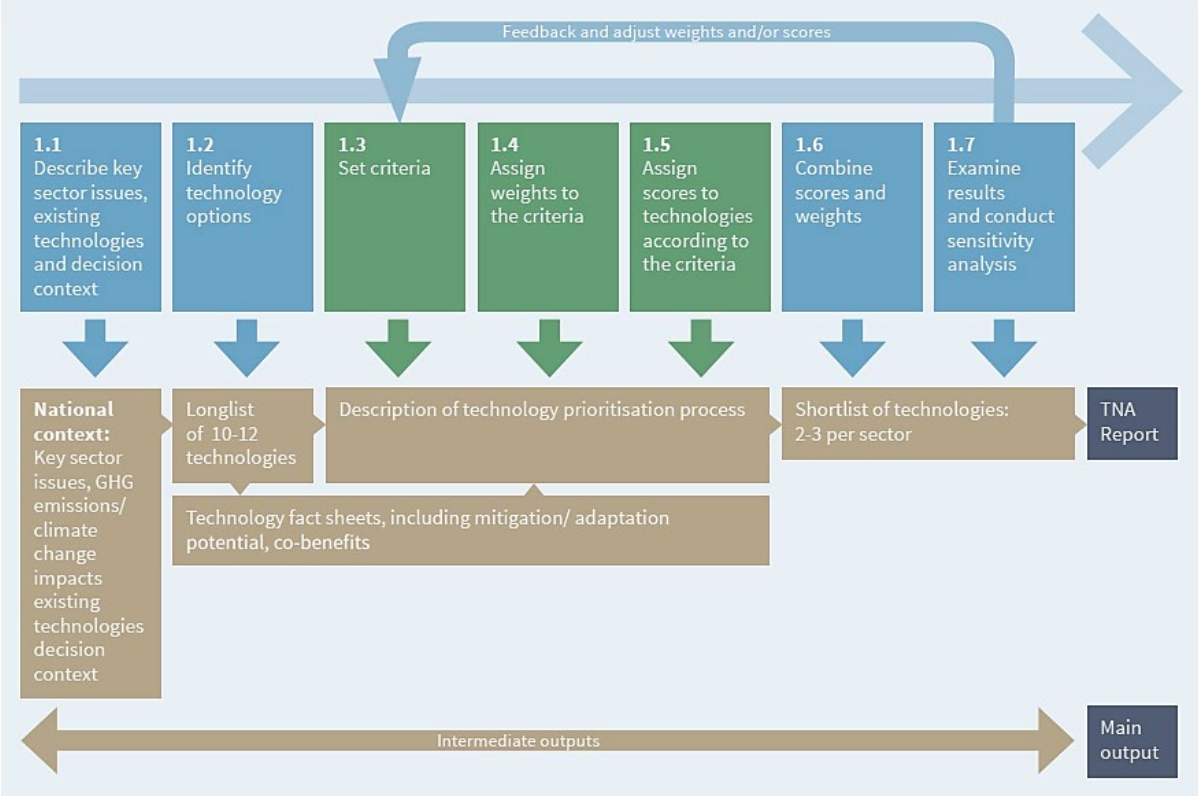


Figure 2.1. Seven steps in the technology prioritisation process **(UNEP-CCC, 2024)**

Alongside these national documents, the authors reviewed guidance materials issued by the UNFCCC on the TNA procedure, consulted technical literature (e.g., research papers) on energy sector mitigation technologies, reviewed reports by intergovernmental organizations (e.g., the UN, the World Bank, and Asian Development Bank), and examined relevant online

sources, including news articles reporting interviews with Kazakh officials, Ministry of Ecology and Natural Resources and Ministry of Energy representatives.

2.1 Technology options in Energy sector

Kazakhstan's electricity sector remains structurally dependent on fossil fuels, reflecting both its abundant domestic coal resources and the historical development of its power system. Coal-fired generation continues to serve as the backbone of national electricity supply, particularly for baseload demand in the northern and central regions of the country. Many coal power plants were commissioned between the 1960s and 1980s and operate with subcritical steam-cycle technology, resulting in relatively low thermal efficiencies—often in the range of 30–35%—and elevated greenhouse gas emissions per unit of electricity produced (IEA, 2023). Coal-fired generation typically emits approximately 0.9–1.0 t CO_2 per MWh, with additional emissions of sulphur dioxide, nitrogen oxides, and particulate matter contributing to local air quality impacts.

By comparison, modern natural gas combined-cycle gas turbine (CCGT) plants can achieve efficiencies of 55–60% and emit significantly less CO_2, typically ~0.35–0.5 t CO_2 per MWh under optimal conditions. Renewable energy technologies—wind, solar photovoltaic (PV), and hydropower—produce electricity with near-zero operational emissions, with life-cycle emissions generally below 50 g CO_2-eq per kWh for wind and solar, and often below 20 g CO_2-eq per kWh for hydropower, depending on site conditions (IRENA, 2021).

In 2023, Kazakhstan's total installed electricity generation capacity exceeded 24 GW, with annual electricity generation of approximately 115–120 TWh. Per capita electricity consumption stands at roughly 6,000 kWh per year, reflecting the country's energy-intensive industrial structure, including mining, metallurgy, oil and gas processing, and chemicals (IEA, 2023). Alongside the power sector, the transportation and building sectors remain major contributors to national greenhouse gas emissions. These sectors present substantial opportunities for emissions reductions through electrification, district heating modernization, improved insulation standards, and higher-efficiency appliances, all of which would increase electricity demand and reinforce the importance of low-carbon power generation.

Kazakhstan's electricity generation mix and capacity structure remains heavily skewed toward fossil fuels, as shown below (IRENA, 2024-2025):

- Coal-fired generation: 68%
- Natural gas: 14%
- Hydropower: 10%
- Solar PV: 5%
- Wind: 2%
- Other (bioenergy, pumped storage, small-scale technologies): 1%

Coal-fired plants contribute more than 70% of total power-sector CO_2 emissions, even as their share of installed capacity gradually declines. The average emissions intensity of Kazakhstan's electricity system is estimated at approximately 700–800 g CO_2 per kWh, significantly higher than the OECD average and well above levels compatible with long-term climate neutrality pathways (IEA, 2023).

To address these challenges, Kazakhstan has initiated a program of power plant modernization and efficiency upgrades. This includes rehabilitation of boilers and turbines, improved control systems, and selective fuel switching. In parallel, the expansion of combined-cycle gas turbine capacity is intended to replace the most carbon-intensive coal units and provide flexible generation during peak and shoulder-load periods. Such measures can reduce CO_2 emissions per MWh by up to 50% compared to legacy coal plants while also improving ramping capability and start-up times—key attributes for integrating variable renewable energy (IEA, 2023).

Natural gas–fired generation plays a strategic role in Kazakhstan's transition pathway. The country possesses substantial natural gas reserves, estimated at over 3 trillion cubic meters, although production and pipeline infrastructure are unevenly distributed geographically. Gas-fired plants, including fast-ramping open-cycle turbines, are increasingly used to balance supply and demand, manage renewable variability, and provide ancillary services such as frequency regulation. However, the long-term effectiveness of gas as a transition fuel depends on minimizing methane leakage, ensuring competitive gas pricing, and avoiding long-lived carbon lock-in (IRENA, 2021).

Solar and wind power deployment has expanded rapidly since the introduction of competitive renewable energy auctions in 2018. By 2024, installed solar PV capacity exceeded 1.5 GW, while wind capacity approached 0.8 GW, with projects concentrated in regions with high solar irradiation and favourable wind conditions. Levelized costs of electricity (LCOE) for new solar and wind projects have declined significantly, with recent auction prices falling below USD 40–50 per MWh, making renewables increasingly competitive with fossil-based generation (IRENA, 2024-2025).

Hydropower remains a cornerstone of Kazakhstan's low-emission electricity supply, particularly in the southern regions. Large hydropower plants provide stable generation and contribute to seasonal balancing, while small and medium hydropower projects offer additional localized supply. In some configurations, hydropower facilities support energy storage and load-following services, reducing the need for fossil-fuel-based peaking plants and enhancing grid stability as renewable penetration increases (IRENA, 2021). In 2022 installed generation capacity for hydropower reached 2808 MW.

A major structural shift in the generation mix is expected from the development of nuclear energy. Kazakhstan commenced construction of its first nuclear power plant, with a planned capacity of 2.4 GW, in August 2025. Nuclear power is anticipated to provide low-carbon baseload electricity with capacity factors above 85–90%, potentially displacing significant volumes of coal-fired generation once operational. Given Kazakhstan's position as the world's largest uranium producer—accounting for more than 40% of global uranium supply—the nuclear program also leverages domestic resource advantages (IEA, 2023).

Despite progress in generation diversification, grid infrastructure remains a limiting factor. Transmission bottlenecks, aging substations, and limited cross-border interconnections constrain efficient dispatch and renewable integration, particularly in remote or resource-rich regions. The national grid operator has identified the need for substantial investment in high-voltage transmission lines, digital monitoring systems, and enhanced regional interconnections to improve reliability and flexibility (KEGOC, 2022).

The Government of Kazakhstan has articulated decarbonization and energy transition objectives through national strategies and sectoral programs. These include modernization of existing thermal plants, accelerated renewable energy deployment, electricity market reforms, grid upgrades, and evaluation of advanced technologies such as carbon capture, utilization, and storage (CCUS) for coal-fired facilities. Collectively, these measures aim to reduce the carbon intensity of electricity generation, support economic competitiveness, and ensure the security and affordability of electricity supply during the transition (Ministry of Energy of the Republic of Kazakhstan, 2022).

2.1.1 Process of identifying technologies

The initial extended list of 40 technologies in the energy sector (see Annex 1) was developed based on the technologies database of the IGTIPC (International Green Technologies and Investment Projects Center). This database was complemented by proposals submitted by a dedicated working group, which included representatives of the Ministry of Energy, key industry experts, and a national expert. The formation of the extended list aimed

to ensure a comprehensive and balanced coverage of advanced and emerging energy technologies that are relevant to national priorities and global energy transition trends and mitigation efficiency.

The preliminary selection of technologies was conducted to enable the working group to evaluate a wide range of technologies.

As a result, the extended list comprised a diverse range of technology groups reflecting both supply-side and demand-side energy solutions. These groups included modernization of conventional power generation assets (coal generation), nuclear and gas-fired power plants, and renewable energy technologies such as wind power, solar photovoltaics, and small hydropower. In addition, the extended list covered emerging and cross-cutting solutions, including biofuels, hydrogen technologies, heat pumps, building energy management systems, electrification of private and public transport, and the application of artificial intelligence (AI) in the energy sector. This broad scope ensured that the extended list captured both established and innovative technologies across the entire energy value chain.

Following the development of the extended list, a structured shortlisting process was carried out through working group meetings and a formal selection procedure. The prioritisation exercise was implemented using Google Forms to ensure transparency, consistency, and ease of participation. The working group consisted of 14 members, each of whom was required to assess and prioritize the technologies independently. Participants assigned priority scores to each technology on a scale from 1 (lowest priority) to 10 (highest priority), based on their expert judgment and the agreed evaluation criteria.

All members of the working group (100% participation rate) completed the prioritisation procedure. The individual scores were aggregated, and each technology received a total number of points reflecting the collective assessment of the group. Based on the aggregated results, the technologies were ranked accordingly. The 11 technologies that achieved the highest overall scores were selected for the long list of energy technologies. Consequently, a final list of 11 priority technologies was established, forming the basis for further detailed analysis and subsequent stages of the Multi-Criteria Analysis (MCA).

2.1.2 Long list of technology options

The shortlist of energy technologies selected for the Multi-Criteria Analysis (MCA) encompasses a broad and well-balanced range of technology groups (Table 2.1). These include nuclear energy, energy storage systems, renewable energy technologies such as solar and wind power, small hydropower, grid development and modernization, electrification of private and public transport, as well as modernization of the conventional energy sector represented by natural gas combined cycle power plants. Together, these technology groups represent key components of a resilient, low-carbon, and efficient energy system.

Table 2.1. The long list of energy technologies

#	Name of the technology
1	Nuclear power
2	BESS and energy storage systems for regulation of renewable energy sources generation output profile
3	Power grid interconnection within Central Asia and Caucasus region
4	Small hydropower (<10 MW) in south and north-east Kazakhstan
5	Large scale on-grid solar farms (0.1-1 GW)
6	Energy management system in buildings for public sector
7	Electrification of urban public and municipal transport
8	Electric vehicles (EV) including the charging points grid

#	Name of the technology
9	Energy management system in buildings for private sector
10	Natural gas combined cycle power plants for flexible power grid supply
11	Large scale on-grid wind farms (0.1-1 GW)

The outcomes of the preliminary selection process strongly align with Kazakhstan's national energy and climate priorities, addressing the country's specific development needs and long-term strategic objectives. The listed technologies reflect a balanced focus on energy security, system reliability, decarbonization, and efficiency improvements, while also considering global trends in climate change mitigation and energy transition. Moreover, the long list ensures sufficient diversity across different technology categories, enabling a comprehensive and comparative assessment within the MCA framework and supporting informed decision-making for future energy sector development.

2.2 Technology prioritisation process

2.2.1 Setting criteria

For the final technology prioritisation process, the Simple Multi-Criteria Analysis (MCA) Tool was applied, using a total of 12 evaluation criteria (table 2.2). These criteria are grouped across six key domains: Cost, Technology Diffusion, Policy, Social, Climate, and Environment. This structured framework was selected to ensure a comprehensive and balanced assessment of each technology, capturing not only economic and technical considerations but also broader policy alignment, social implications, environmental and most important climate impacts. Applying these criteria allowed the working group to filter out technologies with limited applicability or insufficient maturity, while retaining those with strong potential for deployment and impact.

The evaluation criteria were initially selected based on key principles such as relevance, feasibility, measurability, and current applicability. These principles helped ensure that the criteria were practical and suitable for assessing technologies within the national context. As a result, the final set of criteria covered all major dimensions of technology evaluation, including economic aspects, the country's readiness level, policy alignment, social considerations, as well as environmental and climate impacts.

The criteria were then reviewed and refined through a series of working group meetings and a structured evaluation process conducted using Google Forms. This approach allowed experts to provide feedback in a clear and consistent manner. Comments and suggestions from working group members were carefully considered and, where appropriate, incorporated into the final report.

2.2.2 Assigning weights

The Energy Working Group was involved in the process of assigning weights to the evaluation criteria. The working group consisted of 14 participants, all of whom contributed to this process by independently assigning a weight to each criterion on a scale from 1 (lowest importance) to 10 (highest importance). This approach ensured that the weighting process reflected a broad range of expert perspectives and sectoral experience.

All members of the working group (100% participation) completed the criteria weighting process. The individual scores assigned by participants were aggregated, and each of the 12 criteria received a total number of points based on the input of the group members. These total scores were then normalized to derive the final weights for each criterion. The resulting weights (table 2.2) represent a consensus-based assessment of the relative importance of the criteria and were subsequently applied in the MCA Analysis to support transparent and

balanced technology prioritisation. It can be seen that all criteria obtained similar weight in the range of 8-9 points except social gender impact.

Table 2.2. Criteria and weights for the Simple MCA Tool

Category	Criteria	Weight	Scoring scale	Type
Technology diffusion	3. Technology implementation country readiness level	9	126	qualitative
Policy	6. Compliance with national development policies and priorities	9	124	qualitative
Environment	10. Reduction of air pollution	9	124	qualitative
Technology diffusion	4. Market potential/economic growth	9	123	quantitative
Social	8. Access to energy/Quality of energy service/Energy safety	9	123	qualitative
Climate impacts	12. GHG emission reduction	9	121	quantitative
Technology diffusion	5. Complexity of implementation	9	120	qualitative
Cost	1. Capital cost (CAPEX)	8	119	quantitative
Cost	2. Annual operational expenses (OPEX)	8	119	quantitative
Social	9. Creation of new jobs	8	117	quantitative
Environment	11. Biodiversity/general environment impact	8	114	qualitative
Social	7. Gender impact	5	67	qualitative
Sum		100		

It can be seen that climate impacts criteria has got similar weight in comparison with other criteria despite it has high priority according to the TNA process. This deficiency was addressed in the sensitivity analysis of the assessment result, which is described below.

2.2.3 Scoring

Each technology is being evaluated against each criterion by the Energy Working Group (see Annex 4), with the National Consultant acting as a facilitator to guide discussions, consolidate inputs, and ensure methodological consistency. The assessment process involves expert deliberations and the use of standardized evaluation tools to support objective and balanced decision-making. Comprehensive descriptions of the technologies, along with all assumptions, data sources, and parameters applied in the evaluation, are documented in the Technology Fact Sheet (TFS) section (see Annex 2), which provides the technical and analytical basis for the scoring exercise.

The evaluation framework distinguishes between two types of criteria: quantitative and qualitative. Quantitative criteria include: 1. Capital cost (CAPEX), 2. Annual operational expenses (OPEX), 4. Market potential and economic growth, 9. Creation of new jobs, and 12. GHG emission reduction. These criteria are assessed using numerical data and measurable indicators. All other criteria are qualitative and are evaluated based on expert assessments, policy relevance, and contextual considerations. The full set of quantitative values for all technologies is available in the TFS (see Annex 2), allowing stakeholders to review and verify the underlying data.

Technologies are scored on a scale from 0 to 100 for each criterion, where 100 indicates the highest level of performance relative to that criterion. This scoring system enables a clear comparison among technologies. However, for certain criteria—specifically 1. Capital cost (CAPEX), 2. Annual operational expenses (OPEX), and 5. Complexity of implementation—the scoring logic is reversed. Under these criteria, a score of 0 corresponds to the highest cost or complexity (i.e., the least favorable outcome), while a score of 100 corresponds to the lowest cost or complexity (i.e., the most favorable outcome). This approach maintains coherence across the evaluation results, ensuring that higher scores consistently reflect better overall performance.

2.3 Prioritised technologies for Energy sector

Prioritized technologies for Energy sector were performed by MCA analysis by applying the criterion weights by multiplying the scores in each column. The result of the prioritization is presented in the final decision matrix (Table 2.3).

2.3.1 Combining scores and weights

The total scoring and decision process is visible in the three working matrices (Performance, Scoring, and Decision, see Annex 3).

The Performance matrix contents initial indicators and values of each technology against each criterion. The matrix is based on a clearly defined and agreed set of criteria, which are listed at the top of the table and form the basis for comparison across all technologies. Stakeholders participating in the process provided consensus-based scores for each technology against every criterion and its corresponding indicators.

Scoring matrix represents normalized values of the initial indicators.

Within the Decision matrix, each criterion is applied, and the associated indicators are weighted in accordance with the predefined criterion weights. These weights are subject to final review, approval, and confirmation by the key stakeholders who participated in the workshop. For the 11 technologies under consideration, performance scores are recorded on a standardized scale ranging from 1 to 10, enabling a clear and comparable assessment of relative performance and well reflects the prioritisation outcomes.

2.3.2 Result examination and sensitivity analysis

As the final criteria weights were very close to one another, a sensitivity analysis was conducted to test the robustness of the prioritisation results. The purpose of this analysis was to assess how changes in the weighting of key criteria could influence the overall ranking of technologies and to better understand the impact of priority assumptions on the final outcomes.

Given that the initiative's objective is focused specifically on climate aspects, priority will be given to the climate agenda.

For the sensitivity analysis, two domains: Economy, and Environment and Climate were selected for increased emphasis, reflecting their strategic importance. Within the Economy criteria group, the weights assigned to Capital Expenditure (CAPEX) and Annual Operational Expenditure (OPEX) were increased from 9 to 20. Similarly, within the Environment and Climate criteria group, the weights for the criteria related to reduction of air pollution and greenhouse gas (GHG) emission reduction were increased from the initial range of 8-9 to 20. To maintain balance within the overall framework, the weights of all other criteria were adjusted accordingly. Final scoring table is represented in the Table 2.3.

Table 2.3. Final technology scores based on decision matrix

Technology	Climate scenario		Standard (equal weights) scenario		Economy scenario	
	Score	**Ranking**	**Score**	**Ranking**	**Score**	**Ranking**
Large scale on-grid solar farms (0.1-1 GW)	8046	1	7110	1	7603	1
Energy management system in buildings for private sector	7399	2	6067	2	5630	5
Large scale on-grid wind farms (0.1-1 GW)	6909	3	5902	3	6409	2
Energy management system in buildings for public sector	6810	5	5602	4	5163	7
Electric vehicles (EV) including the charging points grid	6825	4	5257	5	5725	4
Nuclear power	5292	9	5239	6	5544	6
Electrification of urban public and municipal transport	6661	6	5150	7	5151	8
BESS and energy storage systems for regulation of renewable energy sources generation output profile	6130	7	4823	8	3697	9
Small hydropower (<10 MW) in south and north-east Kazakhstan	3224	11	4330	9	5984	3
Power grid interconnection within Central Asia and Caucasus region	5090	10	4196	10	2900	10
Natural gas combined cycle power plants for flexible power grid supply	5476	*8*	3920	11	2729	11

The results of the sensitivity analysis are also demonstrated in the figure below. The changes in weight values are shown in relative units for each technology, numbered from 1 to 11. This visualization illustrates the effect of the adjusted weighting scheme on technology rankings and supports a clearer interpretation of the stability and reliability of the MCA results.

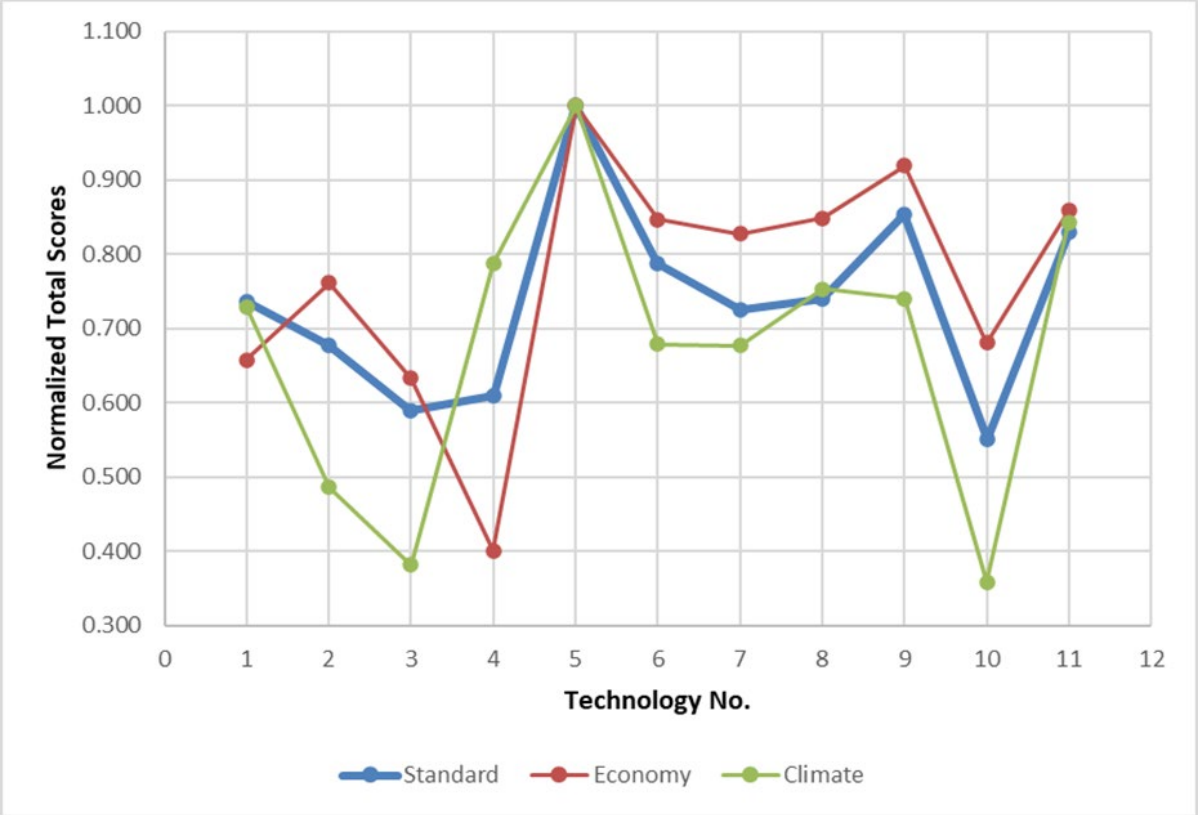


Figure 2.2. Sensitivity analysis results for three scenarios in energy sector – initial (standard), economy preference and climate preference

The climate sensitivity scenario revealed that several technologies are particularly responsive to changes in climate- and environment-related weighting. The most sensitive technologies under this scenario include: #2 Battery Energy Storage Systems (BESS) and other energy storage solutions for regulating the output profiles of renewable energy sources; #3 Power grid interconnections within the Central Asia and Caucasus region; and #10 Natural gas combined-cycle power plants designed to provide flexible support to the power grid. These technologies show notable negative shifts in score when greater emphasis is placed on greenhouse gas emission reductions and air pollution mitigation, highlighting their relative weakness in climate-focused policy frameworks.

Under the economic sensitivity scenario, #4 Small hydropower plants (below 10 MW) in southern and north-eastern Kazakhstan emerged as the most sensitive technology. This indicates that changes in the weighting of capital and operational cost criteria have a significant influence on the relative attractiveness of small hydropower, reflecting its strong dependence on investment costs and long-term economic performance.

It can be seen that #5 Large scale on-grid solar farms (0.1-1 GW) has highest score for all three scenarios.

The top-ranked technologies are presented in Table 2.4. Their selection is based on the results of the standard MCA assessment as well as the two sensitivity analysis scenarios, considering that the climate scenario has the priority according to the TNA process and the country National energy strategy (The Government of Kazakhstan, 2023) This combined approach ensures that the final prioritisation is robust and accounts for different strategic perspectives. Overall, the results reflect a balanced consideration of Kazakhstan's national needs, the current level of technology acceptance, economic feasibility, and potential climate impact.

Table 2.4. Final top-ranked technologies for the Energy Sector

Technology	Total score	Ranking
5. Large scale on-grid solar farms (0.1-1 GW)	1.000	1
11. Large scale on-grid wind farms (0.1-1 GW)	0.843	2
4. Small hydropower (<10 MW) in south and north-east Kazakhstan	0.787	3

The technologies presented in the table 2.4 can be recommended for following development within TNA process.

At the same time, several other technologies that did not reach the highest ranking remain promising for implementation in Kazakhstan. In particular, technologies related to grid interconnection, energy efficiency and energy-saving measures, as well as modernization of conventional power generation, demonstrate strong potential and could play an important role in the country's medium- to long-term energy sector development.

Chapter 3 Technology prioritisation for Waste sector

3.1 Technology options in Waste sector

While the energy sector remains the primary source of national emissions, the waste sector represents a critical area for targeted mitigation due to its significant contribution to non-CO2 greenhouse gases, particularly methane. According to recent national inventory data, the waste sector accounted for approximately 2.0% of total national GHG emissions (UNDP, 2025). The sector faces substantial challenges related to fragmented regulatory measures, systemic inefficiencies in recycling/recovery rates, the sheer volume of waste generation, and the legacy of historical unsanitary landfilling practices.

To facilitate the identification of mitigation technology options for the waste sector, a preliminary selection of suitable technologies was compiled based on a systematic desk review of Kazakhstan's waste sector infrastructure and related policies, paralleling the approach conducted for the energy sector (see *Section 2.1*). This review encompassed national climate policies, strategic national documents submitted to the UNFCCC, existing waste sector infrastructure in Kazakhstan, previous Technology Needs Assessments (TNAs) and Technology Action Plans (TAPs), technical literature, and guidance materials on the selection of waste management technologies from intergovernmental organizations, such as the United Nations, World Bank, and Asian Development Bank. A synthesis of national priorities, strategies for climate mitigation, and the current state of the waste sector in Kazakhstan is presented below. Subsequent sections 3.1.1 and 3.1.2 outline the process of identifying these technologies and the resulting prioritized long list.

National Priorities for Climate Mitigation in the Waste Sector

Kazakhstan has identified waste management as a central element of its climate change mitigation strategy and broader transition towards a green economy. The waste sector is included in the country's updated NDC, the Concept for Transition towards a Green Economy, and the Environmental Code adopted in 2021. Collectively, these policies establish a framework that seeks to transform the sector from a predominantly linear "collection–disposal" model into a circular economy system that prioritizes prevention, reuse, recycling, and recovery (PAGE, 2020).

Specific Targets for the Waste Sector

Several quantifiable targets have been adopted to guide the transformation of the waste sector:

- **Recycling of Municipal Solid Waste:** Increase the recycling rate to 40 percent by 2030 and 50 percent by 2050 (Khavratova, 2021). The 2024 update to this concept strengthened these goals, targeting 50% recycling by 2040 and 60% by 2050 (UNDP, 2025). At the end of 2025, the "Concept for the Management of All Types of Waste for 2026–2030" was adopted (The Government of Kazakhstan, 2025), targeting a reduction of at least 10 percent in the volume of municipal waste sent to landfills.
- **Population Coverage with Waste Collection and Disposal:** Achieve universal coverage (100 percent) by 2030, compared with current levels of approximately 70–80 percent, with gaps particularly evident in rural areas (Mustafina, 2021).
- **Landfill Compliance with Environmental Standards:** Ensure that 95 percent of landfills comply with sanitary and environmental regulations by 2030. Presently, only about one-fifth of Kazakhstan's 2,600–3,000 registered landfills meet these standards.
- **Industrial Waste Recycling:** Reach a recycling/utilization rate of 44 percent for industrial waste by 2024, as specified in the Strategic Plan of the Ministry of Ecology, Geology and Natural Resources (Mustafina, 2021). However, this goal was not achieved, with the actual

recycling and utilization rate recorded at 27.5 percent. Consequently, this target has been revised under the "Concept for the Management of All Types of Waste for 2026–2030," which shifts the focus toward a 10 percent incremental increase in reused volumes rather than the previous fixed percentage (Government of Kazakhstan, 2025).

- **Wastewater Treatment:** Emissions from wastewater treatment and discharge totaled 3.5 million tonnes CO_2e in 2022 (UNDP, 2025). Kazakhstan aims to increase the treatment of anthropogenic wastewater to 45% by 2030, 65% by 2040, and achieve 100% treatment by 2050 (Ministry of Ecology and Natural Resources, 2025).

Phased Bans on Landfilling Specific Waste Types

To reduce methane emissions and incentivize recycling, Kazakhstan has introduced phased prohibitions on the landfilling of specific waste categories. These bans are an integral part of the Environmental Code and are being implemented progressively:

- Since 2016, the disposal of mercury-containing items, scrap metal, used oils and liquids, batteries, and electronic waste has been prohibited.
- Since 2019, bans have extended to plastics, paper, cardboard, and glass.
- Since 2021, the disposal of food and construction waste has also been prohibited.

These measures aim to divert large waste streams from landfills, stimulate the development of recycling enterprises, and promote investment in alternative waste treatment technologies, including Waste-to-Energy facilities.

Strategies and Measures for Implementation

To achieve its ambitious targets, Kazakhstan is pursuing a mix of regulatory, economic, and technological measures:

- **Waste-to-Energy (WtE):** The Environmental Code establishes WtE as a strategic tool. In 2021, auctions were held for six incineration plants with a combined capacity of 100 MW, designed to reduce landfill volumes while generating electricity.
- **Extended Producer Responsibility (EPR):** Introduced in 2016, the EPR system obliges producers and importers to finance the recycling of waste generated from their products. Since 2022, the state-owned company **Zhasyl Damu JSC** has operated the system, channeling funds to recycling enterprises and infrastructure development.
- **Investment and Infrastructure Development:** Plans are in place to construct 37 new waste processing plants and modernize 8 existing facilities, thereby increasing processing capacity to 1.5 million tons annually (ITA, 2024). Preferential loans at 3 percent interest are provided to businesses in waste sorting, recycling, and transportation. Infrastructure for separate collection is being expanded nationwide.
- **Strengthening Regulation and Oversight:** The Environmental Code requires licensing of waste processing companies, GPS monitoring of waste transport vehicles, and space-based monitoring to identify illegal dumpsites.

Current State of the Waste Sector in Kazakhstan

Currently, Kazakhstan's waste sector is undergoing gradual transformation under the framework of the Concept for Transition to a Green Economy and the Environmental Code. While ambitious targets have been set, progress remains slow. The sector continues to face systemic issues in both solid waste management and wastewater treatment, limiting its contribution to national climate change mitigation goals.

Types of Waste Managed

The sector handles multiple waste streams, classified by origin, nature, and management method. Key categories include:

- **Municipal Solid Waste:** 4.5–5 million tons annually, primarily generated from households, commerce, and institutions (egov.kz, 2023). Food waste (31%), paper (25%), and plastics (11%) dominate the waste composition (Orazbekov, 2025). Economic growth and urbanization are expected to increase volumes.
- **Industrial Solid Waste:** Exceeds 1 billion tons annually, with a cumulative total of 31.6 billion tons, making it the largest waste stream in terms of both scale and environmental impact (Zhanbyrshin, 2025). This waste primarily originates from mining and processing industry by-products, such as overburden, ash, and man-made mineral formations.
- **Hazardous Waste:** Includes chemical residues, mercury-containing items, batteries, and electronic waste, managed both by dedicated and merchant plants.
- **Wastewater Treatment Sludge:** Residual waste from wastewater treatment plants, has a very high water content in its original form.
- **Clinical Waste:** Potentially infectious waste from healthcare institutions.

Waste Management Infrastructure and Practices

Collection: In 2021, waste collection services covered 70% of the population (100% in large cities, lower in rural areas) (Mustafina, 2021). By 2023, 808 specialized companies were operating, with universal coverage targeted for 2030 (Orazbekov, 2025).

Landfills: Landfilling remains the primary disposal method (Zhanbyrshin, 2025); approximately 80% of MSW goes to landfills without sorting or recycling (IEA, 2022). Out of 3,292 landfills in 2020, only 18.2% met sanitary standards (Orazbekov, 2025). In 2023, 3,016 landfills existed, with compliance modestly increasing to 21% (624) (Kwan, 2024). Illegal dumping remains widespread, with 4,868 unauthorized sites identified in 2023, only 32% of which were eliminated (Kwan, 2024). Total landfill volumes reached 48.3 million tons in 2024, with annual increases of 10% to 12% that significantly outpace population growth.

Recycling and Sorting: Kazakhstan aims for 100% sorting of municipal solid waste by 2040 and is implementing separate collection systems. The recycling rate was 24% in 2023, far below targets (Kwan, 2024). Although separate collection was introduced in 94 cities/districts and sorting lines were installed in 80 settlements as of late 2020 (egov.kz, 2023), utilization of sorting capacity remained low (19% in 2023) (Orazbekov, 2025).

Gaps and Challenges in Waste Management

Despite policy reforms, the sector continues to face structural challenges:

1. **High Methane Emissions from Landfills**
   - Methane is the predominant GHG in Kazakhstan's waste sector, accounting for 94% of its emissions, which primarily originate from unmanaged landfills and wastewater discharge.
   - The gradual increase in methane emissions, particularly from these unmanaged landfills, presents a significant challenge for reducing the sector's overall GHG contribution.
2. **Low Recycling Rates and Infrastructure Deficiencies**
   - Recycling remains well below targets due to inadequate collection, sorting, and processing infrastructure.
   - Planned construction of 37 new plants and modernization of 8 existing facilities is expected to address capacity gaps.
3. **Non-Compliant Landfills and Illegal Dumping**
   - Around 80% of landfills do not meet environmental standards, posing environmental and public health risks. The government has committed to raising compliance to 95% by 2030, a target that will require large-scale investments, stricter enforcement, and public-private partnerships.

- Illegal dumpsites persist despite satellite monitoring and enforcement efforts.

4. **Insufficient Waste Sorting**
   - Lack of source separation severely limits recycling effectiveness, reducing potential recovery rates from 50% to as little as 5–7% (Khavratova, 2021).
   - Public awareness and environmental education remain inadequate.
5. **Economic and Financial Barriers**
   - Low Tariffs: Waste collection tariffs often fail to cover operational costs. Artificially suppressed utility tariffs that range from USD 0.60–1.50 per capita per month.
   - Limited Financing: High commercial loan rates hinder investment, despite preferential financing schemes.
6. **Weak Market for Secondary Raw Materials**
   - Recycling companies face difficulties in selling the secondary raw materials they produce due to lack of regulatory mechanisms such as mandatory recycled content standards.
7. **Fragmented Governance and Limited Competition**
   - Regulatory responsibilities are spread across multiple ministries, creating inefficiencies.
   - State-owned enterprises dominate the sector, constraining private sector engagement.

Gaps and Challenges in Wastewater Treatment

Compared to solid waste, wastewater management receives less attention in national reporting, but significant deficiencies exist:

- **Infrastructure Deficits:** Much of the wastewater system relies on outdated Soviet-era infrastructure, inadequate for modern urban demand. Coverage remains uneven, particularly in rural areas and informal settlements.
- **Pollution and Water Quality Risks:** Untreated or poorly treated effluents from households and industries are a major source of water pollution, affecting rivers, lakes, and groundwater.
- **Need for Modernization and Investment:** Rehabilitation of wastewater infrastructure is urgent. The establishment of pollutant-specific treatment facilities for industrial zones and the integration of green or nature-based solutions are recognized as priorities.
- **Policy Alignment:** Kazakhstan's NDC highlights the need to increase population coverage with wastewater treatment services, particularly in urban areas.

3.1.1 Process of identifying technologies

The technology long list was developed through a two-phase process. First, a preliminary selection of suitable technologies was compiled based on the aforementioned systematic desk review of Kazakhstan's waste sector infrastructure and related policies. This desk study provided a robust foundation for assessing national circumstances within Kazakhstan's waste sector and for informing subsequent steps in technology identification and prioritization. Accordingly, the identification of technology options focused on solutions capable of delivering necessary benefits, primarily mitigating methane emissions and advancing the national transition toward a circular economy. The initial list of potentially beneficial technologies was then refined in coordination with the National TNA Team into an expert-derived extended list of 24 technologies (see Annex 5), categorized into five key areas: improved waste collection, energy and material recovery, engineered waste disposal, legacy dumpsite rehabilitation, and wastewater treatment.

Then, the extended list of 24 technologies was presented to relevant stakeholders for a formal consultation process. This process involved an online meeting to present the

methodology and the technologies, followed by the distribution of an online questionnaire. Along with the questionnaire, we provided a complementary document with brief descriptions for each technology to ensure a clear understanding. Stakeholders were asked to score the 24 technologies based on their perceived suitability. The questionnaire results and stakeholder feedback were analyzed by sectoral experts, and technologies deemed too costly, technically immature for the region, or redundant relative to existing infrastructure were screened out, thereby establishing the consolidated long list.

3.1.2 Long list of technology options

Based on stakeholder consultations and survey analysis, the 12 technologies with the highest potential for climate change mitigation in Kazakhstan's waste sector have been identified. Table 3.1 presents the list of these technologies along with their respective scores and rankings.

Table 3.1. The long list of waste technologies

No.	Name of the technology	Stakeholder Score (%)
1	Integrated Remote Sensing and GPS-Based Vehicle Tracking System for Illegal Dumpsite Detection and Waste Transport Control	82.5
2	Anaerobic digestion of sewage sludge in municipal wastewater treatment plants for energy production	81.7
3	Extraction of metals from industrial waste using integrated mechanical and hydrometallurgical processes	79.4
4	Circular Economy-Based Management of Construction and Demolition Wastes, Metallurgical Slags, and Mining Wastes to Recover Resources for the Construction Sector	78.6
5	Transition from a dual-stream to a multi-stream waste separation system to improve material recovery efficiency in urban areas	76.2
6	Enclosed Composting of Organic Fraction of Municipal Solid Waste and Other Biomass Types in Urban Areas	76.2
7	Organic fraction of municipal solid waste and other types of biomass for biogas production	76.2
8	Open-air composting in rural areas	73.0
9	Alternative fuels from waste (RDF) for industrial processes and power plants	73.0
10	Sanitary landfills with methane recovery systems for generating renewable energy	73.0
11	Collection and use of landfill gas from Existing Landfills via retrofitting for generating electricity and heat	69.0
12	Remediation of Legacy Dumpsites (leachate control and biological oxidation of diffuse methane emissions via biocovers)	65.9

The national consultants prepared technology factsheets (TFS), one for each of the shortlisted 12 technologies in the waste sector, for circulation amongst stakeholders. TFS for long listed technologies in the Waste Sector were given in Annex 6.

3.2 Technology prioritisation process

3.2.1 Setting criteria

The establishment of criteria for the Multi-Criteria Analysis (MCA) was an iterative and participatory process, designed to align with the UNEP-CCC TNA Step-by-Step Guidebook while rigorously addressing the specific operational context of Kazakhstan's waste sector.

The criteria selection began with a review of national strategic documents, including the Green Economy Concept and the Environmental Code, to identify key performance indicators relevant to the waste sector. Next, a preliminary framework was presented to the Sectoral Working Group (SWG) and key stakeholders through a comprehensive online survey. This consultation allowed stakeholders to evaluate the relevance of proposed indicators and suggest refinements.

Following the analysis of stakeholder feedback, the initial set of criteria was refined to better capture critical local factors. For instance, feedback highlighted the need to distinguish between upfront investment capabilities and long-term operational sustainability. Consequently, the economic dimension was split into distinct Capital (CAPEX) and Operational (OPEX) cost metrics. Similarly, to ensure the selected technologies are viable in Kazakhstan’s severe continental climate, a specific focus on Technology Readiness (TRL) and Replicability was integrated.

In its final form, the criteria developed for the MCA process consisted of 7 Main Categories and 10 Sub-categories. These ten criteria were selected to ensure a holistic evaluation of each technology's life-cycle performance. Cost factors were split into distinct capital and operational expenditure metrics. Technical criteria focused on the maturity of the solution (TRL) and its adaptability to local conditions, particularly the severe continental climate. The category of Economic benefits comprises the broader economic impact of the technology by assessing its long-term financial viability, market competitiveness, and potential for revenue generation through resource recovery, alongside its capacity to stimulate national employment. Environmental and social indicators were included to measure pollution prevention, job creation, and public health benefits, while a dedicated climate criterion quantified the specific GHG mitigation potential. Governance category assesses the technology's alignment with Kazakhstan’s national climate strategies and legal frameworks, evaluating the availability of enabling regulations, administrative feasibility, and the robustness of institutional monitoring systems. The detailed definitions and assessment scope for each criterion are presented in Table 3.2.

Table 3.2. Criteria for the Simple MCA Tool.

Main Category	Sub-category/ Criterion	Description and Assessment Scope	Assessment Method
1. Cost of Waste Treatment	**1.1. Annualized Capital Cost (CAPEX)**	Details the direct financial requirements for initial investment. The metric is the annualized capital expenditure per metric ton of waste processed (EUR/ton/year), calculated over a specific planning horizon (e.g., 15 years). A higher score indicates lower costs.	Quantitative (EUR/ton/year)
	1.2. Annual Operational Cost (OPEX)	Measures the recurring annual expenses required to operate the technology, expressed as operational expenditure per metric ton of waste processed (EUR/ton/year). A higher score indicates lower costs.	Quantitative (EUR/ton/year)

2. Technology Diffusion	**2.1. Technology Readiness Level (TRL)**	Assesses the maturity and proven performance of the technology using the standardized nine-level TRL metric, ranging from basic research (TRL 1) to fully proven operational systems (TRL 9).	Mixed (100-900)
	2.2. Ease of Implementation and Replicability	Evaluates the enabling environment for deployment in Kazakhstan, including ease of installation, maintenance, and scalability. It assesses the availability of qualified personnel and supply chains, identifying risks associated with the severe continental winter and the potential for mobilizing financing (e.g., PPPs).	Qualitative (1-5)
3. Economic Benefits	**3.1. Economic Viability**	Qualitatively assesses long-term financial sustainability by evaluating market demand for recovered outputs (materials, energy) and competitiveness. It considers financial metrics (e.g., Payback Period), reliance on subsidies, and avoided costs (e.g., reduced remediation expenses).	Qualitative (1-5)
	3.2. Job Creation Potential	Quantifies the direct economic benefit of the investment by estimating the contribution to nationwide employment generation resulting from the technology's implementation and operation.	Quantitative (Total number of jobs)
4. Environmental Benefits	**4.1. Pollution Prevention and Environmental Protection**	Offers a holistic assessment of performance in minimizing contamination to air, water, and soil. It covers the management of process residues, compliance with environmental standards, land-use requirements, and potential ecosystem impacts.	Qualitative (1-5)
5. Social Benefits	**5.1. Social Co-benefits**	Evaluates impacts on public health, safety, and quality of life (e.g., odor reduction). It addresses social equity, including poverty reduction, inclusion of vulnerable groups, and the level of community participation required.	Qualitative (1-5)
6. Climate Related	**6.1. Climate Mitigation Potential**	Quantifies the reduction in net Greenhouse Gas (GHG) emissions, expressed in CO_2 equivalent (tCO_2e) per ton of waste processed. This is determined using a Life Cycle Assessment (LCA) approach, accounting for direct reductions and avoided emissions via resource recovery. Scoring considers the total mitigation potential in absolute numbers under realistic conditions.	Quantitative (tCO_2e/t)
7. Governance	**7.1. Compliance with National Targets and Legislation**	Analyzes alignment with Kazakhstan's national climate strategies and legal frameworks. It assesses the existence of enabling regulations, administrative feasibility, permitting processes, and the robustness of monitoring and enforcement systems.	Qualitative (1-5)

3.2.2 Assigning weights

Weights of the criteria were assigned using a two-step hierarchical methodology. First, raw importance scores (1-10) from the stakeholder consultation (questionnaire results) were transformed into scores from (1-9) and then normalized to assign a 'Global Weight' to each of the 7 main criterion categories. Second, for categories with multiple sub-criteria, this Global Weight was effectively distributed among the sub-criteria proportional to their specific stakeholder scores. This ensured that the number of sub-criteria in a category did not artificially

inflate that category's overall importance. Finally, weights used for MCA calculated based on normalized questionnaire scores are given in Table 3.3.

Table 3.3. MCA criterion weights

Main Categories	Criterion	Total Score	Normalized Average Score (%)	Normalized Average Score (%) for main categories	Global Weights (%) for main catergories	Normalized Average Score (%) for sub-categories	Sub-category Weights	Assigned Weight (Linear)
1. Costs	1.1 Annualized Capital Cost (CAPEX)	120	84.1	84.1	84.13	84.1	7.34	7.35
	1.2 Annual Operational Cost (OPEX)					84.1	7.34	7.35
2. Technology Diffusion	2.1. Technology Readiness Level (TRL)	118	82.5	80.2	13.99	82.5	7.20	7.2
	2.2. Ease of Implementation	112	77.8			77.8	6.79	6.8
3. Economic Benefits	3.1. Economic Viability	119	83.3	81.0	14.13	83.3	7.20	7.2
	3.2. Job Creation Potential	113	78.6			78.6	6.79	6.8
4. Environmental Benefits	4.1. Pollution Prevention and Environmental Protection	125	88.1	88.1	15.37			15.4
5. Social Co-Benefits	5.1. Social Co-benefits	114	79.4	79.4	13.85			13.9
6. Climate Related	6.1. Climate Mitigation Potential	116	81.0	81.0	14.13			14.1
7. Governance	7.1. Compliance with National Targets and Legislation	114	79.4	79.4	13.85			13.9
							Total:	100.0

Note that main criterion category '1. Costs' also divided into 2 sub-criterion category (1.1 Capital Costs and 1.2 Operational Costs) and the weight of these sub-categories were calculated by dividing the global weight of category 1 into 2 in the final MCA scoring matrix.

3.2.3 Scoring

The performance of each shortlisted technology was evaluated against the defined criteria (Table 3.2) using a standardized scoring system to ensure comparability. All criteria were assessed on a scale of 0 to 100, where 100 represents the highest level of performance or desirability. This uniform scale allows for a clear and direct comparison across diverse technological options, with the complete scoring matrix provided in Annex 7.

For quantitative criteria based on measurable data—including annualized capital and operational costs, technology readiness levels, job creation, and climate mitigation potential—a linear interpolation method was employed. This mathematical approach converts raw physical values into normalized scores, ensuring that performance is rated relative to the best-performing technology in the group. To maintain coherence, an inverse scoring logic was applied to criteria representing expenditures (i.e., 1.1 CAPEX and 1.2 OPEX). In these instances, a score of 0 corresponds to the highest cost, while a score of 100 indicates the lowest, ensuring that higher numerical values consistently reflect a more favorable outcome regardless of whether the underlying metric is a benefit or a barrier.

Criteria that could not be measured in physical units, such as economic viability, pollution prevention, social co-benefits, and legislative compliance, were evaluated qualitatively on a scale of 1 to 5. These assessments relied on expert judgment and stakeholder consensus, with descriptive performance levels mapped to specific numerical values on the 0–100 scale as described above for quantitative criteria. This methodology integrates institutional readiness and social acceptance into the Multi-Criteria Analysis framework, providing a holistic evaluation of each technology's viability within the national context.

3.3 Prioritized technologies for Waste sector

3.3.1 Combining scores and weights

The shortlisted 12 technologies were subjected to a detailed Multi-Criteria Analysis (MCA) to determine prioritized technologies for the waste sector. This primary analysis was conducted using weights derived directly from stakeholder consultation to reflect national preferences and local context. Detailed decision matrices for this base case can also be found in Annex 7.

The primary Multi-Criteria Analysis (MCA), conducted using weights derived directly from stakeholder consultation, identified "Multi-stream Waste Separation" as the highest-ranked technology (Technology 5), achieving a normalized score of 100% (corresponding to a numerical total score of 6967; see Annex 7). Its leading position is largely driven by its exceptional performance in socio-economic categories; specifically, it received maximum scores (100/100) for Job Creation Potential and Social Co-benefits. This reflects a strong stakeholder preference for technologies that support the circular economy and public engagement, even if they come with higher operational costs.

The runner-up, "Anaerobic Digestion of Sewage Sludge" (Technology 2), followed closely with a score of 97%. It had perfect scores in Pollution Prevention and Climate Mitigation. However, its ranking was slightly constrained by operational expenditures (OPEX), which penalized it in the cost-weighted categories compared to the labor-intensive but socially beneficial separation technology. It should be noted that 'costs' for anaerobic sludge digestion were calculated per ton of total solids—that is, based on the dry weight of the input material—whereas the input materials for all other technologies have significantly higher moisture levels. The "Sanitary Landfills with Methane Recovery" (Technology 10) ranked third with a score of 95%, serving as a reliable baseline improvement over current predominant practices of uncontrolled dumping of municipal solid waste.

3.3.2 Result examination and sensitivity analysis

To test the robustness of the rankings determined in the base MCA case, three sensitivity analysis scenarios—Economy-Focused, Environment/Climate-Focused, and Equal Weights—were executed by selectively increasing the weighting of prioritized categories while redistributing the remaining influence proportionally relative to specific stakeholder scores, or by applying a neutral, uniform weight across all main criteria categories to simulate varying strategic emphases. Top five technologies with the highest scores based on the base case results, along with the rankings of the sensitivity analyses conducted based on three different criteria weighting scenarios, are presented in Table 3.4. Additionally, the variation in normalized total scores across all four weighting scenarios (the Base case & the three sensitivity analysis runs) is visually summarized in Figure 3.1. Detailed matrices showing the results of the three sensitivity analyses are given in Annex 8.

Table 3.4. Top-ranked technologies for the Waste sector and the sensitivity analyses

Rank	Base MCA Case with Weights based on Stakeholder View	Economy Focused Sensitivity Analysis	Environment /Climate Focused Sensitivity Analysis	Sensitivity Analysis with Equal Weights
1	5. Multi-stream Waste Separation	2. Anaerobic Digestion of Sewage Sludge	2. Anaerobic Digestion of Sewage Sludge	1. Integrated Remote Sensing and GPS-Based Vehicle Tracking System

2	2. Anaerobic Digestion of Sewage Sludge	5. Multi-stream Waste Separation	5. Multi-stream Waste Separation	10. Sanitary Landfills with Methane Recovery
3	10. Sanitary Landfills with Methane Recovery	1. Integrated Remote Sensing and GPS-Based Vehicle Tracking System	10. Sanitary Landfills with Methane Recovery	5. Multi-stream Waste Separation
4	1. Integrated Remote Sensing and GPS-Based Vehicle Tracking System	10. Sanitary Landfills with Methane Recovery	1. Integrated Remote Sensing and GPS-Based Vehicle Tracking System	2. Anaerobic Digestion of Sewage Sludge
5	6. Enclosed Composting of Organic Fraction of MSW	4. Circular Economy-Based Management of C&D and Mining Wastes and Metallurgical Slags	7. Organic Fraction of MSW for Biogas Production	4. Circular Economy-Based Management of C&D and Mining Wastes and Metallurgical Slags

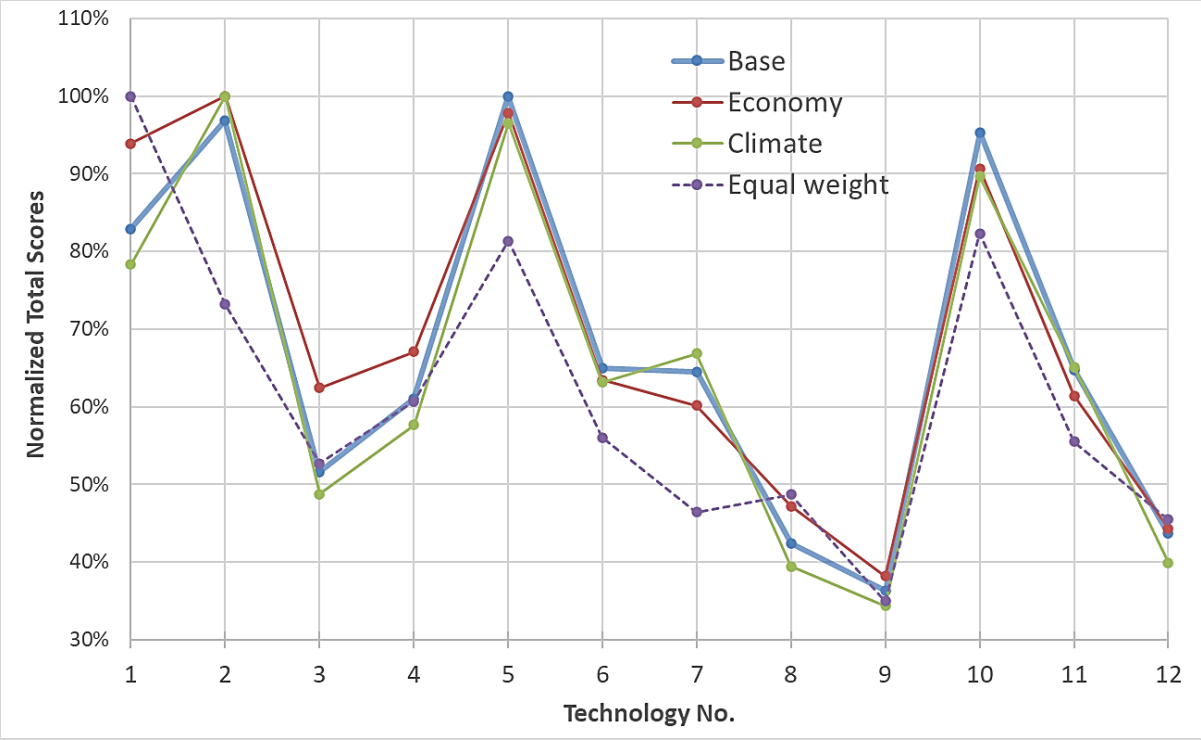


Figure 3.1. Normalized total scores of waste sector technologies under the Base MCA and 3 sensitivity analysis scenarios

As illustrated in Figure 3.1, the top-tier technologies demonstrated varying degrees of resilience to these weighting changes. In the Economy-Focused scenario, where weights for Capital/Operational Costs and Economic Viability were significantly increased (totaling approx. 36% of the decision power), "Anaerobic Digestion of Sewage Sludge" rose to Rank 1 with a perfect score of 100%. This technology's ability to generate revenue (energy) makes it the economic winner, while "Integrated Remote Sensing (GPS)" (Technology 1) jumped to Rank 3 (94%), highlighting its value as a cost-effective governance tool in budget-constrained scenarios.

In the Environment/Climate-Focused scenario, where Pollution Prevention and GHG Emission Reduction dominated the matrix, "Anaerobic Digestion of Sewage Sludge" again

secured Rank 1 (100%), confirming its status as the superior option for environmental targets, while "Multi-stream Waste Separation" remained competitive at 97%. This scenario confirms the mitigation potential of these technologies, aligning with the primary climate objectives of the TNA.

Notably, the Equal Weight scenario, which applies a neutral weighting structure across all main criteria categories, produced a unique result: "Integrated Remote Sensing and GPS-Based Vehicle Tracking System" took Rank 1 with a score of 100%. This indicates that when the heavy weighting on "Job Creation" and "Social Benefits" (which favored Multi-stream Separation) is removed, the low-cost and high-implementability of the GPS system allows it to outperform complex infrastructure projects statistically, causing the base-case winner (Technology 5) to drop to 81%.

A broader examination of the quantitative results reveals a distinct stratification among the 12 evaluated options. Technologies 2, 5, and 10 consistently maintained scores above 90% across the stakeholder-weighted scenarios (Base, Economy, and Climate), indicating a robust consensus on their utility regardless of the specific strategic lens applied. Conversely, Technologies 8, 9, and 12 consistently scored below 50% in all scenarios (ranging between 34% and 49%), suggesting fundamental weaknesses in their suitability for the current national context that cannot be overcome by re-weighting criteria.

The analysis reveals a distinct trade-off between social, technical, and governance objectives. "Multi-stream Waste Separation" remains the preferred choice when prioritizing employment and circular economy principles, aligning closely with the current stakeholder consensus. However, "Anaerobic Digestion of Sewage Sludge" emerges as the most robust 'heavy' infrastructure technology, capturing the top spot in both economic and environmental stress tests despite its high-cost scores. Consequently, a balanced Technology Action Plan should likely prioritize Multi-stream Separation to meet social targets, while simultaneously advancing Anaerobic Digestion projects for climate mitigation and utilizing the GPS Tracking System as an immediate, low-cost governance quick win.

Chapter 4 Summary and Conclusions

This report, TNA Report I, details the technology prioritization process led by the National TNA Team and Sectoral Working Groups. Utilizing the established TNA methodology, experts initially developed extended lists of 40 Energy (Annex 1) and 24 Waste (Annex 5) technologies. These were subsequently refined into long lists of 11 Energy and 12 Waste technologies, leading to the creation of 23 detailed Technology Fact Sheets (TFSs) (Annexes 2 and 6). Each TFS provides critical data on technical parameters, impact statements, and financial requirements, while also identifying implementation constraints related to geographic location, climate, and infrastructure. This level of detail provides a vital visualization of the practical potential for each climate technology.

The prioritization was finalized through a Multi-Criteria Analysis (MCA) and a supplementary sensitivity analysis, conducted in accordance with the TNA handbook. While the sensitivity analysis included numerous sensitivity analysis scenarios for comparative robustness, the final selection process remained firmly grounded in the climate-focused and stakeholder-weighted scenarios to ensure the primary objective of GHG mitigation is met alongside national development goals. This rigorous assessment confirmed that the top-performing technologies deliver a high degree of climate mitigation potential while simultaneously offering significant socio-economic co-benefits. Consequently, a short list of prioritized technologies was established where, per project guidelines, the top three technologies in each sector are recommended for immediate progression to the Barrier Analysis and Enabling Framework (BAEF) and Technology Action Plan (TAP) stages. The key output

of this initial stage is the short list of prioritized technologies, as presented in Table 4.1 and Table 4.2.

Table 4.1. Short list of technologies for energy sector in Kazakhstan

No	Mitigation Technology for Energy Sector	Result
1	Large-scale on-grid solar farms (0.1–1 GW)	Recommended for BAEF/TAP
2	Large-scale on-grid wind farms (0.1–1 GW)	Recommended for BAEF/TAP
3	Small hydropower (<10 MW) in south and north-east Kazakhstan	Recommended for BAEF/TAP

Table 4.2. Short list of technologies for waste sector in Kazakhstan

No	Mitigation Technology for Waste Sector	Result
1	Multi-stream waste separation	Recommended for BAEF/TAP
2	Anaerobic digestion of sewage sludge	Recommended for BAEF/TAP
3	Sanitary landfills with methane recovery	Recommended for BAEF/TAP

The short lists of priority technologies identified above are inextricably linked to a wide spectrum of economic, social, environmental, and political factors. Consequently, the subsequent TNA steps, including the BAEF and the development of TAPs, will be tailored to address the specific requirements and localized challenges of these chosen sectors. These TAPs will serve as national roadmaps designed to integrate seamlessly into government planning and create a robust pipeline of bankable programs and projects.

Ultimately, the results of this TNA project will be instrumental in the operationalization of the country's decisive long-term climate policies, including the *Strategy on Achieving Carbon Neutrality by 2060* and the *Enhanced Nationally Determined Contribution (NDC 3.0)*. By informing efficient GHG reduction pathways, this report provides the technical evidence base necessary to mobilize the significant investment needs estimated for the 2026–2035 period.

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Annex 1: Extended list of technologies (energy sector)

#	Extended list of technologies for energy sector
1	Natural gas combined cycle power plants for flexible power grid supply
2	Coal power plants gasification transition technology
3	CO_2 capture and storage for coal power plants
4	Gas micro power plant of cogeneration type with heat recuperation
5	Nuclear power
6	Power grid interconnection within Central Asia and Caucasus region
7	Old coal power plants with energy efficiency improvement
8	Large scale on-grid solar farms (0.1-1 GW)
9	Roof-top solar PV for private sector
10	Roof-top and ground base solar PV for public sector
11	Parallel electricity production from solar and wind power installations
12	Solar water heating technology for rural areas
13	Large scale on-grid wind farms (0.1-1 GW)
14	Off-grid small wind and solar power supply systems for rural areas
15	Agriculture biogas plants with electricity production in internal combustion engines
16	Mechanical and biological treatment of organic fraction of municipal solid waste (MSW) with biogas production
17	Production of biomethane with delivery to natural gas distribution grid
18	Production and use of ethanol as a motor fuel for road transport
19	Production and use of biodiesel as a motor fuel for road transport
20	The use of CNG and bio-CNG for road transport including public buses and municipal vehicles
21	Bio-LNG based biofuel production and use for heavy duty road transport
22	Small hydropower (<10 MW) in south and north-east Kazakhstan
23	Wave power plant in Caspian Sea
24	Geothermal power plant (>100 MW) in south and south-west Kazakhstan
25	Electrolysis system of hydrogen supply for internal combustion engines based on renewable power
26	Mini factories for green hydrogen production
27	Cavitation method of generating hydrogen in water flows
28	Burner technology for combustion of natural gas with hydrogen additive
29	Water-based lithium-ion battery production and use in energy systems
30	BESS and energy storage systems for regulation of renewable energy sources generation

#	Extended list of technologies for energy sector
31	Heat pumps for heating and cooling for public sector
32	Heat pumps for heating and cooling for private sector
33	Old multi-store buildings renovation with energy efficiency measures
34	Energy management system in buildings for public sector
35	Energy management system in buildings for private sector
36	Monitoring and control of heating, hot and cold-water supply systems for buildings
37	Electrification of urban public and municipal transport
38	Electric vehicles (EV) including the charging points grid
39	Electric motorbikes with special charging points grid development
40	System for managing industrial enterprise processes based on the use of artificial intelligence

Annex 2: Technology Factsheets for selected technologies (energy sector)

TFS-E-01:

Technology	#1 Nuclear power
Introduction	Nuclear power is among the most advanced, efficient means of generating large-scale electricity with a very small greenhouse-gas footprint. It relies on fission of heavy nuclei (primarily uranium-235 or plutonium-239), whose neutron-induced split releases heat to produce steam that drives turbines and generators. A nuclear plant operates like a fossil-fuel facility, but heat comes from controlled fission in the reactor core. Uranium fuel rods undergo fission under regulation by control rods that absorb excess neutrons. A coolant—typically water or liquid metal—removes heat and moderates neutrons to maintain a stable reaction. The heated coolant produces steam in a steam generator, which turns turbines; steam is condensed and reused. Modern reactors include robust safety features and containment structures to prevent radiation release. A key advantage is a very low carbon footprint; reactors emit virtually no CO_2 during operation. A tiny uranium pellet contains as much energy as a ton of coal or three barrels of oil, giving high energy density for reliable, large-scale power. Despite these challenges, advancements in next-generation reactor designs and small modular reactors (SMRs) promise safer, more flexible, and more efficient systems. With continued innovation and responsible regulation, nuclear power could play a crucial role in providing clean, stable energy for the future.
Technology characteristics/highlights	• Energy Density: 1 g of uranium fuel ≈ energy of 1 ton of coal or 3 barrels of oil • Efficiency (Capacity Factor): ~83% • Global Reactors (2024): 417 operational reactors producing 377 GW(e) • Annual Electricity Output (2024): ~2,667 TWh (~9% of global total) • Typical Reactor Lifetime: 40–60 years (many extended to 80 years with upgrades) • Waste Volume: <3% of total industrial hazardous waste globally
Country specific applicability and potential	Kazakhstan holds about 14% of global uranium resources, produced roughly 23,270 t U in 2024, and historically operated the BN-350 fast-breeder reactor from 1972 to 1999, with no commercial nuclear plant since; electricity generation remains heavily coal-based (about 60–70%) and there is growing pressure to decarbonize, improve energy security, and meet rising demand. Nuclear power is applicable for energy security and baseload capacity, with the IAEA noting Kazakhstan's interest in diversifying its energy mix; leveraging domestic uranium could move the country up the

	value chain from mining/export to internal generation and possibly fuel fabrication, and supporting its carbon-neutrality goal by 2060 alongside renewables. The Ulken site near the Zhambyl/Almaty region is expected to spur economic and regional development with jobs and investment. The potential plant targets about 2.4 GW(e) of capacity by the mid-2030s, with a cost estimate of US$10–15 billion, and public support was demonstrated by the October 2024 referendum, in which over 70% favored construction.
Status of technology in country	• Kazakhstan has officially begun engineering and geological surveys for its *first modern nuclear power plant* to be constructed near Ulken in the Almaty region (Zhambyl district) under a consortium led by Rosatom. • The selected reactor technology: Two Generation III+ VVER-1200 reactors (each ~1,200 MW) are planned for the first unit (total capacity ~2.4 GW). • The government has approved the area for NPP construction and plans to select a vendor/consortium by July 2025, and conclude intergovernmental & contract agreements by November 2025.
Benefits to economic / social and environmental development	**Economic Benefits**: Nuclear power would diversify Kazakhstan's energy mix (coal ~65%, gas ~20%), enhance energy security with a planned 2.4 GW Ulken plant, and enable value-chain development from uranium mining to enrichment, fuel fabrication, and generation. It would create thousands of jobs, stimulate domestic manufacturing, and position Kazakhstan as a regional energy hub by allowing electricity exports during peak demand. **Social Benefits**: The program would build human capital—nuclear engineers, physicists, and safety experts—through partnerships with IAEA and foreign institutions, while infrastructure around Ulken would be modernized; public engagement is evident in the 2024 referendum with over 70% in favor. By 2030 (during late construction and early operation): a few thousand people employed on the project at any given time (up to 5,000). **Environmental Benefits**: Kazakhstan's carbon-neutrality goal by 2060 would be aided by near-zero CO2 emissions in operation; a 1 GW reactor could offset 6–8 million tonnes of CO2 annually, improving air quality and reducing health costs. Nuclear's smaller land footprint and continuous output, along with designs such as VVER-1200 with closed-loop cooling, minimize water use and thermal pollution.
Climate change mitigation benefits	Kazakhstan aims for carbon neutrality by 2060 under its Strategy for Achieving Carbon Neutrality (2023). With coal accounting for over 60% of electricity, nuclear power would replace high-emission baseload with a reliable, zero-carbon

	alternative. A 1 GW reactor can displace 6–8 Mt CO2 annually; a planned 2.4 GW Ulken plant could cut national emissions by about 15–18 Mt CO2 per year once operational (mid-2030s), comparable to removing more than 3 million passenger vehicles from the road.
Financial Requirements and Costs	• Total CAPEX for 2.4 GW likely between ~US$5.5 billion (low, aggressive vendor/Chinese offer) and US$13–20+ billion (mid-to-high, western/overrun scenarios). Use mid planning band US$8–13B for conservative budgeting. Most modern projects are estimated to fall between **USD 5,000/kW.** • Annual OPEX (mid case): expect roughly US$400–600 million / year for combined fixed O&M + fuel & variable O&M (depends on staffing and fuel arrangements). The average OPEX is **USD 90 per kW** • Indicative LCOE: ~US$40–100 / MWh depending on CAPEX, O&M, financing; achieving the low end requires very competitive CAPEX, low financing cost, and efficient O&M. • Global averages for new nuclear LCOE (cost per kWh over the plant life) are typically in the 8–12 cents USD per kWh, with a broad range from about 5–7 c/kWh in favourable conditions to 15–20 c/kWh in higher-cost environments • Market potential for the first nuclear power plant is **15 billion USD.** Three power plants are announced to be built **(45 billion USD)**
Advantages/Disadvantages	**Advantages** • Zero-carbon, cuts 6–8 Mt CO_2/yr per GW (2.4 GW **– 20 Mt CO_2/yr)**; • High-skill jobs, local industry growth; • Reliable baseload, supports renewables; • Education, global cooperation. **Disadvantages** • Long-term waste storage challenge; • High CAPEX (US $5–15 B) & long payback; • Long construction (8–12 yrs); • Public concern, regulatory complexity.

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TFS-E-02:

Technology	#2 BESS and energy storage systems for regulation of renewable energy sources generation output profile
Introduction	As renewable energy expands, managing variable output has become a key grid challenge. Battery Energy Storage Systems (BESS) address this by providing flexibility and real-time balance between generation and demand. A BESS stores energy in rechargeable batteries—primarily lithium-ion, but also sodium-sulfur, flow, and emerging solid-state chemistries. A typical system comprises battery modules, power conversion systems (inverters/converters), a battery management system, and grid-integrated control software. These components enable energy to be stored for later release or absorbed to meet grid needs. In renewables applications, BESS perform energy shifting: storing surplus when generation exceeds demand and discharging during low production to smooth the output, improve predictability, and boost reliability. They also provide services such as frequency regulation, voltage control, and spinning reserve, responding rapidly to fluctuations to stabilize frequency and prevent outages. This capability allows renewables to participate in ancillary service markets, increasing their value and integration. Advances are making BESS more efficient, compact, and affordable. Smart controls and predictive algorithms optimize charge-discharge cycles to maximize lifespan, while ongoing research targets better battery materials, longer life, and recycling to enhance sustainability. Ultimately, BESS bridge intermittent generation and a stable grid, enabling higher renewable penetration and a more resilient, clean-energy system.
Technology characteristics/highlights	• Fast response time: BESS can respond to grid fluctuations within milliseconds, enabling rapid frequency regulation and balancing of renewables. • High round-trip efficiency: Modern lithium-ion systems achieve 85–95% efficiency, minimizing losses during charge/discharge. • Scalability and modularity: Systems scale from small behind-the-meter installations (kWh) to grid-scale units (hundreds of MWh). • Energy and power flexibility: Configurable for short-duration, high-power needs or long-duration energy shifting. • Integration with renewable plants: Co-locate with solar or wind farms to firm output and reduce curtailment. • Advanced control and monitoring: Intelligent energy management and predictive algorithms optimize operation and enable remote diagnostics.

	• Environmental and operational benefits: No direct greenhouse gas emissions, quiet operation, and low maintenance. • Evolving technology landscape: Ongoing advances in chemistries (solid-state, flow) and cost reductions improve safety, lifespan, and viability.
Country specific applicability and potential	Kazakhstan has strong potential for Battery Energy Storage Systems (BESS) to support its growing renewables. Its vast territory and resources, coupled with ambitious targets, create challenges and opportunities for grid storage. With coal and gas still dominant, renewables are set to reach at least 15% of generation by 2030, mainly from wind and solar. Regional variability and uneven population distribution make grid balancing a key issue. BESS can stabilize frequency, reduce curtailment, and boost reliability, especially when paired with solar in the south (Kyzylorda, Turkestan) and wind in the north/central (Akmola, Kostanay). Distributed or hybrid storage can lower transmission costs and improve rural energy access, given the high costs of grid expansion.
Status of technology in country	Kazakhstan is at the pilot stage for large-scale BESS, with a ~7.5 MW system at a Kokshetau substation testing grid integration. To support a higher renewables share, KEGOC estimates a minimum of 3 GW of storage capacity. International agreements are advancing: Masdar (UAE) and Samruk Kazyna plan BESS development up to ~2 GW alongside renewable projects up to ~500 MW. A BESS manufacturing/assembly plant in Kazakhstan has been agreed between the government (via the Ministry of Artificial Intelligence & Digital Development) and Clearbrook Energy Solutions and AG Tech, with investment ~USD 350 million. Envision Energy is building a factory to produce wind turbines and about 1 GWh of storage annually (2 GW wind + 1 GWh storage) as part of localization efforts.
Benefits to economic / social and environmental development	**Economic Benefits**: BESS enhances grid efficiency and resilience by reducing curtailment and stabilizing supply, boosting ROI (Return on Investment) for solar and wind. A local manufacturing/assembly sector—developing with international partners—will boost domestic production, create high-skilled jobs, enable technology transfer, and reduce imports, strengthening energy security. It also opens ancillary-service revenues for utilities and IPPs. **Social Benefits**: Storage improves reliability and power quality in rural and remote grids. Hybrid renewables-plus-storage can provide uninterrupted electricity to isolated communities, supporting regional development and digital inclusion. Local manufacturing and training centers (e.g., Nazarbayev University Energy Storage Competency Center) will build a

	skilled workforce, attract youth, and promote education, innovation, and diversification from fossil fuels. Estimated total jobs by 2030 (cumulative, direct + indirect, including early O&M): roughly 12,000 jobs. **Environmental Benefits:** BESS supports emissions reductions and higher renewable shares by smoothing generation and reducing fossil-fuel peaking. It optimizes energy use and reduces waste and air pollution; recycling and second-life use will further lower the footprint. A flexible, low-carbon grid improves air quality and health while reducing water use.
Climate change mitigation benefits	Energy storage reduces renewable curtailment by storing excess generation for use during higher demand, maximizing clean power and lowering CO2 per kWh while reducing reliance on coal-fired peaker plants. It provides rapid grid balancing, cutting emissions by avoiding inefficient fossil backup in standby. Systemically, BESS accelerates decarbonization as renewables expand; electrification of industry, transport, and heating rises, amplifying climate benefits across the economy.
Financial Requirements and Costs	Early utility project (import-heavy) • Size: 100 MW / 400 MWh (4-hour system) • CAPEX assumption: $320 / kWh (imports, remote site) • Total CAPEX = 400,000 kWh × $320 = $128 million. • For a 4-hour system, the total cost for the power component would be approximately (192 kWh*4 hours=**USD 768 per kW**) • Fixed O&M (1.5% of CAPEX) ≈ $1.92 million / year (~$4.80/kWh-yr when normalized to energy capacity), (**per 1 KW ~ 12 USD**) • Variable O&M & other costs ≈ $0.5 – $1.5 million / year. • Total OPEX ≈ $2.4 – $3.4 million / year (≈ $6 – $8.5 / kWh-yr). • Levelized cost of storage (LCOS) over the project life: roughly $ 0.20 per kWh stored, depending on storage duration (4–8 hours), utilization, and financing.
Advantages/Disadvantages	**Advantages** Provides rapid response for frequency and voltage regulation. Reduces curtailment and enables smoother renewable generation profiles. Strengthens reliability in remote or weak-grid regions. It is expected to reduce annual CO_2 emissions by more than 0.5 Mt CO_2/yr Attracts foreign investment and partnerships (e.g., Masdar, EBRD, ADB ~5 GW installed capacity). Market potential is about **5 billion USD**. **Disadvantages** Requires advanced grid management systems and trained personnel for integration.

	Limited duration (typically 1–4 hours) restricts long-term or seasonal storage capability. High initial CAPEX (USD 220–380 per kWh in Kazakhstan). Battery replacement adds future costs. Requires significant grid investment for large-scale integration and coordination.

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TFS-E-03:

Technology	#3 Power grid interconnection within Central Asia and Caucasus region
Introduction	The Central Asia and Caucasus region faces rising demand for reliable, sustainable, and efficient power systems to support growth and energy security. Strengthening cross-border grid interconnection among Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan, Azerbaijan, Georgia, and Armenia is essential for regional resilience. Modernization enables upgrading aging infrastructure, integrating renewables, and expanding cross-border electricity trade. Core enablers are HVDC (High-Voltage Direct Current) and FACTS (Flexible Alternating Current Transmission Systems: HVDC allows long-distance, low-loss transmission to link remote renewables (hydropower in Kyrgyzstan and Tajikistan, wind/solar in Kazakhstan) with demand centers; FACTS improve AC stability and controllability for safe cross-border exchanges. Smart-grid technologies—digital monitoring, automation, and communication—optimize energy flow and real-time coordination. Advanced sensors, SCADA (Supervisory Control and Data Acquisition), and AI (Artificial Intelligence) analytics help predict demand, prevent outages, and manage variable renewables. EMS (Energy Monitoring System) and WAMS (Wide Area Management Systems) across borders provide a unified view for coordinated dispatch and emergency response. Renewable integration drives flexible, resilient grids with battery storage, pumped hydro, and demand-side management, supported by digital twin modelling and grid simulations for planning. Cybersecurity and data protection become integral, with encryption, segmentation, and real-time threat detection to secure exchanges. Overall, strengthened regional interconnection is a strategic investment in energy security, economic cooperation, and sustainability, enabling a more connected, efficient, and cleaner power system.
Technology characteristics/highlights	• HVDC Transmission • Efficient long-distance, low-loss links between countries. • Connects asynchronous grids for interoperability. • Improves stability with controllable flow and frequency regulation. • Scalable for linking remote renewables to regional demand centers. • FACTS • Dynamic voltage and reactive power control boosts reliability and reduces outages. • Optimizes power flow across networks. • Increases transmission capacity on existing lines without new infrastructure.

	• Smart Grid and Digitalization • Real-time monitoring, automation, sensing, IoT (Internet of Things), and SCADA to detect faults and optimize flow. • AI analytics forecast demand and renewable output for proactive management. • Secure, rapid data exchange via advanced communications between control centers.
Country specific applicability and potential	Kazakhstan plays a central role in advancing regional power-grid interconnection across Central Asia and the Caucasus. As the region's largest energy producer with abundant resources and a growing renewables sector, it is well positioned to be both supplier and transit hub for cross-border electricity, strengthening national diversification and regional energy security. Its grid, already extensive and connecting to Russia, Kyrgyzstan, Uzbekistan, and China, needs modernization to support rising renewables and long-distance transfers, with HVDC and FACTS essential for efficient interconnection and stability. Smart grids, advanced control systems, and real-time monitoring will help balance flows and stabilize the network amid variable generation. Kazakhstan's significant wind and solar potential—strengthening the Caspian Green Energy Corridor—aims to export clean power from Central Asia and the Caucasus to Europe via high-capacity HVDC links and submarine cables under the Caspian Sea to Azerbaijan and Georgia. Participation would diversify export routes, leverage regional synergies, attract investment in grid modernization and storage, and accelerate decarbonization toward carbon neutrality by 2060. Through strengthened interconnections, Kazakhstan can shape a more resilient regional network and serve as a pivotal energy bridge between Central Asia, the Caucasus, and Europe.
Status of technology in country	Kazakhstan maintains strong interconnections with Russia and growing links to Kyrgyzstan and Uzbekistan via CAPS (Central Asian Power System), though southern grid sections were temporarily isolated due to aging assets; modernization programs supported by the ADB (Asian Development Bank) and World Bank are upgrading substations, transmission lines, and protection to restore synchronization and regional reliability. KEGOC (Kazakhstan Electricity Grid Operating Company) is deploying Smart Grid elements (SCADA/EMS) and digital substations, with Wide Area Monitoring Systems using PMUs (Phasor Measurement Unit) to improve real-time visibility and stability; integration of FACTS is under consideration to better manage voltage and extend long-distance transmission. Renewables are expanding, with wind and solar contributing over 6% of generation in 2025 and a 15% target for 2030; to address intermittency, pilots in Battery Energy Storage, automated demand management, and other flexibility measures are being pursued. Kazakhstan leads the Caspian Green Energy Corridor, developing HVDC

	links and Caspian submarine cables to Azerbaijan and Georgia for European exports, with feasibility and design advancing under EU support. Digitalization and cybersecurity are accelerating, with KEGOC investing in data analytics, predictive maintenance, and cybersecurity, and establishing a National Energy Dispatch Center for integrated monitoring and coordination.
Benefits to economic / social and environmental development	**Economic Benefits**: Expanding cross-border interconnections increases export revenue by selling surplus renewables to neighbors and Europe; the Caspian Green Energy Corridor positions Kazakhstan as a regional green-power hub. Attracts foreign investment through HVDC, smart grids, and digital substations, enabling PPPs (Public-Private Partnership) (and tech transfer. Improves grid reliability and efficiency by reducing losses and outages, boosting industrial competitiveness. Drives jobs and industrial growth in renewables and grid infrastructure, plus local manufacturing. **Social Benefits**: Better energy access and reliability in rural areas, raising living standards. Strengthens regional cooperation and stability via shared infrastructure. Builds workforce capacity through modernization and new-energy training. Supports digital services in health, education, and public administration. Cumulative jobs through 2030 (construction + operations + supply chain): around 6,000–12,000 **Environmental Benefits**: Accelerates decarbonization by integrating wind, solar, and hydro; supports 2060 carbon neutrality. Reduces fossil-fuel dependence and improves air quality. Enables efficient cross-border use of renewables, minimizing curtailment. Enhances climate resilience with a flexible, digitally managed grid.
Climate change mitigation benefits	Modern HVDC lines, FACTS, smart grids, and energy storage enable efficient integration of Kazakhstan's wind and solar resources, linking the Caspian, central, and southern zones to demand centers to replace coal with clean electricity and raise renewable penetration. Cross-border interconnections allow exporting surplus renewables and importing lower-carbon power during peak demand, with the Caspian Green Energy Corridor facilitating clean exports to the Caucasus and Europe and reducing regional emissions. Upgraded conductors, digital substations, and automated controls cut technical losses, boosting transmission efficiency and lowering fuel use and emissions. A stronger, flexible grid

	supports gradual coal retirements while renewables, storage, and demand-side management lower the national carbon footprint in line with Paris Agreement goals. Digitalized, interconnected grids enhance resilience to heatwaves, droughts, and extreme weather through better monitoring, analytics, and grid flexibility, ensuring reliable clean energy.
Financial Requirements and Costs	• **Near-term incremental reinforcement** to support renewable integration and reliability: **~USD 0.12–0.42B CAPEX**, modest OPEX. • **National modernization** to enable large internal transfers and regional exports: **~USD 0.9–3.2B CAPEX**, OPEX ~3% of CAPEX annually. • **Full Caspian Green Energy Corridor export build-out** is a major infrastructure program: **USD 1.5–9+B (1.3 GW ~ 7 USD/kW)** depending on route and capacity; expects OPEX at **~1–5% (0.35 USD/kW)** of CAPEX annually with higher unit O&M for subsea components. • **Weighted average:** ~3.5 cents/kWh across key interconnection projects, rounded to **3.2–4.0 cents/kWh** for range variability.
Advantages/Disadvantages	**Advantages** Boosts electricity trade and export revenues. It is expected to reduce annual CO_2 emissions by more than 0.2 Mt CO_2/yr Attracts foreign investment and creates jobs. Improves efficiency and lowers energy losses. Supports large-scale renewable integration. Strengthens Kazakhstan's regional energy role. **Disadvantages** High upfront capital costs. Long payback period and financing risks. Complex system coordination. Possible land use and ecological impacts during construction.

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TFS-E-04:

Technology	#4 Small hydropower (<10 MW) in south and north-east Kazakhstan
Introduction	Kazakhstan has strong potential for small hydropower (SHP, <10 MW), especially in the southern (Almaty, Zhambyl, Turkestan) and north-east (East Kazakhstan) regions where mountains and rivers support renewable generation. SHPs can improve electricity access in rural areas, reduce transmission losses, and advance a greener economy. In the south, rivers from the Tien Shan (Talas, Aksu, Ili) offer favorable run-of-river sites; the Irtysh basin in the NE provides low- to medium-head options near existing lines for easy grid integration. Run-of-river tech minimizes environmental impact by returning water to the river, avoiding large reservoirs. Advances in automation, modular turbines, and prefabricated components reduce costs, shorten construction, and ease maintenance, while digitalization helps SHPs feed smart grids for reliable rural power. SHP projects also generate construction and operations jobs and supply clean power to rural industries, with a smaller ecological footprint and fewer social disruptions than large dams, aided by standard environmental measures (fish passages, sediment control, seasonal flow regulation). Overall, SHP development in southern and NE Kazakhstan can diversify supply, strengthen energy independence, stabilize rural electricity, and support the 2060 carbon neutrality goal.
Technology characteristics/highlights	Installed Capacity and Scale: SHP ranges from 100 kW to 10 MW; modular construction allows phased expansion to match demand and water availability. Type of System: Run-of-river design; diverts river flow through a turbine then returns water, avoiding large dams and minimizing environmental impact. Turbine Technologies: Pelton for high-head, Francis for medium-head, Kaplan for low-head; modular units to simplify maintenance. Environmental and Social Integration: Fish ladders, ecological flow releases, sediment management; minimal land use. Construction and Materials: Prefabricated components and compact powerhouses; use of locally sourced materials to reduce costs. Efficiency and Lifespan: 75–90% efficiency; 30–50-year lifespan with low O&M costs. Grid and Off-Grid Capability: Can operate standalone or connected to the national grid; potential for hybrid systems with solar or wind. Sustainability Benefits: Renewable, low-carbon electricity; enhances energy security and supports local employment.
Country specific applicability and potential	Kazakhstan small hydropower (SHP) technical potential exceeds 13–15 TWh/year, with Ili, Talas, Irtysh, and Bukhtarma basins ideal for low- to medium-head SHP sites

	using run-of-river designs that minimize reservoirs and environmental impacts. The policy framework supports SHP within the 2030 renewables target (15%) and 2060 carbon neutrality, via feed-in tariffs, auctions, and laws guaranteeing permitting and grid access. SHPs suit remote rural and mountainous areas, enabling off-grid or hybrid operations with solar or wind, boosting energy security and local development. Environmental benefits include low land use and measures for ecological flow and fish migration. Development prospects focus on southern run-of-river schemes and north-eastern cascade opportunities, modernization of Soviet-era SHPs, and the growth of automation and modular turbines to enhance grid integration and cost-competitiveness.
Status of technology in country	• The country has an increasing number of small hydropower plants (SHPs). For example, in 2024 the installed capacity of small hydro plants was reported at ~287.7 MW. • SHPs are contributing to growth: output from small-scale hydropower plants rose by 16% in 2023 to ~949.1 million kWh. • Auctions are being held to stimulate new SHP projects. For instance, on 23 June 2025 an auction for 50 MW of SHP capacity was held (though not all capacity was bid). • Site-identification efforts: in the eastern region (East Kazakhstan Region) an "atlas" of ~95 prospective SHP sites was developed, with combined potential ~2 GW. • A recent project example: a cascade of two small hydropower plants on the Baskan River in Almaty region was commissioned in 2024, planned generation ~76.5 GWh/year.
Benefits to economic / social and environmental development	**Economic Benefits** SHPs stimulate economic growth in rural and remote areas by providing stable electricity for local businesses, farms, and small industries. This fosters entrepreneurship, especially in agriculture, food processing, and tourism sectors in mountainous regions like Almaty and East Kazakhstan. **Social Benefits** Many settlements in Kazakhstan's mountainous and remote areas face limited or unreliable power supply. Small hydropower plants can operate independently (off-grid) or in hybrid systems, providing continuous, clean energy to communities not connected to the national grid. Reliable electricity supply enhances access to lighting, heating, water pumping, education, and healthcare services, significantly improving quality of life in rural communities. With the reference to the current status of the hydropower around 5,000 people could be employed in the small hydropower sector in Kazakhstan. **Environmental Benefits**

	Small hydropower produces electricity with almost no direct greenhouse gas emissions. Run-of-river SHP designs require little or no reservoir storage, avoiding large-scale flooding or displacement. They maintain natural river flow and preserve aquatic ecosystems. SHPs can contribute to regulating local water flow, reducing flood risks and providing steady water availability for irrigation and domestic use in nearby areas.
Climate change mitigation benefits	SHPs generate electricity without burning fossil fuels, avoiding 0.8–1.0 kg of CO_2 per kWh compared to coal. Current SHP generation (~1 billion kWh/year) prevents around 1 million tonnes of CO_2 emissions annually. Expanding SHPs decreases reliance on coal and gas, helping decarbonize Kazakhstan's power sector and diversify the energy portfolio with stable, renewable sources. Producing electricity near consumption sites reduces transmission losses and overall energy waste, further cutting indirect emissions. SHPs provide steady base-load and flexible generation to balance intermittent solar and wind power, enabling greater renewable penetration in the grid. SHP development directly contributes to Kazakhstan's Paris Agreement targets and 2060 carbon neutrality strategy, advancing both climate action and energy security.
Financial Requirements and Costs	• Investment costs for small hydropower (1–10 MW) are typically in the range of USD 2,000 to USD 7,500 per kW of installed capacity. • Typical annual O&M costs are 1.5% to 2.5% of the initial investment cost for small hydropower plants (~190 USD per kW). • The Levelized Cost of Energy (LCOE) for new small hydropower projects in Kazakhstan is projected to be in the range of USD 0.02 to USD 0.10 per kilowatt-hour (kWh).
Advantages/Disadvantages	**Advantages** Renewable, low-carbon, uses local water resources. Minimal land use, no large reservoirs, low emissions. Creates local jobs, supports rural industries, reduces fuel imports. Provides reliable power for remote or off-grid areas. Market potential could reach 1,7 GW installed capacity or 9 billion USD. It is expected to reduce annual CO_2 emissions by more than 28 Mt CO_2/yr **Disadvantages** Dependent on river flow; generation may fluctuate seasonally. Possible effects on aquatic ecosystems if not properly managed. Grid connection can be costly in mountainous regions. Limited local manufacturing; some equipment imported.

	Vulnerable to climate change effects on water availability.

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TFS-E-05:

Technology	#5 Large scale on-grid solar farms (0.1-1 GW)
Introduction	Utility-scale on-grid solar farms are large photovoltaic (PV) power plants — from ~100 MW to 1,000 MW — built to supply electricity directly into the transmission grid. They use fields of fixed-tilt and/or single-axis tracking PV modules, ground-mount racking, inverters, step-up substations and medium-/high-voltage transmission lines. Modern large plants favor high-efficiency crystalline silicon modules, centralized or string inverters, automated cleaning and monitoring systems, and increasingly integrate battery energy storage systems (BESS) to firm output and provide ancillary services. A typical 100 MW plant covers tens to a few hundred hectares, generates electricity during daylight hours (peaking at midday) and is sized with a DC:AC ratio (nameplate module DC relative to inverter AC) optimized for local irradiance and grid rules. Developers design the plant around resource data (irradiance, soiling, snow), grid connection capability, land availability and offtake arrangements (power purchase agreements or merchant sales). Construction timelines for utility projects are short relative to thermal plants — often 6–18 months for a 0.1 GW project — and the bulk of cost is module + BOS (balance of system), land preparation, civil works and grid interconnection. Operationally, utility PV offers predictable hourly profiles, low marginal cost (near zero fuel cost), and low staffing needs (O&M largely remote monitoring plus periodic preventative maintenance). Integration into grids with high fossil generation requires planning for variability: grid codes, dispatchable reserve, and often storage or flexible generation to maintain reliability.
Technology characteristics/highlights	• **PV type:** Dominantly crystalline silicon (mono- or multi-) with >20% module efficiencies common for new projects. • **Trackers:** Single-axis trackers raise annual yield by ~10–25% vs fixed tilt in good sites. • **Inverters:** String inverters for modularity; central inverters still used for very large blocks. • **Performance ratio:** Typical PR ~0.75–0.85 depending on soiling, temperature, losses. • **Storage option:** PV+ESS (Energy Storage System) is increasingly standard to provide capacity firming and ancillary services; storage costs falling rapidly.
Country specific applicability and potential	• **Solar resource:** Kazakhstan has good solar resources — annual global tilted irradiation in southern regions ranges roughly **1,300–1,800 kWh/m²/yr** (southern regions higher; average GHI (Global Horizontal Irradiance) ~3.8–4.6 kWh/m²/day in many areas). This is attractive for utility PV.

	• **Land & siting:** Large sparsely populated areas, steppe and semi-desert in the south offer abundant land with low competing uses. Solargis/Global Solar Atlas confirms high-insolation zones suitable for large farms. • **Grid & market:** Kazakhstan's grid is dominated by coal and large thermal generation; integrating large PV requires transmission upgrades and flexibility mechanisms. Existing experience (Burnoye 50→100 MW and other 50–100 MW plants) demonstrates feasibility but also the need for planning at scale.
Status of technology in country	Kazakhstan has moved from pilot/early utility projects to multiple utility plants (several 50–100 MW installations, incl. Burnoye expanded to ~100 MW). By the first half of 2024 reported utility solar capacity reached the low-to-mid gigawatt scale (1,200–1,400 MW reported across many small and medium plants), showing accelerating deployment. Many projects were financed/co-financed by IFIs (EBRD, ADB, etc.).
Benefits to economic / social and environmental development	**Economic:** New investment and construction jobs, local O&M (Operations and Maintenance) jobs, reduced exposure to volatile fossil fuel markets, diversification of energy mix, potential for local manufacturing/service hubs (O&M, EPC (Engineering, Procurement, and Construction)). **Social:** Improved energy security in remote regions, potential lower electricity tariffs where solar displaces expensive generation, reduced air pollution (health benefits). It is expected to create around 12,000 of temporary construction jobs leading up to 2030, and hundreds of long-term, permanent positions for each operational project. **Environmental:** Directly reduces local air pollutants (SOx, NOx, particulates) and fossil-fuel CO_2 emissions per MWh displaced. International finance has supported Kazakhstan's low-carbon projects.
Climate change mitigation benefits	Kazakhstan's power sector is carbon-intensive. Depending on source and method, grid emission factors are reported in the range **~516 g CO_2/kWh (IEA average)** to **~797 g CO_2/kWh (some IFI default factors)**. Displacing 1 MWh of grid electricity with solar therefore avoids roughly **0.5–0.8 t CO_2/MWh**. For a 100 MW plant producing ~150–180 GWh/yr (typical for a well-sited southern Kazakh plant), avoided CO_2 is roughly **75,000–144,000 t CO_2 per year** (range based on emission factor used).
Financial Requirements and Costs	• **100 MW plant** CAPEX range: **USD 80–150 million** (approx. $800–1,500/kW). • Annual OPEX: ~USD 1–2.5 million/yr for 100 MW (≈ $10–25/kW-yr). • **Typical annual generation: ~120–180 GWh/yr** for southern Kazakhstan siting (capacity factor ~13–20% to 20–25% with trackers), yielding an LCOE often in **$30–60/MWh** before storage.

	• The average cost of electricity (Levelized Cost of Energy or LCOE) from a large-scale, on-grid solar farm typically ranges between **USD 0.024 and USD 0.10 per kilowatt-hour (kWh).**
Advantages/Disadvantages	**Advantages** Very low marginal cost / no fuel price risk. Rapid construction and modular scalability. Large CO_2 and air-pollution reductions where fossil generation is displaced. It is expected to reduce annual CO_2 emissions by more than 20 Mt CO_2/yr Proven finance structures via IFIs in Kazakhstan (lower financing risk). Market potential is about **10 billion USD** or 10 GW of the installed capacity. Low operational staffing / predictable O&M costs. **Disadvantages** Variable output — daytime only without storage. Grid integration needs (flexibility, transmission upgrades). Requires large land areas; competing land-use & permitting hurdles. Curtailment risk in weak/rigid grids; needs market/contract reform. Performance affected by soiling, snow, extreme temps — higher maintenance in harsh climates.

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4. Global Solar Atlas / Solargis — solar resource maps for Kazakhstan. globalsolaratlas.info+1
5. Burnoye Solar Plant / EBRD coverage — *Burnoye 50→100 MW* project and EBRD financing press releases. ЕБРР+1
6. PVKnowHow / regional reporting — Kazakhstan capacity and updates (installed solar capacity figures). PVKnowhow
7. Qazaq Green / Astana Times / Power-Technology — reporting on Kazakhstan renewable project lists and developments (installed plants, new projects). QazaqGreen+2The Astana Times+2
8. IEA / Kazakhstan country energy profile and emissions (power-sector carbon intensity context). OECD+1
9. IFI default grid emission factor references (examples used for avoided-emissions range). Breeze
10. LBNL / Utility-Scale Solar, 2024 Edition (cost/O&M slides and analysis). eta-publications.lbl.gov
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TFS-E-06:

Technology	#6 Energy management system in buildings for public sector
Introduction	An Energy Management System (EMS) is a hardware + software solution that continuously monitors, controls and optimizes how a building uses energy — lighting, HVAC (Heating, ventilation, and air conditioning), hot water, pumps, meters and increasingly distributed generation (solar, batteries). In public buildings (schools, hospitals, municipal offices) an EMS links sensors, submeters and building automation controllers to a central dashboard and algorithms that produce schedules, fault alerts, demand-response signals and performance reports. The practical outcome is simpler operations, fewer comfort complaints, earlier detection of faults (leaky valves, failed boilers), and predictable, lower bills. For governments the attraction is especially strong: public buildings are concentrated loads, under a single owner/manager and often have predictable occupancy patterns — so the same technical package (sensors, Energy Management System (BMS)/EMS software, integration to existing HVAC) can be replicated and financed at scale. When paired with retrofits (insulation, windows, efficient boilers/heat pumps, LED lighting) the EMS makes those investments measurable and enforceable through KPIs (kWh/m², peak kW, comfort setpoints). International experience and multi-donor projects show scalable energy savings and measurable financial payback when EMS is used to optimize operations rather than just monitor. In Kazakhstan, national and municipal programs to upgrade public-sector efficiency have already funded retrofits and pilot monitoring projects (World Bank–supported Energy Efficiency Project, municipal EE plans for Astana/Almaty, and UNDP/other donor activities). These programs created both technical familiarity and procurement channels that reduce implementation friction for EMS roll-outs. That institutional groundwork — combined with finance tools emerging in the Kazakh green finance market — makes EMS a pragmatic next step to lock in savings, support carbon targets, and enable demand-side flexibility in the national grid.
Technology characteristics/highlights	• Modular and scalable: from single-site BEMS (Building Energy Management System) to citywide dashboards. • Interoperability: BACnet/Modbus/IoT protocols. • Quick wins: lighting controls, setpoint resets, night setbacks, scheduling — low CAPEX, fast payback. • Advanced: ML (Machine Learning) analytics for anomaly detection, demand response & peak shaving.

Country specific applicability and potential	Kazakhstan's public building stock was identified as high-intensity energy users in World Bank studies; municipal retrofit programs (Astana, Almaty) and national EE (Energy Efficient) projects provide a pipeline of buildings and procurement experience. EMS can be deployed across schools, clinics, administrative buildings and district heating interfaces (about 8000 buildings) — delivering typical energy reductions when combined with operational changes. Scaling EMS nationally is aligned with Kazakhstan's energy modernisation and green finance frameworks.
Status of technology in country	Donor-backed retrofit projects have completed multiple pilot public-building retrofits (reported batches under the Kazakhstan Energy Efficiency Project). There are local integrators and growing supplier interest; however, widespread integrated EMS adoption remains at early/mid stage — many projects still use one-off controls or standalone metering rather than a full EMS ecosystem.
Benefits to economic / social and environmental development	**Economic:** lower energy bills, reduced maintenance costs (detect faults early), longer asset life, and budget predictability. **Social:** improved comfort in schools/clinics, fewer service disruptions, better indoor environment for occupants. It is expected to create around from 15,000 to 20,000 jobs of temporary construction jobs leading up to 2030, and hundreds of long-term, permanent positions for each operational project. **Environmental**: reduced fuel use and CO_2 emissions; enables integration of renewables and demand response.
Climate change mitigation benefits	By reducing energy use and enabling higher shares of on-site renewables and demand flexibility, EMS contributes to building-sector decarbonisation. Policy analysts estimate that modern energy-efficiency measures in Kazakhstan's building sector could improve efficiency by ~30% in some scenarios, meaning substantial reductions in fuel consumption and CO_2 emissions when EMS is scaled with retrofits.
Financial Requirements and Costs	Typical CAPEX ranges (ballpark): • Basic EMS (monitoring + dashboard + submetering) ≈ **USD 20–USD 30 / m²** (WBCSD guidance – per kW saved power) — example: a 10,000 m² municipal building ≈ **USD 200k–USD 300k**. • Simpler IoT-first EMS approaches (sensor + cloud) can be lower —≈ **$27–$75 / m²**, but integration complexity and local commissioning can raise costs. Use lower IoT numbers for small pilots, WBCSD numbers for robust full BEMS. Typical OPEX (annual): • Software, cloud & licenses: **5–15% of CAPEX / year** (depends on licensing model).

	• Maintenance and sensor replacements: **1–3% of CAPEX / year** plus electricity for gateways (negligible). (6 USD per saved kW) • Commissioning and continuous optimization of staff time (may be internal or contracted). • Implementing Energy Management Systems (EMS) in public sector buildings does **not directly change the price (tariff) of electricity per kilowatt-hour (kWh)** set by utilities in Kazakhstan. Instead, an EMS influences the *total electricity bill* and the *effective cost of consumption* by drastically reducing the **quantity of electricity consumed.**
Advantages/Disadvantages	**Advantages** Reliable energy & cost savings; Faster fault detection → lower maintenance & downtime. Enables renewables, demand response & reporting for climate targets. Scalable & repeatable across public portfolio. Market potential can reach **15 billion USD**. It is expected to reduce annual CO_2 emissions by more than 15 Mt CO_2/yr **Disadvantages** **Upfront** CAPEX can be a barrier. Requires skilled commissioning & ops staff (capacity building). Interoperability/integration with old HVAC can be complex. Cybersecurity & data governance considerations.

1. World Bank — Energy Efficiency Transformation in Astana and Almaty; Kazakhstan Energy Efficiency Project (P130013) (project documents & reports). World Bank+1
2. UNDP Kazakhstan — Building a greener future: energy efficiency in construction (blog/summary discussing EMS and retrofits). UNDP
3. WBCSD — Business case for Building Energy Management Systems (cost guidance: €20–€30 / m²). WBCSD Publications
4. IET Africa / industry pieces — BEMS cost ranges (commercial estimates $2.5–$7/ft²) and other vendor analyses. IET Africa+1
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6. World Bank video/article: Towards Building a Green Kazakhstan (context on municipal energy intensity and projects). Всемирный банк
7. GGGI / scoping studies and national modernization coverage (examples of energy-efficient buildings in Kazakhstan). gggi.org
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TFS-E-07:

Technology	#7 Electrification of urban public and municipal transport
Introduction	Electrifying urban public and municipal transport means replacing diesel or CNG (Compressed Natural Gas) buses, minibuses and some municipal vehicles (e.g., refuse trucks, street sweepers, light service vans) with battery-electric vehicles (BEVs), trolleybuses, or hydrogen fuel-cell vehicles, and equipping depots, termini and corridors with appropriate charging or overhead power infrastructure. The technology package includes the vehicle (battery, motor, power electronics), depot charging or opportunity/fast chargers, energy management and smart charging software, grid upgrades and substation works, and staff training for maintenance and operations. In operation, electric buses typically charge overnight at depots (slow/overnight charging) or use fast opportunity chargers (pantograph/station) to replenish energy during layovers; some systems mix both approaches to maximize range and utilization. Integration with renewable electricity, vehicle-to-grid (V2G) or stationary storage can lower operating costs and smooth electricity demand. Electrification requires upfront capital — bus purchase and charging infrastructure — but reduces fuel costs, noise, and maintenance needs because electric drivetrains have fewer moving parts and higher energy efficiency. For cities, the result is cleaner air, quieter streets and the opportunity to retrofit routes into higher-quality, high-throughput services that improve public transport modal share and social inclusion. Operational planning, depot layout, and grid capacity are critical technical constraints; successful rollouts pair pilot fleets with clear procurement practices, financing (grants, green bonds, concessional loans, or leasing) and performance monitoring.
Technology characteristics/highlights	• Vehicle: battery electric buses (BEB) — typical battery sizes 150–450 kWh (single-decker → 150–350 kWh). • Charging modes: depot (overnight), opportunity/fast (pantograph), and on-route (rare). • Key infrastructure: chargers (AC/DC), substation upgrades, energy management software, spare-parts & battery storage. • TCO (Total Cost of Ownership) profile: higher CAPEX, lower or comparable OPEX (energy + maintenance) over lifecycle depending on electricity prices and vehicle utilization.
Country specific applicability and potential	Kazakhstan's large cities (Almaty, Astana and regionals) are good early adopters because they already run organized municipal fleets, have concentrated routes suitable for depot charging, and are seeking air-quality and climate solutions. Almaty has publicly committed to a large shift toward cleaner public transport and has a history of electric trolleybus and

	tram infrastructure that eases transition in corridors. Kazakhstan's EV market and charging network remain small relative to need (low EV uptake and limited public chargers) but growing, creating a clear potential for targeted municipal electrification projects in major cities. There are approximately 100 000 buses in Kazakhstan.
Status of technology in country	• EV and charging stock is nascent (single-digit-thousands of EVs; low number of public charging stations nationwide). • Municipal pilots and procurement plans exist (Almaty, other cities are announcing green fleet targets and green financing mechanisms).
Benefits to economic / social and environmental development	**Economic:** lower lifetime fuel & maintenance costs per vehicle-km (where electricity is cheap), new green jobs (maintenance, charging ops), local financing opportunities (green bonds, concessional loans). **Social:** improved air quality and reduced noise in dense urban neighborhoods, higher comfort for passengers, inclusive mobility if used to upgrade routes and frequency. The sector would contribute to the approximately 5,000 of general "green jobs" through manufacturing, infrastructure installation, maintenance, and operation. **Environmental:** reduced tailpipe PM (Particulate Matter) and NOx; CO_2 reduction depends on electricity carbon intensity but is positive if grid decarbonization proceeds. Kazakhstan's transport sector is a material source of emissions—transport CO_2 was assessed at ~23.5 Mt (recent profile)—so electrification can contribute meaningfully.
Climate change mitigation benefits	Electrified bus fleets cut tailpipe CO_2 directly and can cut lifecycle CO_2 significantly when charged with low-carbon electricity. The scale of mitigation depends on fleet size and grid mix; shifting a typical city's diesel bus fleet to BEBs can reduce CO_2 emissions by tens of thousands of tonnes per year per 100 buses (order-of-magnitude results depend on annual km, diesel vs electricity intensity). Coupling fleet electrification with renewable power (PV on depots, PPAs) multiplies benefits.
Financial Requirements and Costs	Typical unit CAPEX (industry ranges): • Battery electric single-deck bus (new, landed cost): **USD 250,000 – 550,000 per vehicle** (example values: ~USD 330,000 in many deployments ~ 1100 USD per kW). • Depot charger (overnight DC or high-power charger): **USD 20,000 – 60,000** per charger (varies by power, installation, civil works). • Grid / substation & depot upgrades: **project dependent** — typically **USD 1–10 million** for a 50–200 bus depot (transformer, cabling, land works). OPEX outlook (typical, indicative):

	• Energy: BEB energy consumption ~1.0–1.5 kWh/km; electricity cost and duty cycles drive cost/km. Studies show OPEX per km can be lower or comparable to diesel depending on local electricity prices and battery replacement assumptions ~ 11 USD per kW. • Maintenance: lower for BEBs (fewer moving parts), though battery replacement (mid-life) is a significant cost item to budget for. • The electrification of urban public and municipal transport in Kazakhstan is unlikely to significantly affect the general, nationwide *price* of electricity in the near term due to the currently low number of electric vehicles (EVs) relative to the total vehicle fleet. However, mass adoption in major cities could eventually put pressure on local grid infrastructure, potentially leading to specific tariff structures or fluctuations in wholesale prices if charging is not managed efficiently.
Advantages/Disadvantages	**Advantages** Zero tailpipe emissions, lower local air pollution. Lower noise, lower drivetrain maintenance. Improved passenger comfort & city image. Opportunity to integrate renewables and storage. Can reduce net CO_2 with renewable electricity 23.5 Mt CO_2/yr Market potential is about 10 billion USD or 100 000 vehicles. **Disadvantages** High upfront CAPEX (bus + chargers + grid). Grid upgrade needs; peak power demand management. Battery degradation and replacement costs. Requires operational changes (charging scheduling). Supply chain / procurement complexity (import dependence).

1. Kursiv — “Kazakhstan reports twofold increase in EVs” (Sep 19, 2024). https://kz.kursiv.media/en/2024-09-19/kazakhstan-reports-twofold-increase-in-evs/ Kursiv Media Kazakhstan
2. AICAR Global / eDrive.kz — “Kazakhstan New Energy Electric Vehicles and Charging Piles Market Analysis” (2024). https://aicarglobal.com/news/kazakhstan-new-energy-electric-vehicles-and-charging-piles-market-analysis-2024/ aicarglobal.com
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6. Asian Transport Observatory / Transport & Climate Profile — “Kazakhstan transport and climate policy” (2024). (PDF). asiantransportobservatory.org
7. Transjakarta / ITDP procurement & business case (example CAPEX figures for e-buses and chargers). itdp-indonesia.org

8. Changing-Transport / TRASfer — “Public bus electrification” (cost ranges for mini-buses, case studies). Changing Transport
9. UITP — “Financial planning for the electric bus” knowledge brief (CAPEX/OPEX examples). UITP
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TFS-E-08:

Technology	#8 Electric vehicles (EV) including the charging points grid
Introduction	Electric vehicles (EVs) are cars, buses and light commercial vehicles powered (mostly) by onboard batteries and electrical motors instead of internal-combustion engines. The vehicle itself is only part of the system: to make EVs practical at scale you need a reliable charging grid — a layered network of chargers ranging from low-power home and workplace units (AC "Level-2") to high-power public fast chargers (DC fast chargers, 50–350 kW and above), plus the digital systems that manage payments, load, and roaming between networks. Chargers are connected to the local distribution grid and sometimes co-located with short-term battery storage and local renewable generation (solar, wind) to reduce peak loads and increase uptime. Technically, modern charging deployments combine power-electronics (AC/DC converters, charging control), communications (OCPP-type protocols), and back-office platforms (billing, telemetry, predictive maintenance). Fast chargers require substantial site works: power connection upgrades, transformer capacity, protection, civil works, and cooling for high-power units. Smart charging software (V1G) and vehicle-to-grid (V2G / bidirectional) are maturing; they allow charging to be shifted in time or feed power back to the grid to provide grid services, reducing cost and improving stability as EV numbers grow. From a rollout perspective, operators balance charger density, power level and location: slow chargers (home/work) solve daily needs; medium power (~22–50 kW) suit short urban top-ups; high-power corridors (150–350 kW) enable long-distance travel and minimal dwell times for fleet operations. In all cases, interoperability, standard connectors and clear tariffs are essential for user trust.
Technology characteristics/highlights	• Charger types: Level-2 AC (≈3–22 kW), DC fast chargers (50 kW, 150 kW, 350 kW). • Key components: power rectifier, battery management interface (CHAdeMO/CCS), payment/communications (OCPP). • Site needs: transformer upgrade, grid connection, civil works, cooling for >150 kW. • Smart features: scheduled charging, demand response, V2G (emerging).
Country specific applicability and potential	Kazakhstan has rapidly growing urban centers, long intercity distances, and an automotive fleet that's gradually modernizing. EVs can reduce urban air pollution and fuel import dependence, and enable electrification of municipal fleets (buses, municipal vans). However, Kazakhstan's electricity mix remains heavily fossil-fuelled (major share

	from coal and gas), so the net greenhouse-gas benefits depend on parallel decarbonization of power generation.
Status of technology in country	EV fleet & chargers: Reports indicate roughly 12–13k registered electric passenger cars by early 2025 and around ~600 public charging "piles" by end-2023, concentrated in Almaty and Astana. Market analysts project rapid expansion toward several thousand chargers in the next 2–3 years. New mandatory technical standards for charging stations were adopted on 22 April 2024, clarifying construction and interoperability rules.
Benefits to economic / social and environmental development	**Economic:** lowers operating cost per km for vehicles; creates local jobs in installation, operation and maintenance of chargers; can reduce fuel import exposure if electricity is domestically produced. **Social:** improved urban air quality, quieter streets, health co-benefits from reduced tailpipe pollution. The sector would contribute to the approximately 5,000 of general "green jobs" through manufacturing, infrastructure installation, maintenance, and operation. **Environmental & climate**: EVs eliminate tailpipe CO_2 and local pollutants; climate mitigation depends on grid carbon intensity — in Kazakhstan with high coal share, benefits are smaller today but increase as the grid decarbonizes (renewables, planned nuclear capacity).
Climate change mitigation benefits	Electrifying transport cuts direct road transport CO_2 emissions; studies show overall lifecycle benefits once electricity mixes decarbonize or if EVs displace older, inefficient ICE vehicles. Where grids are coal-heavy, the timing of emissions breakeven (EV life-cycle vs. internal combustion) matters — delaying EV uptake without grid decarbonization reduces net climate gain. Pairing EV rollout with renewable generation, storage and smart charging yields the largest CO_2 reductions.
Financial Requirements and Costs	Unit cost assumptions (industry benchmarks): • Home / Level-2 AC charger (supply + basic install): **US$1,000–3,500** each (retail/consumer context). • Commercial Level-2 charger (per port, full site): **US$3,000–12,000** installed. • DC fast charger (per head / per unit installed): **US$80,000–250,000+** depending on power (50–350 kW), site electrical upgrades and civil works. ICCT spatialized install costs show 50–350 kW projects scale up quickly with site complexity. In average USD 750 per kW. OPEX (typical): • Annual maintenance & operations (network-level): **~2–5% of CAPEX** (maintenance, network fees, software, card fees). Electricity cost: depends on tariff; for a charger that

	supplies 50,000 kWh/year at $0.06–0.12/kWh the energy bill is $3k–6k/year. In average USD 37 per kW. • A small, incremental change in demand from a niche sector (EVs) does not meet the threshold required for regulators to revise the national tariff structure.
Advantages/Disadvantages	**Advantages** Lower operating cost per km; reduced urban air pollution. It is expected to reduce annual CO_2 emissions by more than 30 Mt CO_2/yr New jobs: installation, O&M, software and services. Enables fleet electrification (buses, taxis) with significant local health benefits. Smart charging / V2G can add grid flexibility and integrate renewables. Market potential is about **2 billion USD**. **Disadvantages** Large upfront CAPEX for fast chargers and grid upgrades. Grid emissions high today (coal), so near-term CO_2 gains are limited. Need for interoperability rules, maintenance, and consumer trust; rural coverage expensive. High-power chargers are expensive per site and require skilled technicians.

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TFS-E-09:

Technology	#9 Energy management system in buildings for private sector
Introduction	For private-sector an Energy Management System EMS (also called BEMS or BMS when tightly coupled to building controls) brings together meters, sensors, HVAC controls, lighting controls, and cloud analytics to give real-time visibility, automated control, fault detection and data for continual improvement. In practice an EMS can be a lightweight IoT-based dashboard that reads meters and smart plugs (good for small offices and retail), or a full building automation suite that controls chillers, boilers, variable-speed drives and lighting zones across a portfolio. The immediate, visible benefits are energy savings (typically in the low-double digits), lower operating costs, extended equipment life and improved tenant comfort. Less visible but equally important are operational gains: remote commissioning, predictive maintenance, automated demand response during high tariff periods, and verifiable emissions reporting for ESG and green-financing claims. For private owners the EMS business case is usually a mix of: (1) energy cost savings and peak-demand lowering, (2) reduced maintenance and downtime, (3) higher tenant satisfaction and potentially higher rents or occupancy, and (4) ability to access green loans, subsidies or carbon accounting advantages. Implementation can be phased: start with metering + analytics, then add zone controls and HVAC optimization. That staged approach lowers initial capital outlay and demonstrates early wins that underwrite later investment.
Technology characteristics/highlights	• Real-time meter & sensor telemetry (electricity, gas, heat, water). • Automated control of HVAC, lighting, blinds, and pumps with schedules & occupancy logic. • Fault detection & diagnostics (FDD) and predictive maintenance alerts. • Analytics & reporting (energy, demand, emissions; supports green financing/ESG). • Integration readiness: supports demand response and on-site renewables (PV + storage).
Country specific applicability and potential	Kazakhstan's private building sector has significant energy-efficiency gaps and aging HVAC/thermal envelopes; municipal plans and national green-economy policies identify energy efficiency as a priority, creating a favorable policy context for EMS uptake. EMS is especially relevant in cities (Almaty, Astana, Aktau) where commercial real-estate owners can reduce high heating/electricity bills, participate in demand-side programs, and strengthen ESG reporting for international investors.

	Potential scale: Large potential in private sector buildings — especially where baseline energy losses are high (UNECE/World Bank analyses estimate many buildings lose large shares of thermal energy). Widespread EMS adoption could be an immediate, cost-effective contributor to Kazakhstan's Green Economy and NDC goals.
Status of technology in country	• Policy & strategy: Kazakhstan has a Green Economy Concept and national action plans that emphasize energy intensity reduction and energy efficiency measures; municipal energy efficiency plans (e.g., for Almaty and Astana) exist and have piloted measures. • Market maturity: EMS/BMS adoption is growing but still limited compared with OECD peers — many large commercial and industrial sites have partial automation; small/medium buildings are under-penetrated due to financing barriers and low energy prices (subsidies historically depressed paybacks). International donors (GIZ, UN-PAGE, World Bank) are active in capacity building.
Benefits to economic / social and environmental development	**Economic** Direct energy cost savings (10–30% typical). Reduced maintenance and longer asset life; better operational staffing productivity. Proved access to green loans and investor interest due to verifiable performance data. **Social** Improved thermal comfort and indoor environmental quality → better occupant well-being/productivity. Job creation in installation, commissioning, analytics services and retrofitting. It is expected to create 15,000 to 20,000 temporary construction jobs leading up to 2030, and hundreds of long-term, permanent positions for each operational project. **Environmental** Lower CO_2 emissions via reduced energy use; enables higher shares of on-site renewables by managing intermittency.
Climate change mitigation benefits	EMS reduces building energy demand (directly reducing fuel combustion and electricity consumption). Typical savings of **10–30%** translate into immediate reductions in CO_2 emissions, helping Kazakhstan meet near-term NDC targets and medium-term decarbonization pathways — especially when EMS is paired with grid decarbonization and on-site renewables. EMS also enables demand response, lowering peak generation needs and grid emissions intensity.
Financial Requirements and Costs	CAPEX (rough indicative ranges) • **Small building / pilot (500–1,000 m²)** — basic monitoring + analytics + a few zone controllers: **~$1,250 – $7,500** (≈ $2.5–$7.5 / m²). • **Medium building (5,000 m²)** — more sensors, HVAC integration, controls: **~$12,500 – $37,500** (using $2.5–$7.5 / m²).

	• **Large or full automation (10,000 m²)** — full BEMS: **~USD 200,000 – USD 300,000** (EU WBCSD benchmark USD 20–USD 30 / m² ≈ – per kW saved power), i.e. **$200k–$300k**. OPEX (annual) • **Software licensing & cloud + support: ~10–25%** of software/license CAPEX per year (commonly 15–22% maintenance rates are used by enterprise vendors). • Maintenance & tune-up (technician time, sensors replacement): ~1–5% of CAPEX per year (depends on local labor & spare parts). (7 USD per saved kW) • The financial benefit to the private sector comes from **reducing energy consumption by 10% to 20%**, and sometimes as much as 30-50% in inefficient buildings, by optimizing existing systems and operational practices.
Advantages/Disadvantages	**Advantages** Immediate and measurable energy & cost savings (10–30%). Improves asset life, reduces maintenance and downtime. Enables emissions accounting, demand response and integration with renewables. Supports tenant comfort and ESG/financing claims. Market potential can reach **20 billion USD**. It is expected to reduce annual CO_2 emissions by more than 20 Mt CO_2/yr **Disadvantages** Upfront CAPEX can be significant for full BEMS deployments. Requires skilled installers/operators and sometimes vendor lock-in (licensing). Older buildings may need retrofits (piping, controls) that increase cost and complexity. Energy price subsidies / low tariffs can weaken near-term business case.

1. WBCSD — *The Business Case for Building Energy Management Systems (BEMS)* (WBCSD publication). WBCSD Publications
2. MidAtlantic Controls — "How Much Does a Building Management System Cost?" (industry cost guide). info.midatlanticcontrols.com
3. WBCSD / National Resources Canada cost benchmark — average **€20–€30 / m²** for basic BEMS. WBCSD Publications
4. IEA — *Buildings energy system overview* (context on buildings energy use). IEA
5. PNNL — *Energy Savings and Economics of Advanced Control* (detailed HVAC control savings). PNNL
6. The Climate Drive / Action Library — EMS typical savings **10–15%** guidance. theclimatedrive.org
7. National Energy Report / Kazenergy — *Kazakhstan's National Energy Report 2023* (national energy context). kazenergy.com+1
8. UN-PAGE — *Kazakhstan's Transition to Green Economy* (policy context & opportunities). un-page.org

9. World Bank — *Energy Efficiency Transformation in Astana and Almaty* (municipal EE plans & pilots). World Bank
10. GIZ — *Energy and Resource Efficiency (Kazakhstan)* project page (programmatic support and barriers). giz.de
11. NREL / Sensors & Controls review — (role of sensors & controls; penetration stats). docs.nrel.gov
12. Industry guides and market summaries (MidAtlantic, OP-INT, Euristiq) on BMS/BEMS market sizing and cost ranges. info.midatlanticcontrols.com+2Euristiq+2
13. Vendor/technical sources on software licensing & maintenance: typical enterprise maintenance ~15–22% of license cost. broadcomnegotiations.com

TFS-E-10:

Technology	#10 Natural gas combined cycle power plants for flexible power grid supply
Introduction	Modern natural-gas combined-cycle (NGCC) power plants pair a gas (combustion) turbine with a steam turbine that recovers waste heat from the gas turbine exhaust to produce extra electricity. That two-stage use of the fuel makes NGCC plants far more efficient than simple-cycle gas or coal plants: efficiencies commonly exceed 55% HHV for H-class machines. Beyond efficiency, today's NGCC designs are engineered for flexibility — fast starts, wide operating ranges, low minimum loads, rapid ramping and frequent cycling — so they can follow variable renewable output (wind, solar) and provide grid stability services (frequency response, inertia emulation, spinning or quick-start reserve). Flexibility improvements come from turbine controls, inlet fogging/bleed systems, HRSG (heat recovery steam generator) designs with bypass options or supplementary firing, and operational strategies (hot-standby, partial loading) that balance thermal stress with value from electricity markets. These plants are therefore often chosen as the backbone "firming" resource in grids with high renewables because they deliver large firm capacity with lower CO_2 intensity than coal and the operational characteristics needed for a fast-changing energy mix. Recent techno-economic studies and government cost tables show NGCC's capital intensity is moderate (hundreds to low thousands USD per kW) and its non-fuel O&M is relatively low — but fuel (natural gas) dominates the operating cost and the carbon footprint unless methane leakage or low gas prices change the picture. NGCC can also be retrofitted for carbon-capture in the future or paired with hydrogen blends to reduce lifecycle emissions, giving planners a near-term dispatchable option with a transition pathway toward lower-carbon operation.
Technology characteristics/highlights	• Two-stage cycle: gas turbine + HRSG + steam turbine → high thermal efficiency (>50% HHV for modern designs). • Designed for flexibility: fast start (tens of minutes to full load for advanced units), ramp rates of several %/min, low minimum load (10–30% of nameplate) with enhanced controls. • Modular scaling: single-shaft blocks (100s of MW) up to multi-block plants (600–1,200+ MW). • Retrofit potential: carbon-capture or hydrogen co-firing feasible though CAPEX rises substantially.
Country specific applicability and potential	Kazakhstan has large natural-gas resources and a power system historically dominated by coal; policymakers are planning generation modernization and gas NGCC projects (e.g., planned Kyzylorda CCGT ~1,100 MW) to diversify, improve air quality, and firm increasing renewables. NGCC is

	therefore highly applicable: uses domestic gas, replaces coal in many dispatch hours, and helps integrate solar/wind.
Status of technology in country	Existing gas plants exist but coal still dominates. New CCGT projects are being planned/announced and investment programs for the power sector were launched (several GW of projects to 2029). Implementation is ongoing and financing/pipework remain key constraints.
Benefits to economic / social and environmental development	**Economic**: firm, flexible capacity for grid stability; supports industrial power needs; can use domestic gas (energy security); creates construction and operation jobs. IEA **Social:** lower local air pollution than coal (NO_x/SO_2/PM reductions), improved reliability for consumers and critical services. Around 6,000 permanent jobs places could be created. **Environmental:** lower CO_2 per MWh vs coal (coal→gas switching can reduce CO_2 emissions ~40–60% depending on plant efficiencies and methane leakage), and enables higher shares of renewables.
Climate change mitigation benefits	• Immediate: substituting efficient NGCC for coal reduces CO_2 intensity of power generation substantially. • Transitional: NGCC can act as a flexible "bridge" while renewables + storage scale up; later retrofits (CCS) or hydrogen blending can lower lifecycle emissions further. Notice: methane supply-chain emissions must be managed to preserve net climate benefit.
Financial Requirements and Costs	Representative CAPEX (2023 USD, industry/government estimates) • **Typical modern single-shaft NGCC (H-class, ~600–650 MW net)** — **~$920–1,200 / kW** (EIA case example: **$≈921 / kW**, total capital cost ≈ **$577 million** for a 627 MW unit). Location, equipment class, grid interconnection and carbon measures change this number. • **Range** for utility CCGT plants: **~$700 – $1,500 / kW** depending on size, class (F vs H), local labor, environmental controls, and contingency. (Global project databases show regional variation). OPEX • **Fixed non-fuel O&M: ~$16 / kW-yr** (EIA case for single-shaft CC). • **Variable O&M (non-fuel): ~$3.3 / MWh** (EIA). Fuel cost (natural gas) is the dominant operating expense; levelised operating cost is therefore highly sensitive to gas price and plant capacity factor. • Estimated LCOE Range (Global Context): New NGCC power plants typically have a Levelized Cost of Energy between USD 0.041 and USD 0.076 per kWh globally, heavily dependent on natural gas prices.
Advantages/Disadvantages	**Advantages**

	High thermal efficiency (>50% HHV) → lower CO_2/MWh than coal. Fast start, good ramping and low min-load — ideal to back up VRE. Relatively mature, modular technology with retrofit paths (CCS, H_2). Lower local air pollution than coal — immediate public health benefits. Market potential can reach **1.2 billion USD**. It is expected to reduce annual CO_2 emissions by more than 3.5 Mt CO_2/yr **Disadvantages** Dependent on natural gas fuel (price volatility, supply security). Still emits CO_2; methane leakage in supply chain can erode climate benefit. Carbon-capture or hydrogen transition requires large additional CAPEX. Long-term lock-in risk if renewables+storage costs fall faster than expected.

1. U.S. Energy Information Administration — Capital Cost and Performance Characteristics for Utility-Scale Electric Power Generating Technologies (Dec 2023). (Detailed NGCC CAPEX, O&M, emissions examples; Case 6 single-shaft H-class 627 MW). U.S. Energy Information Administration
2. IEA — Kazakhstan: country profile / electricity (IEA country page; energy mix, gas & coal context). IEA
3. SK (Samruk-Energy) / Samruk-Kazyna annual report & Kazakhstan power market overview (installed capacity, planned projects). Самрук-Энерго
4. SK.kz / Energy (KZ) — 2024/2025 report mentioning Kyzylorda combined cycle project (Power International). Самұрық-Қазына
5. IEA — The role of gas in today's energy transitions (analysis of coal→gas switching and lifecycle benefits). IEA
6. Repsol — "Gas combined cycle: What is it and how does it work?" (primer on combined-cycle operation). REPSOL
7. Spitz, T. — Operating flexibility of natural gas combined cycle power... (technical assessment of flexible operation). ScienceDirect
8. Abudu, K. — Impact of gas turbine flexibility improvements on combined... (2021 study on MEL and ramp rates). ScienceDirect
9. Global Energy Monitor / industry reports — regional project cost summaries and observed CAPEX ranges. Global Energy Monitor
10. Astana Times — reporting on Kazakhstan power sector investments and planned projects (2025).

TFS-E-11:

Technology	#11 Large scale on-grid wind farms (0.1-1 GW)
Introduction	Large-scale on-grid onshore wind farms are collections of utility-scale wind turbines (from dozens to hundreds) connected to the electricity grid through substations and transmission lines. Typical project sizes in the range from 100 MW (0.1 GW) up to ~1,000 MW (1 GW). A modern large onshore plant uses multi-MW turbines (3–6+ MW each), medium- to high-hub heights (100–170 m) and long rotor diameters to capture steadier winds and higher capacity factors. Plant design balances turbine spacing, site topography, access roads, grid connection and environmental constraints. Power is sold either via market contracts, PPAs (Power Purchase Agreement), or through auctioned feed-in arrangements; many projects now pair wind with battery storage or grid reinforcement to firm output. Construction timelines for 0.1–1 GW projects typically run from ~18–36 months once permits and financing are in place. Operational life is usually 20–30 years with opportunities for repowering (replacing turbines with newer, larger machines) after ~15–20 years.
Technology characteristics/highlights	• Modular and scalable: easily built in phases (e.g., 2×50 MW stages to reach 100 MW). • Rapid learning & maturity: turbine sizes and performance have improved steadily; costs dropped substantially over the past decade. • Low variable costs: fuel-free generation with predictable O&M profiles. • Integrability: increasingly paired with batteries or hybrid gas/battery to manage variability.
Country specific applicability and potential	• Resource & potential: Kazakhstan has excellent onshore wind resources across northern and central steppe regions (strong, persistent winds) and significant technical potential. The government's Power Sector Development plans include several GW of new renewables including wind energy. • Market momentum: by early-to-mid 2025 Kazakhstan had ~3 GW of renewables installed (wind ~1.6 GW), and the state approved auctions for multi-GW of new capacity (2024–2027), including wind + storage tenders. That creates a favorable policy window for 0.1–1 GW projects.
Status of technology in country	Kazakhstan has moved from pilots to utility-scale deployment: dozens of wind parks are operational; auctions and power sector plans through 2035 envisage further large projects and integration with storage. Implementation challenges remain (grid bottlenecks, permitting, and financing).

Benefits to economic / social and environmental development	Economic: local job creation (construction, O&M), foreign investment, diversification of generation and export potential, reduced import fuel exposure. Social: energy security, rural economic stimulus (road upgrades, local services), potential for community benefit schemes. It is expected to create around 6,000 temporary construction jobs leading up to 2030, and hundreds of long-term, permanent positions for each operational project. Environmental: near-zero direct emissions in operation, reduced air pollution vs fossil generation, minimal freshwater use.
Climate change mitigation benefits	Large wind farms directly displace fossil generation, cutting CO_2 per MWh by the emissions intensity of the grid (coal/gas). Scaling to several GW in Kazakhstan can materially lower the power sector's CO_2 footprint and help national climate targets when combined with grid decarbonization and storage.
Financial Requirements and Costs	High-level CAPEX (installed cost) — onshore wind: • Recent reference ranges vary by technology, region and project scope. Published reviews show a widespread: roughly **USD 800 – 2,500 per kW** as a practical mid-2020s global spread (country & supply chain dependent). More conservative engineering references and US DOE/NREL datasets record ranges from around **USD 1,000/kW** (mature, low-cost markets) up to **USD 3,000+ /kW** for higher-cost cases or smaller/remote projects. For practical project planning in Kazakhstan, budgeting **USD 1,000–1,800/kW** (i.e., **USD 1.0–1.8 million per MW**) is a reasonable starting assumption depending on turbine choice, transport and grid works. OPEX (operations & maintenance): • Typical O&M ranges widely by country/scale and age; global studies report **~USD 20–90 per kW-year** (i.e., **USD 20,000–90,000 per MW-year**). A midpoint for planning: **USD 30–50/kW-year** (USD 30,000–50,000 /MW-year). • The price of electricity from large-scale wind farms in Kazakhstan is determined through competitive auctions and has achieved prices as low as **USD 0.027 per kWh** in recent years.
Advantages/Disadvantages	**Advantages** Very low emissions at operation; low marginal costs. Rapid build and modular scaling (phased construction). Strong technical maturity & global supply chain. Long asset life with repowering options. Market potential can reach **7 billion USD**. It is expected to reduce annual CO_2 emissions by more than 20 Mt CO_2/yr **Disadvantages** Intermittent output — needs grid flexibility / storage.

	Upfront CAPEX and grid upgrade costs can be high. Siting/permits, environmental and social impacts (birds, land use), and public acceptance issues. O&M logistics and spare-parts supply chains must be established locally.

1. Kazakhstan to launch 93 renewable energy projects with a cumulative capacity — Qazaq Green / news summary (May 26, 2025). QazaqGreen
2. Kazakhstan renewable capacity / auctions / status reporting — Qazinform / Kazakh Ministry statements (May 2025). qazinform.com
3. Astana Times — Renewable energy steady growth and storage challenges in Kazakhstan (Dec 13, 2024). The Astana Times
4. Kursiv / coverage of Kazakhstan renewable share and installed wind capacity (Q1 2025). Kursiv Media Kazakhstan
5. IEA — Wind overview and global onshore dominance. IEA
6. GWEC Global Wind Report 2024 / industry deployment trends. img.saurenergy.com
7. NREL — *Cost of Wind Energy Review: 2024 Edition* (data on cost ranges, technology baselines). docs.nrel.gov
8. IRENA — *Renewable Power Generation Costs in 2024* (summaries on LCOE and O&M ranges). Rinnovabili+1
9. IEA Wind TCP Annual Report 2023 — capacity factor and fleet performance context. iea-wind.org
10. Lazard LCOE+ (2025) — context on LCOE ranges and capital-cost sensitivities. https://lazard.com
11. Land-Based Wind Market Report (2024 edition) — industry cost drivers and O&M trends. eta-publications.lbl.gov
12. Qazaq Green. https://qazaqgreen.com/en/news/kazakhstan/2412/

Annex 3: Performance, Scoring and Decision Matrices for MCA (energy sector)

Performance matrix

	Costs		Benefits									
			Technology diffusion			Policy	Social			Environmental		Climate related
	1. Capital cost (CAPEX)/USD per kW	2. Annual operational expences (OPEX)/USD per kW	3.Technology implementation country readiness level	4. Market potential/economic growth/Billion USD	5. Complexity of implementation	6. Compliance with national development policies and priorities	7. Gender impact	8. Access to energy/Quality of energy service/Energy safety	9. Creation of new jobs	10. Reduction of air pollution	11. Biodiversity /general environment impact	12. GHG emission reduction)/Mt CO_2/yr
Nuclear power	5000	90	30	45	90	100	20	80	5000	100	70	20
BESS and energy storage systems for regulation of renewable energy sources generation output profile	768	12	70	5	50	90	20	70	12000	60	50	0.5
Power grid interconnection within Central Asia and Caucasus region	0.35	9	80	9	70	40	30	90	12000	40	30	0.2
Small hydropower (<10 MW) in south and north-east Kazakhstan	7500	190	90	9	40	40	20	80	5000	80	60	28
Large scale on-grid solar farms (0.1-1 GW)	1500	25	80	10	30	70	60	70	12000	100	80	20
Energy management system in buildings for public sector	30	6	30	15	80	90	50	80	20000	80	30	15
Electrification of urban public and municipal transport	1100	11	80	10	60	60	50	60	5000	70	60	23.5
Electric vehicles (EV) including the charging points grid	750	37	80	2	50	60	50	60	5000	70	60	30
Energy management system in buildings for private sector	30	7	50	20	60	80	40	60	20000	70	70	20
Natural gas combined cycle power plants for flexible power grid supply	1500	16	80	1.2	60	80	40	60	6000	40	50	3.5
Large scale on-grid wind farms (0.1-1 GW)	1800	50	80	7	60	90	30	70	6000	100	70	20

Scoring matrix

	Costs		Benefits									
			Technology diffusion			Policy	Social			Environmental		Climate related
	1. Capital cost (CAPEX)	2. Annual operational expences (OPEX)	3. TRL (technology readiness level)	4. Market potential/economic growth	5. Complexity of implementation	6. Compliance with national development policies and priorities	7. Gender impact	8. Access to energy/Quality of energy service/Energy safety	9. Creation of new jobs	10. Reduction of air pollution	11. Biodiversity /general environment impact	12. GHG emission reduction)
Nuclear power	33	54	0	100	0	100	0	67	0	100	80	66
BESS and energy storage systems for regulation of renewable energy sources generation output profile	90	97	67	9	67	83	0	33	47	33	40	1
Power grid interconnection within Central Asia and Caucasus region	100	98	83	18	33	0	25	100	47	0	0	0
Small hydropower (<10 MW) in south and north-east Kazakhstan	0	0	100	18	83	0	0	67	0	67	60	93
Large scale on-grid solar farms (0.1-1 GW)	80	90	83	20	100	50	100	33	47	100	100	66
Energy management system in buildings for public sector	100	100	0	32	17	83	75	67	100	67	0	50
Electrification of urban public and municipal transport	85	97	83	20	50	33	75	0	0	50	60	78
Electric vehicles (EV) including the charging points grid	90	83	83	2	67	33	75	0	0	50	60	100
Energy management system in buildings for private sector	100	99	33	43	50	67	50	0	100	50	80	66
Natural gas combined cycle power plants for flexible power grid supply	80	95	83	0	50	67	50	0	7	0	40	11
Large scale on-grid wind farms (0.1-1 GW)	76	76	83	13	50	83	25	33	7	100	80	66
Scoring scale	0= Very high --> 100= Very low	0= Very high --> 100= Very low	0= Very low --> 100= Very high	0= Very low --> 100= Very high	0= Very high --> 100= Very low	0= Very low --> 100= Very high	0= Very low --> 100= Very high	0= Very low --> 100= Very high	0= Very low --> 100= Very high	0= Very low --> 100= Very high	0= Very low --> 100= Very high	0= Very low --> 100= Very high
Criterion weight	8	8	9	9	9	9	5	9	8	9	8	9

Decision matrix

	Costs			Benefits									
				Technology diffusion			Social			Environmental		Climate related	
	1. Capital cost (CAPEX)	2. Annual operational expences (OPEX)	3. TRL (technology readiness level)	4. Market potential/ economic growth	5. Complexity of implementation	Compliance with national development	7. Gender impact	to energy/Quality of energy service/E	9. Creation of new jobs	10. Reduction of air pollution	Biodiversity/general environment	12. GHG emission reduction)	Total Score
Nuclear power	267	435	0	900	0	900	0	600	0	900	640	598	5239
BESS and energy storage systems for regulation of renewable energy sources generation output profile	718	774	600	78	600	750	0	300	373	300	320	9	4823
Power grid interconnection within Central Asia and Caucasus region	800	787	750	160	300	0	125	900	373	0	0	0	4196
Small hydropower (<10 MW) in south and north-east	0	0	900	160	750	0	0	600	0	600	480	840	4330
Large scale on-grid solar farms (0.1-1 GW)	640	717	750	181	900	450	500	300	373	900	800	598	7110
Energy management system in buildings for public sector	797	800	0	284	150	750	375	600	800	600	0	447	5602
Electrification of urban public and municipal transport	683	778	750	181	450	300	375	0	0	450	480	704	5150
Electric vehicles (EV) including the charging points grid	720	665	750	16	600	300	375	0	0	450	480	900	5257
Energy management system in buildings for private sector	797	796	300	386	450	600	250	0	800	450	640	598	6067
Natural gas combined cycle power plants for flexible power grid supply	640	757	750	0	450	600	250	0	53	0	320	100	3920
Large scale on-grid wind farms (0.1-1 GW)	608	609	750	119	450	750	125	300	53	900	640	598	5902
Criterion weight	8	8	9	9	9	9	5	9	8	9	8	9	

Annex 4: List of stakeholders involved (energy sector)

Name	Affiliation (Ministry, Department, Company, etc.)	Form of consultation
Kazbek Rysbekov	Acting Director, Sectoral Competence Department 1 (SCD-1), "Zhasyl Damu" JSC	Active participation in the MCA-based prioritization process, including the design of weighted scoring matrices and the formation and validation of the technology shortlist to guarantee alignment with high-level national strategies and sectoral growth pathways
Ainura Baydalina	Manager, Sectoral Competence Department 1 (SCD-1), "Zhasyl Damu" JSC	
Aydyn Bakdolotov	Climate Policy Analyst, UNDP Kazakhstan	
Aislu Dossanova	Director of the Environmental Regulation Department, KAZENERGY Association	
Rustam Nasirkhan	Director, Department of Modeling, Analysis, and Forecasting (DMAF), "Zhasyl Damu" JSC	
Alexander Cherednichenko	Senior Manager, Sectoral Competence Department 1 (SCD-1), "Zhasyl Damu" JSC	
Nurgali Rakhmanov	Director, Public Foundation "Digital Society"	
Nicholas Pomeroy	Founder and Director, AngloKazakh Limited	
Aida Maksut	Board Member of the "Qazaq Green" RES Association and Director, LLP "SSDC"	
Alisher Kairat	Head of Multilateral Cooperation Division, Department of International Cooperation, Ministry of Energy of the Republic of Kazakhstan	
Meruert Nizamutdinova	Senior Expert, Electric Power Development Department, Ministry of Energy of the Republic of Kazakhstan	
Zhanel Zhakupova	National Coordinator of Global Cleantech Innovation Program in Kazakhstan, UNIDO/IGTIC	
Akbota Zhakaeva	Senior Expert (Energy), KAZENERGY Association	
Anton Merkulov	Candidate of Technical Sciences. Senior member IEEE	

Annex 5: Extended list of technologies (waste sector)

#	Extended list of technologies for waste sector
	Improved Waste Collection Practices
1	Integrated Remote Sensing and GPS-Based Vehicle Tracking System for Illegal Dumpsite Detection and Waste Transport Control
2	Automated and AI-Assisted Mechanical Sorting Systems for Enhanced Fractionation Efficiency in Material Recovery Facilities Processing Municipal Solid Waste
3	Upgrade from Two-Stream to Multi-Stream Source-Separated Waste Collection Systems for Enhanced Material Recovery in Urban Areas
4	Smart Waste Management System Integrating Barcode/RFID Tracking, GIS-Based Route Optimization, and Digital Citizen Engagement for Enhanced Source-Separated Waste Collection
	Energy and Material Recovery from Waste
5	In-vessel Composting of Organic Fraction of Municipal Solid Waste and Other Biomass Types in Urban Areas
6	Open-Air Composting of Biomass in Rural Regions (Windrow or Aerated Static Pile)
7	Waste-to-Energy: Incineration of Non-Recyclable Municipal Solid Waste and Biomass for Volume Reduction and Renewable Energy Recovery with Emission Control
8	Waste-to-Energy: Biomethanation of Biomass for Biogas Production
9	Refuse-Derived Fuel (RDF) Production from Wastes as a Standardized Alternative Fuel for Industrial Processes and Power Plants
10	Pyrolysis of Mixed or Non-Recyclable Plastics for Energy and Chemical Feedstock Recovery
11	Gasification of Carbon-Rich Industrial Wastes for Syngas Production
12	Beneficial Use of Industrial Solid Wastes as Aggregates in Construction Sector
13	Metal Recovery from Industrial Wastes through Integrated Mechanical and Hydrometallurgical Processes
14	Circular Economy-Based Management of Construction & Demolition Waste for Resource Recovery and Material Reuse
	Engineered Waste Disposal Sites
15	Sanitary Landfills with Landfill Gas Collection and Flaring for Methane Emission Mitigation without Energy Recovery
16	Sanitary Landfills with Landfill Gas-to-Energy Systems for Methane Capture and Renewable Energy Generation
17	Bioreactor Landfills for Accelerated Waste Stabilization and Optimized Landfill Gas Production
	Rehabilitation of old waste disposal sites for methane emission mitigation and leachate control
18	Pipe Network Installation for Landfill Gas Capture at Legacy Dumpsites with Flaring or Biofiltration for Methane Mitigation
19	Pipe Network Installation for Landfill Gas Capture at Legacy Dumpsites with Methane Utilization for Heat/Electricity Recovery
20	Capping Legacy Dumpsite Surfaces with Biocovers to Oxidize Fugitive Methane Emissions

#	**Extended list of technologies for waste sector**
21	Installation of Leachate Collection, Containment, and Treatment Systems for Environmental Remediation of Legacy Dumpsites
	Wastewater Treatment
22	Specialized Wastewater Treatment Plants in Industrial Parks
23	Anaerobic Digestion of Sewage Sludge in Wastewater Treatment Plants for Energy Recovery
24	Incineration of Sewage Sludge in Cement Production or Waste-to-Energy Facilities

Annex 6: Technology Factsheets for selected technologies (waste sector)

TFS-W-01:

Category	Description & Data
1. Technology Name	**Integrated Remote Sensing and GPS-Based Vehicle Tracking System for Illegal Dumpsite Detection and Waste Transport Control**
2. Technical Overview	**Function:** A high-tech digital platform integrating satellite positioning (GPS) on waste vehicles with Earth Remote Sensing (ERS) and Geographic Information System (GIS) to manage waste handling processes. **Process:** Firstly, each vehicle is equipped with sensors to provide real-time data on location, route, speed, and stops. This ensures operational fleet management, route optimization, and documents non-compliance (unauthorized stops/off-route travel) to enforce legal transport to sanctioned facilities. Secondly, the system utilizes ERS and GIS capabilities for the automatic detection, monitoring, and assessment of existing illegal dumps and unauthorized disposal sites. While satellites detect the result (the dump), GPS tracks the cause (the vehicle). More advanced systems use Artificial Intelligence (AI), the Internet of Things (IoT) and real-time data on traffic and waste generation rates to dynamically adjust collection routes and schedules, minimizing fuel consumption and vehicle emissions. **Components:** Requires mature, affordable and widely available GPS hardware for real-time data transmission in each vehicle and centralized GIS software for oversight and data interpretation. **Current Capacity:** Given Kazakhstan's vast size of 2.7 million km^2, physical patrolling for illegal waste disposal is impractical. Satellite monitoring offers the only scalable solution for environmental control and oversight. The Government of Kazakhstan employs this technology through “JSC NC Kazakhstan Gharysh Sapary” (NC KGS JSC), the National Operator of the Earth Remote Sensing Space System. Since 2018, NC KGS JSC has utilized space monitoring services—specifically high and medium-resolution spacecrafts like KazEOSat-1 (1-m resolution) and KazEOSat-2 (6.5-m resolution)—to detect and track unauthorized dumpsites across the country.
3. Technology Readiness Level (TRL)	**TRL 9 (Mature Technology).** Components (GPS hardware, GIS software) are fully established and reliable. Digitalization is a global megatrend in waste management. The government has high resolution satellite-based monitoring infrastructure. Its integrated deployment as a mandatory national enforcement system is a planned regulatory innovation in Kazakhstan.
4. Ease of Implementation and Replicability	**Potential:** Extremely high replicability nationwide due to the urgent priority of eliminating illegal dumps (over 5,000 sites documented in 2023). It is also essential for monitoring the highly fragmented Kazakh market of 800+ specialized waste collection companies.

	Constraints: Its implementation requires upfront investment in GPS hardware and creation of software for integration with existing remote satellite monitoring capacity, as well as substantial institutional capacity to manage, analyze, and enforce data-driven oversight. As such, it remains a forward-looking intervention rather than a widely established practice.
5. Financial Requirements and Costs	**Capital Expenditure (CAPEX):** Includes one-time cost for purchasing and installing GPS hardware (price varies by device sophistication) and developing/licensing the centralized GIS platform. **Operational Expenditure (OPEX):** Includes recurring tracking software subscription fees, data transmission (SIM card) charges, and system maintenance. **Context:** While costs are generally low relative to total fleet operations, they constitute a significant burden for small operators under the current low-tariff regime. However, the goal of fleet tracking and route optimization software (using GPS/GIS) is to maximize the tons collected per day by minimizing non-collection time. Optimized routes can save significant travel distance, time, and fuel. **Estimated Total Cost** It is assumed that 4.5 million tons of MSW is generated annually. The total CAPEX is estimated at €1,400,000 (the installation of ruggedized hardware on approx. 2,600 waste collection vehicles; server infrastructure; software and personnel training), with an annualized CAPEX of approximately €320,000 per year (hardware amortized over 5 years; software/infrastructure over 10 years). The total OPEX is estimated at €1,900,000 per year (covering data transmission, satellite tasking, and salaries). Total Life-Cycle Cost is estimated at €0.49 per ton of waste processed. This aggregates an annualized CAPEX of €0.07 per ton and an annual OPEX of €0.42 per ton.
6. Pollution Prevention and Environmental Protection	**Prevention:** Significantly reduces the creation of new illegal dumpsites by ensuring waste is routed strictly to authorized facilities. This directly mitigates local pollution and health risks associated with unauthorized dumping. **Monitoring:** ERS/GIS components allow for real-time pollution tracking and assessment of existing sites. **Control:** Supports tighter state environmental control. By ensuring diversion to managed sanitary landfills with cover systems, the technology prevents the formation of unauthorized dumpsites that lack bottom liners, thereby mitigating soil and groundwater contamination from toxic leachate containing heavy metals. Furthermore, it reduces air pollution from open burning (black carbon, dioxins) common at unmanaged sites.
7. Economic Viability	**Efficiency:** Enhances viability through route optimization and improved logistics, leading to substantial fuel savings (approximately 15% reduction) and reduced fleet operating costs. **Revenue:** Maximizes benefits by ensuring waste reaches proper recovery facilities rather than illegal sites.

	Cost Avoidance: The cost of detecting illegal dumping is lower by orders of magnitude than the cost of remediating it. The cost to physically liquidate (clean up) an illegal dump is conservatively estimated at €25 per ton (machinery +labor +transport). **Risk:** Financial sustainability is sensitive to low waste tariffs, which challenges the profitability of smaller collection companies attempting to implement this mandatory system. **Estimated Payback Period:** The project is expected to pay for itself within 1.2 years solely through avoided cleanup costs (not including fuel savings and lowered maintenance), assuming the system prevents illegal dumping equal to 10% of the national municipal solid waste stream (4.5 million tons annually). The asymmetry between cheap digital monitoring and expensive physical remediation drives the high return.
8. Job Creation Potential	**Specialized Roles:** Creates demand for qualified personnel to process and interpret complex remote sensing and GPS data. Specific roles include approximately 10 full-time analysts for the central monitoring center and additional field inspection teams for validation. **Government Roles:** Generates positions within regulatory bodies for data analysis, monitoring, and effective enforcement of environmental controls. **Estimated Number of New Jobs:** It is clear that this system will create more white-collar jobs (i.e., GIS Analysts, Remote Sensing Specialists, Data Scientists, Software Engineers and Fleet Managers) in comparison to blue-collar jobs. It is estimated that 100-200 new permanent job positions will be created nation-wide.
9. Social Co-benefits	**Public Trust:** Fosters trust in the formal waste system through transparent monitoring and improved service reliability. The system provides digital evidence to enforce the "Polluter Pays" principle, reducing corruption and administrative opacity. **Health:** Improves urban cleanliness and reduces public health risks associated with localized pollution specifically odors and smoke from spontaneous combustion at open dumps.
10. Climate Change Mitigation Benefits	**Direct Reduction:** Prevents illegal dumping uncontrolled anaerobic decomposition, thereby reducing methane emissions. **Avoided Emissions:** Ensures waste is disposed of in managed landfills which are legally required to have gas collection systems or daily cover, capturing or oxidizing methane that would otherwise be released into the atmosphere. **Operational Reduction:** Route optimization lowers fuel consumption, reducing CO2 emissions from transport. **Net Reduction:** 0.55 tons CO_2e per ton of waste processed. This figure is derived from a rough Life Cycle Assessment (LCA) comparing a Business-as-Usual scenario (uncontrolled methane from illegal dumpsites; 1.36 tCO_2e/ton) against the modelled scenario (diversion to sanitary landfills with cover systems, which oxidizes ~10% of methane, and optimized transport; 0.81 tCO_2e/ton). This corresponds to a national mitigation potential of approximately 2.4 million tons of CO_2-equivalent per year,

	assuming the system prevents illegal dumping equal to 10% of the national municipal solid waste stream (4.5 million tons annually).
11. Compliance with National Targets and Legislation	**Mandate:** The 2021 Environmental Code mandates that waste disposal organizations equip their vehicles with GPS sensors, establishing a clear legal basis for this technology. This mandate is a strategic necessity that provides real-time data on vehicle movement, complementing existing satellite monitoring to ensure waste reaches authorized disposal facilities, prevent the creation of new illegal dumpsites, and enhance data transparency for climate policy. **Targets:** Directly aligns with and supports the priorities of the "Green Kazakhstan" National Project. **Barrier:** While the legal framework exists, institutional capacity for actual enforcement remains a key administrative hurdle.
12. Example Projects	**Quito (Ecuador):** Central system tracks routes and allows citizen reporting of infractions. **Delhi (India):** Transparent management using GPS, radio-frequency identification (RFID) tagging, and management information system (MIS) software. **Hainan Island (China):** Drone and spatial mapping tools used to detect and assess illegal waste sites.
13. Advantages & Disadvantages	**Advantages:** Reduces illegal dumping; lowers fleet operating costs/emissions; enhances transparency and compliance; supports state environmental control; low financial risk and extremely high returns. **Disadvantages:** Financial burden on small operators due to low tariffs; requires institutional capacity building.

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TFS-W-02:

Category	Description & Data
1. Technology Name	**Anaerobic Digestion of Sewage Sludge in Wastewater Treatment Plants for Energy Production**
2. Technical Overview	**Function:** A controlled biological process where microbial consortia decompose organic matter in sewage sludge without oxygen (anoxic), converting it into biogas (50–75% methane) and digestate (nutrient-rich residue). The digestors can also accept external biomass types and co-digest them with sewage sludge. **Process:** Involves four phases: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Occurs in engineered biodigesters under Mesophilic (35°C–40°C) or Thermophilic (55°C) conditions. Thermophilic digestion is preferred for sanitation (pathogen destruction). **Inputs/Outputs:** Treats sludge from municipal/industrial wastewater. Sludge treatment accounts for ~40–45% of total WWTP costs. Reduces sludge volume by 5–15% (organic conversion). Produced biogas is ~2/3 methane can be harnessed in combined heat and power (CHP) units to generate electricity and heat. Generated energy can be used to heat digestors and power biological wastewater treatment units onsite or supplied to the grid. Digestate, a nutrient-rich residue, can be applied as a fertilizer or soil conditioner, replacing energy-intensive synthetic fertilizers and improving soil carbon storage capacity, provided its heavy metal content meets safety standards. **Capacity:** Anaerobic digestion (AD) offers high scalability for wastewater treatment plants (WWTPs). In Kazakhstan, AD adoption for sewage sludge is still emerging, often hindered by low wastewater tariffs that limit profitability. While generally more viable for large installations (50,000 Population Equivalent), smaller plants (approximately 10,000 PE) can achieve cost-effectiveness when integrated with high-load digestion processes. For facilities with capacities exceeding 100 Nm^3 biogas/h, biogas upgrading to biomethane is strongly recommended. AD infrastructure typically has a long operational lifespan (often decades) provided that internal conditions are continuously monitored and maintained for reliability.
3. Technology Readiness Level (TRL)	**TRL 9 (Mature Technology).** Universally recognized as the standard process for sludge stabilization globally. In Europe, it has been successfully applied to municipal sludge for over two decades, confirming it as a fully proven operational system.
4. Ease of Implementation and Replicability	**Potential:** Highly relevant for Kazakhstan to address the rehabilitation of outdated Soviet-era infrastructure. Replicable in major cities aligning with the Green Economy Concept. Kazakhstan processed 683 million m^3 wastewater in 2020. Well-run systems may allow WWTPs to be 50–100% energy self-sufficient, insulating the utility from electricity price hikes. **Enablers:** Financial support available, such as the $105 million EBRD contribution for the Aktobe plant upgrade and preferential

	loans (3%) from the Industrial Development Fund. State programs have planned the construction and reconstruction of wastewater treatment facilities to achieve a combined installed capacity of 2,430,295 m^3/day between 2021 and 2027.
5. Financial Requirements and Costs	**Capital Expenditure (CAPEX):** AD systems for municipal wastewater sludge require substantial initial capital investment, encompassing the construction of digesters, pre-treatment facilities, and biogas utilization equipment. For a representative theoretical 100,000 m^3/day facility in Kazakhstan (Sludge generation =18,000 tons Total Solids (TS)/year; Served Population =500,000 PE), the total CAPEX for the sludge line upgrade alone is estimated at around €30 million. These costs are elevated compared to global averages due to the winterization of the system (insulation, heat tracing) required for the extreme continental climate. CAPEX =€91.3 ton TS/year. **Operational Expenditure (OPEX):** The gross annual OPEX for the modelled AD system in the theoretical facility with 100,000 m^3/day capacity is approximately €2.2 million/year (€123 ton TS/year). **Estimated Total Cost:** The Levelized Cost of Treatment (LCOT) is estimated at €204 per ton of TS over a 20-year facility lifespan.
6. Pollution Prevention and Environmental Protection	**Emissions & Odor:** Replacing open sludge lagoons with anaerobic digestion (AD) eliminates fugitive methane emissions and significantly reduces odors through sealed systems. For example, at the Almaty WWTP, sludge lagoons occupy hundreds of hectares in a rapidly growing metropolitan area, creating a "dead zone" for development due to persistent odor issues. **Sanitization:** Thermophilic digestion destroys pathogens, viruses, and weed seeds, ensuring the digestate is safe for land application. Mesophilic digestion (35–37°C) can be preferred in Kazakhstan to manage the energy balance during severe winters. However, this renders marketing of sewage sludge digest as biofertilizer to the public unviable. **Nutrient Recovery:** While agricultural reuse is currently limited by heavy metal contamination and market barriers, the technology enables the recovery of Struvite (magnesium ammonium phosphate) to protect equipment. The bulk digestate is best utilized for land reclamation (e.g., covering mine tailings or landfills) rather than food-chain agriculture.
7. Economic Viability	**Revenue:** Energy savings from biogas use can offset operational costs, and additional revenue streams include tipping fees for digesting external biomass, fertilizer sales, biogas sales to industry or the grid, and carbon credits from methane reduction. Assuming 100% of biogas is used for onsite consumption to offset grid purchases at the theoretical WWTP, annual combined heat and electricity generation is estimated at 30.6 GWh, based on CHP performance with 40% electrical efficiency, 45% thermal efficiency, and 90% availability. This could result in annual savings of approximately €2.3 million, assuming industrial electricity tariffs of €0.075/kWh.

	Biofertilizer (digestate) marketing is not considered as a source of income. **Sustainability:** Lowers total WWTP operational costs and landfill disposal fees. Financial viability fully relies on estimated avoided costs, which accounts for the avoidance of escalating environmental fines/landfill taxes under the 2021 Environmental Code and lagoon dredging/maintenance. **Payback Period Estimation:** Estimated at 16,7 years under the best conditions (accounting for full heat/electricity savings and avoided disposal costs/environmental fines). This may be unacceptable for commercial loans; however, AD adaptation projects can be viable with below-market-rate loans or favorable financial terms offered by institutions such as the World Bank, EBRD, or Asian Development Bank, which prioritize decarbonization and compliance benefits over immediate cash flow. In a different analysis focusing on Korea, the operation of an anaerobic digestion system becomes economical (benefit/cost ratio = 1), when the capacity is 100,000 m^3/day or more. **Carbon Credits:** If Kazakhstan implements a robust Emission Trading Scheme (ETS) or if the project sells credits on the voluntary market (Article 6 of the Paris Agreement), the reduction GHG emissions could yield additional revenue.
8. Job Creation Potential	**Green Jobs:** Generates skilled employment in the renewable energy and waste sectors. **Roles:** Specialized positions in plant design, construction, technical operations, maintenance, and laboratory analysis for process monitoring. **Estimated Potential:** Estimated at approximately 10 jobs per 10,000 metric ton of processed TS/year. With widespread AD adoption nationwide, 200-400 permanent operational jobs can be created.
9. Social Co-benefits	**Public Health:** Reduces public exposure to pathogens found in untreated sludge. **Agriculture:** Provides high-quality soil amendments for food security. **Modernization:** Demonstrates commitment to upgrading municipal infrastructure, improving urban sanitation standards.
10. Climate Change Mitigation Benefits	**Kazakhstan's Energy Sector Emissions:** In 2022, the energy sector (electricity and heat) accounted for 79.9% of total GHG emissions. Around 67–70% of electricity is coal-based, and fossil fuels supply nearly 90% of generation. In 2019, the power sector's carbon intensity averaged ~516 g CO_2/kWh. **Fossil Fuel Substitution:** In Kazakhstan's coal-heavy energy sector, biogas can replace coal for heat and power. Due to the high carbon intensity of the Kazakh grid, displacing grid electricity offers high "carbon leverage". **Avoided Emissions:** By reducing sludge volumes (50-60%), AD lowers the overall need for sludge disposal, contributing to the

	reduction of GHG emissions from waste management. Critically, it avoids the massive methane emissions from open lagoons, where winter freezing traps gas that is pulse released during spring thaw. **Estimated Climate Mitigation:** Theoretical AD unit delivers a net reduction of approximately 3.8 tons CO_2e per ton of processed Total Solids (TS). This estimate uses a Life Cycle Assessment (LCA) approach comparing a "Business as Usual" open lagoon scenario (high fugitive methane) against an AD system with CHP units offsetting gird electricity consumption.
11. Compliance with National Targets and Legislation	**Alignment:** AD is highly relevant given the country's goals under the Concept for Transition to Green Economy and the 2021 Environmental Code. It addresses infrastructure modernization needs, supports circular economy principles, and reduces methane emissions. Kazakhstan aims to increase the treatment of anthropogenic wastewater to 45% by 2030, 65% by 2040, and achieve 100% treatment by 2050. **Strategic Goals:** Critical for the national objective to increase urban wastewater treatment coverage and modernize circular economy infrastructure. **Incentives:** Supported by state financial instruments for infrastructure upgrades.
12. Example Projects	**Aktobe, Kazakhstan:** In Aktobe, the Eurasian Bank of Reconstruction and Development (EBRD) is contributing $105 million to improve the quality of Aktobe Su-Energy Group JSC's wastewater and sewage sludge treatment plant. **Amsterdam, Netherlands:** Large-scale phosphate recovery from sewage sludge for fertilizer production which is enough to fertilize the equivalent of 10,000 football pitches annually. **Tunisia:** A wastewater sanitation project serving 1.6 million people, supported by the World Bank, aims to generate an emission reduction of over 1 million tons of carbon dioxide equivalents annually.
13. Advantages & Disadvantages	**Advantages:** Generates renewable energy at predictable rates (baseload); recovers nutrients (circular economy); effectively sanitizes sludge; reduces landfill volume and costs. **Disadvantages:** High upfront capital requirement; requires modernization of existing WWTPs; technically complex operations; financial sustainability challenged by low tariffs.

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TFS-W-03:

Category	Description & Data
1. Technology Name	**Extraction of metals from industrial waste using integrated mechanical and hydrometallurgical processes**
2. Technical Overview	**Function:** A comprehensive secondary resource recovery system that converts complex industrial waste into high-quality raw materials. **Process:** The metal recovery process is executed in two sequential stages. The first is Mechanical Pre-treatment, where materials undergo shredding, crushing, sieving, magnetic separation, and eddy current separation. This phase concentrates the valuable metal fractions based on their density and magnetic properties. The concentrated material is then fed into the second stage, Hydrometallurgical Processing. This stage involves the dissolution of the concentrated fractions using chemical solutions (leaching), followed by a purification sequence utilizing techniques such as solvent extraction or ion exchange. Finally, the purified metals are recovered from the solution via processes like electrowinning or chemical precipitation. Low-temperature hydrometallurgical processing consumes significantly less energy than pyrometallurgy, lowering the carbon footprint. Integration with bioleaching can further reduce energy needs. **Applicability:** The metal recovery process is strategically applicable to major components of Kazakhstan's industrial waste, including mining tailings, metallurgical slag, sludge, e-waste and spent catalysts. This waste stream represents a significant resource opportunity, as Kazakhstan generates over 800 million tons of industrial waste annually. Over 20 billion tons of industrial wastes have accumulated on the territory of the country. The composition of this waste is predominantly Technogenic-Mineral Formations (TMF), such as overburden from mining activities and bottom ash, which account for approximately 70%. The remaining share consists of processing industry waste (10%) and waste from other activities (20%). **Outputs:** High-purity base metals (Cu, Ni, Zn, Pb, Cr), precious metals, trace elements and inert mineral aggregates that can be used as aggregates in construction sector. “Closing the loop” on critical raw materials reduces dependency on virgin extraction, minimizing mining-related GHG emissions and land use .
3. Technology Readiness Level (TRL)	**TRL 9 (Mature Technology)** Foundational technologies (magnetic separation, shredding, leaching, electrowinning) are standard industrial practices. Integrated systems are fully operational globally, particularly for e-waste and complex residue processing.
4. Ease of Implementation and Replicability	**Potential:** High replicability in regions with concentrated industrial activity (e.g., mining hubs). **Complexity:** Technically challenging; requires customized multi-stage separation schemes tailored to specific waste compositions. Demands skilled personnel and rigorous chemical management.

	Barriers: High capital costs and complexity. Hydrometallurgy faces risks related to poor selectivity or difficult dissolution of certain components. **Enablers:** Hydrometallurgy offers flexibility and lower energy consumption compared to pyrometallurgy.
5. Financial Requirements and Costs	**Capital Expenditure (CAPEX):** CAPEX is high due to specialized equipment for sorting, chemical processing, and waste treatment, though hydrometallurgy generally requires less initial investment than pyrometallurgy. For a theoretical 1.5 million tons per annum (Mtpa) facility processing copper mine tailings and recovering copper, the total initial CAPEX is estimated at €125.5 million. This reflects a capital intensity of approximately €83 per annual ton of capacity. Costs include a "winterization premium" (10–15%) for enclosed structures and heat tracing required by the Kazakh climate. Reprocessing tailings form the basis of the evaluation since most industrial waste in Kazakhstan consists of tailings. **Operational Expenditure (OPEX):** OPEX is estimated at €13 – €18 per ton of waste processed. Key cost drivers are chemical reagents like sulfuric acid (30%), maintenance (23%), and labor (16%). The project demonstrates strong resilience due to Kazakhstan's low industrial electricity tariffs and labor costs. **Estimated Total Cost:** The Levelized Cost of Treatment (LCOT) is estimated at €22–26 per ton processed waste over a 20-year facility lifespan.
6. Pollution Prevention and Environmental Protection	**Benefits:** Reduces land disturbance and water use associated with primary mining. Stabilizes industrial residues, lowering contamination risks compared to landfilling. Theoretically, reprocessing 1.5 Mtpa clears approximately 10 hectares of dumpsite land annually, producing inert sand suitable for construction or remediation. **Risks:** Generates large volumes of waste solutions and secondary toxic streams from leaching. Requires rigorous waste treatment, solution recycling, and wastewater treatment to prevent environmental contamination by reagents.
7. Economic Viability	**Long-term Viability:** High, driven by circular economy principles. Converts liabilities into marketable commodities (metals, aggregates). **Competitiveness:** High-purity outputs enhance marketability. Generator-operated models offer the strongest financial advantage by controlling waste composition. The process leverages a surface deposit with zero mining/exploration costs. By combining mechanical pre-concentration (rejecting 80-90% of mass) with hydrometallurgy, the facility avoids the prohibitive acid consumption that typically makes low-grade reprocessing uneconomic. **Avoided Costs:** Significant cost reduction compared to conventional hazardous waste disposal. Additionally, using recovered materials in industrial processes reduces expenses for raw material procurement. This approach also delivers climate

	benefits by closing resource loops, significantly mitigating energy use and environmental impacts (e.g., land disturbance and water consumption) associated with virgin resource extraction. **Revenue:** Economic feasibility is driven by the high market value of recovered non-ferrous metals (i.e., Cu, Zn). The operating margin is estimated at ~€16 per ton of waste at forecasted 2025 metal prices (Copper ~€9,500/t). **Payback Period Estimation:** 5.4 years.
8. Job Creation Potential	**Green Jobs:** Generates employment in specialized engineering, plant maintenance, chemical process monitoring, and material marketing. **Sector:** Supports the recycling sector and advanced Material Recovery Facilities (MRFs). Strategic importance for "mono-towns" (e.g., Satpayev, Ridder) dependent on the mining sector, offering employment that is not contingent on new primary ore discoveries. **Estimated Potential:** 1.5 jobs per 10,000 tons of processed waste per year. Processing a small fraction of the annual generation (e.g., 5% or 80 million tons/year) would theoretically implying over 5,000 direct jobs nation-wide.
9. Social Co-benefits	**Public Health:** Reduces public health risks associated with industrial pollution and hazardous waste storage. **Sustainability:** Promotes resource conservation and stewardship, reducing the toxicity of industrial wastes. **Community:** Supports the long-term sustainable development of industrial communities in Kazakhstan.
10. Climate Change Mitigation Benefits	**Emissions Avoidance:** The integrated process avoids the energy-intensive excavation and comminution of low-grade primary ores (which require moving ~200 tons of rock per ton of metal). This results in a carbon footprint of ~8.9 ton CO_2e per ton of copper produced, compared to >10 ton CO_2e/ton for domestic primary mining. The mitigation potential is derived by comparing this against the even higher energy intensity of domestic primary mining, which suffers from declining ore grades. For more complex waste streams, mitigation potential can be significantly higher. **Estimated Mitigation:** Net reduction of approximately 1.0–1.5 ton CO_2e per ton of copper produced compared to the Business as Usual (BAU) primary mining scenario. While the current footprint is high due to Kazakhstan's coal-intensive grid (516 g CO_2e/kWh), integrating renewable energy for the electrowinning stage could further reduce emissions to ~5.9 kg CO_2e/kg Cu.
11. Compliance with National Targets and Legislation	**Alignment:** Supports the Circular Economy, Green Economy Concept, and Carbon Neutrality Strategy 2060. **Mandates:** Essential for meeting the 2021 Environmental Code priority on resource recovery and the policies of increasing industrial waste recycling rate. **Standards:** Aligns with Best Available Techniques (BAT) principles.

12. Example Projects	**China (Huizhou):** Ultrasonic recovery from electroplating sludge achieved 95–99% recovery of Cu and Fe. **China (Suzhou):** Solvent extraction recycled 60% of wastewater and recovered metals (Ni, Cr, Cu, Zn) valued at ~$3 million/year. **USA (Missouri):** Conceptual plant design for processing 16,890 metric tons/year of metal finishing wastes (105,000 gallons/day). **Kazakhstan:** RSE Zhezkazganredmet is a state-owned enterprise with about 120 employees, specializing in hydrometallurgical extraction of rare metals from copper production waste. It is the largest producer and exporter of ammonium perrhenate in the CIS, generating approximately $1.5 million annually largely from exporting rhenium compounds and osmium isotopes. The company plays a critical role in global rare metal supply chains for aerospace and electronics industries.
13. Advantages & Disadvantages	**Advantages:** Recovers high-value critical metals; lower energy use than pyrometallurgy; reduces hazardous waste liability; closes resource loops. **Disadvantages:** High CAPEX/OPEX; technically complex; generates chemical waste streams requiring strict management; process specificity limits broad application without customization.

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TFS-W-04:

Category	Description & Data
1. Technology Name	**Circular Economy-Based Management of Construction and Demolition Wastes, Metallurgical Slags, and Mining Wastes to Recover Resources for the Construction Sector**
2. Technical Overview	**Function:** A holistic industrial ecology system designed to convert complex technogenic waste streams—specifically Construction and Demolition (C&D) waste, metallurgical slag, and mining tailings—into high-quality secondary raw materials and aggregates. The system operates on a mechanical and chemical stabilization basis, strictly excluding hydrometallurgical processes for trace metal recovery, focusing instead on physical valorization to transition from a linear "take-make-dispose" model to a circular economy. **Process:** The operational workflow integrates three distinct stages: 1. Selection: Rigorous classification of the new and legacy wastes to determine mineralogy and physical properties. 2. Mechanical Processing: Utilization of energy-efficient electric crushing and screening circuits. This includes magnetic separation for ferrous recovery and air density separation (wind shifting) to remove light contaminants from C&D streams. 3. Stabilization & Valorization (only for Steelmaking Slags): Implementation of "aging" protocols (6–12 months) for steel slag to convert free oxides into stable hydroxides is necessary to mitigate volumetric expansion of the product. Advanced processing includes active carbonation," where calcium silicate-rich slags are cured with CO_2 to form calcite, permanently sequestering carbon while strengthening the aggregate. **Inputs:** C&D waste (concrete, masonry, and reclaimed asphalt pavement). Metallurgical slags (Blast Furnace Slag and Steel Slag from Basic Oxygen Furnace/Electric Arc Furnace processes). Mining wastes (Waste rock and tailings). Kazakhstan generates more than 800 million tons of industrial waste annually. The country has an accumulated inventory of over 20 billion tons of technogenic mineral formations, representing a significant sunk cost in land use and environmental compliance. It is estimated that 9 million tons of C&D waste is generated annually in Kazakhstan. **Outputs:** **Recovered Metals:** Scrap metal (ferrous) recovered via magnetic separation. **Construction Materials:** Stabilized mineral aggregates for road bases, railway ballast, and concrete production. **Cementitious Materials:** Ground Granulated Blast Furnace Slag (GGBFS) serving as a high-value supplementary cementitious material to replace Portland cement.

	Carbon Sinks: Carbonated aggregates that effectively act as industrial carbon sinks.
3. Technology Readiness Level (TRL)	**TRL 8–9 (Almost Mature Technology).** Based on globally established industrial techniques. Mechanical sorting, metal separation, and the use of treated (aged) slag/ash as construction aggregates are conventional practices, provided they meet quality standards. However, the specific advanced component of accelerated carbonation of slag for simultaneous CO_2 sequestration and aggregate enhancement remains closer to TRL 8, representing systems successfully piloted and commercially deployed but requiring site-specific optimization.
4. Ease of Implementation and Replicability	**Potential:** High replicability in Kazakhstan due to massive volumes of technogenic-mineral formations (TMF) and slag dumps. **Requirements:** Strict quality assurance protocols (particle size, safety characterization) and market acceptance. Establishing certified product standards to ensure sector's uptake. **Barriers:** Requires regulatory approval and policies incentivizing secondary materials (e.g., BAT mandates). Complex residues require qualified personnel to develop customized separation schemes. Additionally, operations necessitate adequate drainage and possibly lined industrial lot space for slag aging and carbonation phases.
5. Financial Requirements and Costs	**Capital Expenditure (CAPEX):** Significant initial investment required for sorting, crushing, and metal separation equipment. Financial Viability Analysis predicted capital costs for waste processing hubs at USD 8 per ton/year capacity for C&D waste and USD 15 ton/year capacity for Metallurgical Slags. **Operational Expenditure (OPEX):** Driven by energy for mechanical processing and fuel for transport. Estimated annual OPEX (including all costs and revenues) range from $1.25/ton for C&D waste to $2.10/ton for slag. A conservative USD 1/ton gate fee for C&D waste was assumed. **Revenue:** Generated from sales of recovered metals (e.g., scrap metal from slag at ~USD 200/ton) and secondary aggregates (suggested to be targeted at USD 4–5/ton). Secondary aggregates must be price-competitive with virgin materials. Gate fees can also be charged for C&D waste. **Avoided Costs:** Enhanced by avoiding high landfill fees and reducing contingent environmental liabilities. **Financing:** Projects are eligible for preferential financing at 3% interest rates via the Industrial Development Fund for the 2024-2026 period. **Estimated Total Costs:** The estimated Levelized Cost of Treatment (LCOT) ranges from $2.26 to $2.64 per metric ton of input waste, depending on the specific waste stream and processing intensity. Lifetime of the facility was accepted as 20 years.
6. Pollution Prevention and	**Waste Diversion:** Drastically reduces landfill demand and contamination risks. Stabilization (e.g., geopolymerization)

Environmental Protection	immobilizes heavy metals. Specifically addressing the ban on landfilling C&D waste effective since December 2020. **Resource Conservation:** Substitutes natural raw materials (sand, gravel), reducing the environmental impact of quarrying and mining. **Trade-off:** While minimizing overall pollution, the process involves cross-media effects like energy consumption for processing and transport.
7. Economic Viability	**Market:** The utilization of secondary raw materials creates new market opportunities, specifically by allowing secondary aggregates to replace natural stone in public works such as the "Nurly Zhol" road program. While the use of these low-cost materials significantly reduces infrastructure project costs, the overall success of this approach is contingent upon stable market acceptance and sustained demand for treated aggregates. **Transportation Expanses:** The economic radius for truck transport is strictly limited to ~50km due to logistics costs; rail transport extends this to 300–500km. **Risk:** Success relies on overcoming the "tyranny of distance" in Central Asian logistics and ensuring consistent enforcement of illegal dumping regulations to support gate fees. **Estimated Payback Period:** Payback periods are estimated at 2 years for slag processing (due to high metal recovery value) and 3 years for C&D recycling hubs.
8. Job Creation Potential	**Green Jobs:** Generates employment in high-tech recycling sectors, including mechanical sorting, chemical treatment, quality control, and marketing of secondary materials. **Impact:** Supports new business growth and entrepreneurship in the green economy. **Estimated Number of New Jobs:** A stationary plant (1 million tons/year capacity) requires 10–12 permanent personnel, including plant managers, operators, and maintenance crews. These roles are skilled, commanding wages above the construction sector average. It is estimated that 2500-3500 new jobs can be created nationwide.
9. Social Co-benefits	**Safety:** Diminishes health/safety risks associated with legacy slag dumps and TMFs. Reduces the need for drilling and blasting at virgin quarries, thereby decreasing dust and noise nuisances for local communities. **Community:** Supports the well-being of communities affected by industrial waste sites. Fosters corporate social responsibility by reducing the industrial environmental footprint.
10. Climate Change Mitigation Benefits	**Avoided Emissions:** Prevents landfill emissions and reduces energy/emissions from mining and transporting virgin aggregates. **Substitution:** Using slag in cement production reduces calcination emissions (a major CO_2 source). Recycling steel scrap lowers primary processing emissions. **Carbon Sequestration:** For instance, mineral carbonation of mining waste can sequester 12.27–44.92 g CO_2/kg of material. Active mineral carbonation of metallurgical slags has the

	potential to sequester up to 100,000 tons of CO2 annually per 1 million tons of slag processed, effectively making the operation 'carbon negative'. **Estimated Net Emission Reduction:** The substitution of virgin aggregate with recycled material yields a net saving of ~5 kg CO_2e per ton, accounting for avoided drilling/blasting and embodied carbon.
11. Compliance with National Targets and Legislation	**Alignment:** Fully aligned with the 2021 Environmental Code and Green Economy Concept. **Targets:** Essential for increasing industrial waste recycling rate and Carbon Neutrality 2060. **Mandates:** Adheres to the waste hierarchy and BAT standards promoting resource recovery.
12. Example Projects	The valorization of industrial and mining waste into construction materials is a growing practice globally. **Industrial Slag (Global):** Blast furnace slag is widely treated, often through granulation, and externally used in the cement industry or for road construction. Majority of BOF/EAF steel slag is utilized in construction, including as a substitute for natural aggregate and sand, with standards existing in countries like USA, Germany, Japan, China. **Mining Tailings (Global):** Mine tailings are re-processed for use in construction materials such as geopolymers, chemically bonded ceramics, and concrete admixtures, strengthening mine backfilling operations. **Incineration Residues (EU):** Incinerator bottom ash is treated using crushing, sieving, and magnetic separation to produce a dry aggregate used as secondary construction material, reducing the use of natural raw materials like sand and gravel. These integrated mechanical systems achieve ferrous metal recovery rates of approximately 80%. **C&D Gypsum (EU):** The European GtoG project demonstrated a cradle-to-cradle approach for recycling plasterboard waste, reintroducing the recovered gypsum into the manufacturing process for new gypsum products. **Kazakhstan:** Several companies in Kazakhstan already process metallurgical slag, though on a limited scale. ArcelorMittal Temirtau (Qarmet) handles nearly all of its slag, Ferrochrome JSC (Aktobe) produces crushed stone and slag-based bricks, and KazAvtoZhol incorporates slag and ash in road construction. Despite these activities, a substantial portion of industrial residues remains stockpiled or landfilled, indicating significant market potential for expanded recycling.
13. Advantages & Disadvantages	**Advantages:** Large-scale waste diversion; conserves virgin resources; reduces industrial liabilities; creates local jobs; aligns with circular economy goals. **Disadvantages:** High CAPEX for processing plants; requires strict quality control to avoid contamination; market demand for secondary materials can be volatile; transport costs.

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TFS-W-05:

Category	Description & Data
1. Technology Name	**Transition from a dual-stream to a multi-stream waste separation system to improve material recovery efficiency in urban areas**
2. Technical Overview	**Function:** This intervention upgrades the current legally mandated dual-stream ("wet" vs. "dry") system to a multi-stream collection scheme involving three or more distinct waste categories at the source (e.g., separate bins for paper, plastics, glass, and organics). **Primary Goal:** To sharply reduce cross-contamination inherent in co-mingled "dry" streams. By segregating waste at the source, the technology ensures cleaner feedstock for Material Recovery Facilities (MRFs), reducing rejection rates and downstream energy consumption. **Organic Fraction Management:** A key technical objective is isolating the "wet" organic fraction. It is assumed that clean organic stream allows for biological stabilization (composting or biogas), preventing the generation of methane and leachate associated with mixed-waste landfilling. **Applicability:** Municipal Solid Waste (MSW) generated by households, businesses, and institutions. **Requirements:** Requires expanded infrastructure (color-coded bins), specialized fleet logistics (compartmentalized trucks or distinct schedules), and robust monitoring (GPS) to prevent illegal dumping.
3. Technology Readiness Level (TRL)	**TRL 9 (Commercially Mature)** Source separation is a globally established standard. While Kazakhstan currently operates a dual-stream system (implemented in 130 of 207 cities by 2023), transitioning to multi-stream is a proven method in high-income economies to maximize resource recovery and circularity.
4. Ease of Implementation and Replicability	**Potential:** High replicability in densely populated urban centers like **Astana, Almaty, and Shymkent**, where waste volumes justify the logistical complexity and infrastructure is most advanced. **Challenges:** Requires complex routing and significant space for multiple bins in dense residential areas. Success relies entirely on public compliance. Current awareness is low, and the "dry" fraction is often contaminated. **Enabling Environment:** The Environmental Code mandates GPS monitoring for vehicles, which supports the route optimization required for multi-stream logistics.
5. Financial Requirements and Costs	**Capital Expenditure (CAPEX):** Substantial investment is required for specialized containers, fleet expansion, and public awareness campaigns. Estimates for a multi-stream system indicate a CAPEX of approximately €19 million per 100,000 tons of annual capacity, significantly higher than the €11 million required for an optimized dual-stream system. This includes costs for specialized “bio-trucks,” extensive containerization (6,000

	units per 100k tons), and advanced sorting facilities equipped with optical sorters and composting infrastructure. **Operational Expenditure (OPEX):** High due to labor-intensive sorting and complex logistics. OPEX is estimated at €36.38 per ton for multi-stream collection, compared to €27.50 per ton for dual-stream, driven by increased fuel consumption (6.5 L/ton vs 4.0 L/ton) and higher labor costs. **Life-Cycle Cost:** The total processing cost is estimated using a 15-year facility lifespan and a 10% discount rate. Gross LCOT (CAPEX + OPEX) was estimated at €61.65 per ton collected waste. Despite higher upfront costs, the "Break-even Gate Fee" (the cost to process one ton after revenue deduction) for the multi-stream system is approximately €26.84/ton, which is significantly more cost-effective than the €37.25/ton required for the dual-stream system, due to higher material revenues.
6. Pollution Prevention and Environmental Protection	**Contamination Reduction:** Drastically lowers contamination of recyclables, preventing valuable materials from being diverted to landfills. Specifically, separating the organic fraction prevents moisture migration to hygroscopic materials like paper, which otherwise degrades into a non-recyclable "mush" with humidity exceeding 24% in mixed systems. **Methane Mitigation:** Diverting the "wet" organic fraction prevents anaerobic decomposition in landfills, reducing methane (CH4) generation and leachate production. The technology enables the diversion of up to 90% of organics to aerobic or anaerobic stabilization (assumed to be available), which minimizes methane generation compared to dual-stream landfilling scenarios. **Resource Conservation:** Increases recycling yields, reducing the environmental harm associated with virgin material extraction. Recovery rates for recyclables under this system are estimated at 40% of mass plus 30% biologically stabilized organics, compared to only ~10% recovery in dual-stream systems.
7. Economic Viability	**Market Performance:** Viability hinges on obtaining higher revenues from high-quality secondary raw materials. Clean fractions command premium prices, with clear PET estimated at €180–€270/ton and clean cardboard at €90–€127/ton, whereas contaminated streams often have negligible or negative value. Multi-stream systems can generate average revenues of ~€34.81/ton compared to just €4.50/ton for dual-stream. **Payback Period:** With Extended Producer Responsibility (EPR) support (subsidies/loans), the payback period improves. Under a scenario including Extended Producer Responsibility (EPR) subsidies and tariff corrections, the project achieves a payback period at 7–8 years. **Avoided Costs:** Extends landfill lifespans and reduces environmental remediation expenses. The system avoids potential eco-tax penalties associated with the landfilling of banned recyclables (plastics, paper, glass).

	Enablers: Preferential loans (3%) from the Industrial Development Fund and compensation via the Extended Producer Responsibility (EPR) system.
8. Job Creation Potential	**Scale:** Scaling up multi-stream systems stimulates substantial job creation across collection, sorting, and processing. The transition requires a more diverse fleet configuration (e.g., small bio-trucks alongside standard packers) and increased labor density. **Quantification:** While specific job counts vary by facility size, the operational complexity necessitates a larger workforce for frequent "wet" waste collection (daily or every 48 hours) and specialized sorting operations. **Estimated Job Creation Potential:** Nationwide, it is estimated that 2000 new jobs can be created when collection system is upgraded in urban centers.
9. Social Co-benefits	**Public Engagement:** Visible implementation fosters environmental awareness and ownership of sustainable practices. However, success is sensitive to behavioral risks; "wish-cycling" or indifference can lead to contamination, underscoring the need for sustained public awareness campaigns. **Urban Health:** Improves urban cleanliness, reduces unsanitary conditions, and minimizes localized pollution by using sealed, specialized trucks for organic waste to prevent leakage and odors. **Trust:** Use of mandated GPS monitoring increases transparency in waste management. Social equity measures, such as subsidizing tariffs for vulnerable groups, are recommended to support the transition to cost-recovery models.
10. Climate Change Mitigation Benefits	**Methane Avoidance:** Primary benefit is the prevention of methane generation by diverting putrescible organic waste from landfills. The mitigation potential is modeled using a methane GWP of 28 (over 100 years; IPCC AR5), with the multi-stream system reducing landfill emissions from ~320 kg CO_2e/ton (BAU) to ~32 kg CO_2e/ton. **Fossil Fuel Substitution:** High-yield recycling displaces energy-intensive virgin material production, resulting in substantial avoided GHG emissions. Recycling credits are estimated to save ~250 kg CO_2e/ton in the multi-stream scenario compared to only ~80 kg CO_2e/ton in the dual-stream baseline. **NDC Contribution:** Systematically lowers waste-sector emissions, contributing to Kazakhstan's Paris Agreement commitments. The net mitigation potential is estimated between 0.38 and 0.72 tons of CO_2e per ton of waste processed, effectively transforming the sector from a net source of emissions to a net sink. For a city the size of Almaty (500,000 tons/year), this represents an annual reduction of ~219,000 tons of CO_2e.
11. Compliance with National Targets and Legislation	**Legal Alignment:** Builds upon the Environmental Code (2021) mandate for separate collection. **National Targets**: Critical for achieving national recycling goals of 40% by 2030 and 50% by 2050.

	Ban Compliance: Essential for complying with landfill bans on plastics, paper, glass (effective 2019), and food waste (effective 2021).
12. Example Projects	**Argentina (Trelew):** Transitioned from a dual-stream to a 5-stream system (residual, organic, plastic/metal, glass, paper) to resolve high contamination issues. **South Korea:** Implemented a volume-based waste fee system relying on extensive source separation. **National Context:** Advanced separate collection infrastructure is currently operational in Astana and Almaty, serving as the foundation for this upgrade.
13. Advantages & Disadvantages	**Advantages:** Produces high-purity recyclables; significantly reduces methane emissions; creates green jobs; ensures compliance with 2019/2021 landfill bans; supported by 3% IDF loans. **Disadvantages:** High CAPEX/OPEX; logistical complexity in dense urban areas; high dependence on public behavior change; low tariffs threaten financial sustainability without EPR support.

TFS-W-06:

Category	Description & Data
1. Technology Name	**Enclosed Composting of Organic Fraction of Municipal Solid Waste and Other Biomass Types in Urban Areas**
2. Technical Overview	**Function:** An advanced, industrial-scale biological treatment process using hermetically sealed tunnels or modular containers to convert organic waste into stable compost. The system controls temperature, oxygen, and moisture to ensure sanitation and degradation. **Applicability:** Targets the Organic Fraction of Municipal Solid Waste (OFMSW) and additionally, can process other biomasses like animal manure, yard waste, and sewage sludge. Requires clean, source-separated feedstock (C:N ratio 30:1, moisture 50-55%) and pre-treatment (shredding, metal/plastic removal). **Operational Features:** Enclosed nature ensures resilience to Kazakhstan's cold continental climate, preventing the stalling of decomposition common in open windrows. Utilizes forced aeration and exhaust capture. Electricity for aeration constitutes ~30% of OPEX. **Capacity:** Standard industrial capacity ranges from 20 to 350 tons per day, suitable for centralized municipal operations. System reliability is high due to automated controls.
3. Technology Readiness Level (TRL)	**TRL 9 (Fully Proven Operational System).** The technology is commercially mature and widely established globally, particularly in North America and Europe. Tunnel composting is the global standard for industrial organics. Containerized units (e.g., Tidy Planet) are already operational in Kazakhstan's oilfields (e.g., Tengiz) treating food waste.
4. Ease of Implementation and Replicability	**Potential:** High replicability in major urban centers (e.g., Astana, Almaty) where waste volumes justify the scale. Decentralized modular systems offer potential for smaller settlements. Implementation Time is assumed to be approximately 12 months for civil works and technology installation. **Enabling Environment:** Supported by legal mandates (2021 food waste landfilling ban) and financing mechanisms (EcoQoldau, IDF). **Challenges:** Critical dependence on a consistent supply of clean, source-separated feedstock; current low sorting rates pose a contamination risk (e.g. Pb, Cd from batteries in mixed MSW). Requires specialized technical expertise and a consistent power supply for aeration systems. **Financing:** High capital needs can be addressed through Public-Private Partnerships (PPPs) and preferential loans (3% interest) from the Industrial Development Fund.
5. Financial Requirements and Costs	**Capital Expenditure (CAPEX):** High upfront investment is needed. In the literature, $300–$500 USD (2018) per annual ton of waste processing capacity for complex in-vessel composting was reported. An economic analysis estimated CAPEX (2025) as follows:

	• Centralized facility (50,000 t/y): ~€140 per ton of annual capacity (~€6.98M total), including winterized concrete tunnels and imported biofilters. • Decentralized facility (2,000 t/y): ~€240 per ton (~€480K total), reflecting higher unit costs due to reduced economies of scale. **Operational Expenditure (OPEX):** Estimated OPEX is ~€14.40 per ton processed waste. Figure is competitive globally due to low local energy costs. **Estimated Life-Cycle Cost:** Levelized Cost of Treatment (LCOT) is estimated at €35–€45 per ton. **Context:** These estimated costs can be considered high given the typically low municipal waste tariffs in Kazakhstan.
6. Pollution Prevention and Environmental Protection	**Air Emissions:** Enclosed buildings and biofilters effectively capture and treat odors and Volatile Organic Compounds (VOCs), minimizing local nuisances. **Sanitization:** Thermophilic temperatures (55°C–70°C) effectively destroy pathogens, viruses, and parasites. **Resource Protection:** Prevents groundwater contamination from landfill leachate. The final compost product restores degraded soils and reduces the need for chemical fertilizers. **Footprint:** Requires a significantly smaller land area compared to open windrow methods.
7. Economic Viability	**Revenue:** Generates income from compost sales and potential gate fees. **Sustainability:** Financial viability is currently challenged by low waste tariffs and the lack of a standardized national market for compost products. **Avoided Costs:** Reduces waste volume by 60–90%, significantly extending the lifespan of existing landfills and reducing long-term environmental remediation costs. **Estimated Payback Period:** Under current "Business as Usual" conditions, a structural viability gap exists; combined revenues (~€12.50/ton) cover only 87% of OPEX, resulting in insolvency. Conversely, a modelled scenario—assuming increased gate fees (estimated at €20/ton) and carbon finance (estimated at €12/ton)—projects an Internal Rate of Return (IRR) of 11–13% with a payback period of ~8 years. **Carbon Finance:** Monetizing emission reductions is critical to increase revenue.
8. Job Creation Potential	**Types of Roles:** Generates employment requiring higher technical skills compared to landfilling, including plant managers, specialized equipment operators, mechanics, and laboratory assistants. **Impact:** Contributes to the development of a green economy workforce and creates new business opportunities in compost marketing and distribution. **Estimated Job Creation Potential:** ~10 full-time staff for a 50,000 t/y facility (1 manager, 3 skilled operators, 6 laborers).

	Assuming half of the organic fraction of MSW is processed via this technology, 150-200 permanent new jobs can be created nationwide.
9. Social Co-benefits	**Urban Suitability:** Superior odor control makes it suitable for deployment near populated urban areas, unlike open systems. **Public Health:** Pathogen destruction improves safety in waste handling and end-product use. Alleviates the number of uncontrolled methane fires and rodent vectors associated with the 80% of Kazakh landfills that are unsanitary. **Community:** Promotes sustainable practices and improves soil/water quality for local communities.
10. Climate Change Mitigation Benefits	**Methane Avoidance:** Prevents anaerobic decomposition of organic waste in landfills, significantly reducing methane (CH_4) emissions. **Carbon Sequestration:** Application of compost sequesters carbon in the soil matrix, substituting energy-intensive mineral fertilizers. **Fossil Fuel Substitution:** Displaces the use of energy-intensive synthetic fertilizers, avoiding upstream manufacturing emissions. **Energy Savings:** Compost improves soil water retention, reducing the energy required for irrigation pumping. **Estimated Mitigation Potential:** 0.8–1.3 tons CO_2e avoided per ton of waste processed. *Baseline:* Unsanitary deep landfill (MCF 0.8) generating 1.4 tons CO_2e/ton; *Model:* Enclosed composting process emissions of ~0.21 tons CO_2e/ton. A standard 50,000 t/y facility avoids ~60,000 tons CO_2e annually.
11. Compliance with National Targets and Legislation	**Alignment:** Directly enables compliance with the 2021 ban on landfilling food waste. **Targets:** Critical for achieving the Green Kazakhstan National Project goals of 40% recycling by 2030 and 50% by 2050. **Support:** Aligned with the "Concept for Transition towards a Green Economy," though hampered by a lack of national compost quality standards.
12. Example Projects	**Inland Empire (USA):** Large-scale enclosed Aerated Static Pile system processing 300,000 tons/year. **Edmonton (Canada):** Integrated drum and bed system for MSW and biosolids. **Davenport (Iowa, USA):** Enclosed ASP for biosolids and yard waste. **Kazakhstan (Oil & Gas Sector):** Tidy Planet containerized units deployed in oilfields to treat food waste.
13. Advantages & Disadvantages	**Advantages:** High process efficiency and speed (weeks vs. months); resilience to cold climate; excellent odor control; effective sanitization; significant landfill diversion. **Disadvantages:** High CAPEX and OPEX; dependency on clean feedstock (source separation); requires skilled labor and consistent electricity; financial viability relies on subsidies/tariffs.

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TFS-W-07:

Category	Description & Data
1. Technology Name	**Utilization of the organic fraction of municipal solid waste and other types of biomass for biogas production**
2. Technical Overview	**Function:** A controlled biological process where microorganisms decompose organic matter in an oxygen-free (anaerobic) environment. The biochemical process involves hydrolysis, acidogenesis, acetogenesis, and methanogenesis. **Applicability:** Treating Organic Fraction of Municipal Solid Waste (OFMSW), food waste, agricultural residues, and sewage sludge. Suitable for "wet" (<15% dry matter) or "dry" (>30% dry matter) fermentation. **Operational Features:** Operates in sealed reactors (biodigesters) under specific temperatures: Mesophilic (35°C–48°C) or thermophilic (~55°C, preferred for pathogen kill and faster throughput). Requires pre-treatment to remove impurities (e.g., plastics). Uncontaminated OFMSW could be routed to an AD facility via an MBT plant or directly from the source if clean source separation is feasible. **Outputs:** biogas (50–75% methane) and digestate (nutrient-rich fertilizer). Typical yield: 100–200 m^3 biogas/ton of organic MSW. Solids reduction: 50–60%.
3. Technology Readiness Level (TRL)	**TRL 9 (Mature Technology).** Well-established globally for treating animal waste, wastewater, and MSW. Europe has over 20 years of experience with large-scale facilities treating the organic fraction of MSW.
4. Ease of Implementation and Replicability	**Potential:** High replicability in Kazakhstan due to urbanization trends and legal mandates to divert waste from landfills. In developing economies where organic waste often exceeds 50% of the total waste produced. Particularly suited for waste with high moisture content; MSW usually contains 60-70% moisture. **Barriers:** Early stage of adoption due to significant infrastructure deficits. Requires specialized technical capacity for operation. While large-scale municipal applications are limited in Kazakhstan, small biogas projects are operational at poultry and livestock farms, to little extend providing a domestic foundation for expansion. **Requirements:** Requires a fully sealed vessel and strict source separation or advanced hydro-mechanical pre-treatment to prevent contamination. Complex reactor operations demand highly qualified personnel. **Resilience:** Sophisticated systems use Combined Heat and Power (CHP) heat recycling to maintain reactor temperatures, ensuring resilience against cold ambient conditions. However, heat demand in Kazakhstan may be 20–30% higher than European benchmarks due to extreme winters.

5. Financial Requirements and Costs	**Previously reported investment costs:** High. Initial investment is generally higher than aerobic systems due to reactor complexity. Global estimates for MSW-based systems range from USD 345–600 per annual metric ton of waste processed in Europe and this cost ranges from USD 220–660 per annual ton in the United States, while in China it is approximately USD 325 per annual ton. In 2019 TNA for Ukraine, the investment cost was estimated between EUR 200 and 400 annually for MBT facilities that incorporate Anaerobic Digestion (MBT-AD). **Previously reported operational costs:** Significant due to maintenance, energy (particularly for digester heating) and skilled labor needs. Operational costs in Europe are estimated at USD 31–57 per metric ton, whereas they are USD 22–55 per ton in the United States, and around USD 25 per ton in China. **Drivers:** High costs remain a primary implementation risk. Economic feasibility often relies on "Green Certificates," electricity sales, or gate fees. Energy costs are lower than in aerobic systems because no aeration is required, and heat produced from biogas can be used to heat digesters, further reducing energy expenses. Tipping fees are a major revenue source for offsetting costs. In Europe, AD plants integrated with composting typically charge EUR 70–120 per metric ton. **Estimated Capital Expenditure (CAPEX):** According to evaluations based on a Kazakhstan Specific Scenario (2025), CAPEX is estimated at €370–€390 per ton of annual capacity (Total ~€19.5 million for a 50,000 ton/year facility). Costs are driven by import logistics and necessary winterization. **Estimated Operational Expenditure (OPEX):** ~€38 per ton processed (~€1.9 million/year). Without gate fees, the project runs a deficit. **Estimated Total Life-Cycle Cost:** The estimated gross Levelized Cost of Treatment (LCOT) before revenues is €57.5 per ton. The Net Break-Even Gate Fee is estimated at €20–€25 per ton. This fee is required to cover the operational deficit after electricity revenues (~€19.6/ton derived from electricity sales) are accounted for. **Assumptions:** Estimations based on a 50,000 t/year Biogas-to-Electricity facility (with CHP) processing mixed MSW with mechanical pre-treatment, 20-year project lifetime.
6. Pollution Prevention and Environmental Protection	**Air Emissions:** Sealed vessels minimize fugitive odors and gaseous emissions compared to uncontrolled decomposition. **Water/Soil:** Effectively treats high-COD wastes and reduces sludge volume. Digestate improves soil structure and fertility. **Sanitization:** Thermophilic operation destroys up to 95% of pathogens, enhancing safety for land application.
7. Economic Viability	**Sustainability:** Converts waste liability into an energy resource, supporting the circular economy. Viability is

	strongly linked to supportive regulatory frameworks and incentives. **Revenue Streams:** Direct sales of biogas, electricity/heat generation (CHP), biomethane injection into gas grids, and sale of organic fertilizer (digestate). In Kazakhstan, a scenario involving biomethane production currently faces an economic paradox as domestic natural gas is heavily subsidized, making grid injection uncompetitive without specific financial support. **Estimated ROI:** Converts waste liability into an energy resource, supporting the circular economy. Financial viability in Kazakhstan is currently marginal (ROI 2.5–4.0%) without a gate fee (tipping fee) of at least €20/ton to supplement electricity sales.
8. Job Creation Potential	**Skills Required:** Necessitates skilled personnel for pre-treatment, reactor management, gas conditioning, and maintenance. **Estimated Job Potential:** Generates employment in the regional green economy across collection, processing, and technical support services. A 50,000 t/y reference plant requires approximately 18–20 full-time employees. Processing half of the OFMSW generated in Kazakhstan could produce 540-600 permanent jobs.
9. Social Co-benefits	**Health:** Improves urban sanitation and living conditions by safely managing waste and reducing odors/vectors. **Energy Access:** Provides a sustainable alternative to fossil fuels or wood for cooking and heating, enhancing energy security in developing regions. **Transport:** Upgrading biogas to Bio-CNG for municipal bus fleets (e.g., Almaty) can offer a competitive pathway, displacing diesel and reducing urban transport emissions.
10. Climate Change Mitigation Benefits	**Methane Avoidance:** Prevents uncontrolled methane emissions from landfills by capturing it in a closed system. **Fossil Fuel Substitution:** Biogas displaces fossil fuels for heat/power; biomethane can replace vehicle fuel. **Fertilizer Displacement:** Digestate replaces energy-intensive mineral fertilizers, avoiding upstream industrial CO2 emissions. **Kazakhstan Specific Mitigation Potential:** · **Net Mitigation:** ~1.7 ton CO_2e avoided per ton of OFMSW processed compared to the baseline scenario where OFMSW is dumped to an uncontrolled dumpsite. · **Total Potential:** Processing half of the OFMSW generated in Kazakhstan could theoretically avoid 1.3-1.7 million tons CO_2e/year.
11. Compliance with National Targets and Legislation	**Alignment:** Supports Kazakhstan's “Concept for Transition to Green Economy” and 2021 Environmental Code. Potential support from the EPR operator "Zhasyl Damu". **Mandates:** Critical solution for managing organic waste to comply with the phased ban on landfilling food waste.

	Goals: Contributes to national renewable energy targets and circular economy principles.
12. Example Projects	**Europe:** 244 large-scale facilities operating (as of 2014) with ~8 million tons/year capacity. **Romania:** Pilot project in Seini treating agricultural waste. **Vietnam:** Co-digestion models for organic waste and faecal sludge. **Kazakhstan:** A 120,000-ton MSW MBT+Biogas Production plant (Almaty Oblast) planned to employ 70 people directly.
13. Advantages & Disadvantages	**Advantages:** Generates continuous renewable energy (baseload); produces valuable fertilizer; high pathogen reduction; handles wet waste streams effectively; significant GHG reduction (high impact due to diverting from unmanaged dumpsites). **Disadvantages:** High capital and operating costs; technically complex (requires skilled labor); intolerant of contamination; sensitive to temperature fluctuations without robust winterization (heating/insulation); requires gate fee reform to be bankable in the current Kazakh market context.

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TFS-W-08:

Category	Description & Data
1. Technology Name	**Open-air Composting in Rural Areas**
2. Technical Overview	**Function:** A simple aerobic biodegradation process where organic waste is piled into long rows (windrows) on open pads. It converts biomass into stable humus through natural aeration, aided by periodic mechanical turning. **Applicability:** Ideal for rural regions with high volumes of agricultural biomass (crop residues, manure). Requires blending feedstocks to achieve a C:N ratio of 20:1 to 35:1 and porosity. **Operational Features:** Relies on microbial activity to reach thermophilic temperatures (>55°C) for sanitization (typically 15+ days). Requires active moisture control (supplemental water) and protection from heat loss during continental winters to prevent biological stalling. **Capacity:** Highly scalable; suitable for small-scale on-farm use up to regional facilities (10,000–20,000 tons/year). System reliability is high but operationally weather-dependent.
3. Technology Readiness Level (TRL)	**TRL 9 (Fully Proven Operational System).** Globally recognized as a mature, low-cost, and standard practice for organic waste management. It has a long operational history in agriculture and municipal sectors worldwide.
4. Ease of Implementation and Replicability	**Potential:** High replicability in Kazakhstan's rural districts where land is abundant and inexpensive. The technology is constrained by a logistical “economic radius” of 50–100 km due to transport costs. **Enabling Environment:** Low technical complexity allows operation with standard agricultural equipment (tractors, front-end loaders). **Challenges:** Requires significant land footprint and is sensitive to meteorological extremes. Managing operations during sub-zero winters is a key logistical constraint. **Financing:** Low capital intensity makes it financially accessible for agricultural cooperatives (co-ops) and rural municipalities.
5. Financial Requirements and Costs	**Capital Expenditure (CAPEX):** Estimated at €12–17 per ton of annual capacity (€171,050 for a 10,000-ton facility). Costs are minimized by utilizing tractor-pulled turners rather than self-propelled units. **Operational Expenditure (OPEX):** Ranges from €5 to €8 per ton. Diesel fuel is the primary cost driver (~35% of OPEX), making operations sensitive to fuel price volatility. **Levelized Cost of Treatment (LCOT):** Gross LCOT is estimated at €8.72 per ton 10-year horizon for capital amortization.
6. Pollution Prevention and Environmental Protection	**Air Emissions:** Diversion from dumpsites eliminates fugitive CH_4 emissions. Potential for odor/dust exists but is manageable via wind direction planning and moisture management. **Sanitization:** Effective pathogen destruction if thermophilic temperatures are maintained, rendering the product safe for food-chain application.

	Water Protection: Site design must include compacted clay or concrete liners to prevent leachate from contaminating groundwater. **Footprint:** Reduces waste volume by 30–50%, minimizing final disposal land use.
7. Economic Viability	**Avoided Costs:** Reduces transport costs for waste disposal and offsets the purchase of imported synthetic fertilizers. **Revenue:** Generates value through compost sales (est. €10–15/ton bulk price) and avoided fertilizer costs. Carbon credit revenue potential is significant, potentially exceeding compost sales revenue. **Estimated ROI:** Viability is marginal without Gate Fees or subsidies; base case ROI is ~4.5% but can rise to >36% with tipping fees.
8. Job Creation Potential	**Scale:** Moderate job creator, primarily in blue-collar operational roles. **Quantification:** Approximately 3.5 Full-Time Equivalents (FTE) required per 10,000 tons of annual capacity (1 Manager, 2 Operators, 1 Laborer). **Rural Impact:** Supports local agricultural employment and can create small-business opportunities in organic fertilizer production. **Estimated Potential:** Assuming that 20 to 25 million tons of biomass are available in rural areas, and that 10% of this amount is utilized, then approximately 700–900 permanent operational jobs can be created.
9. Social Co-benefits	**Public Health:** Reduces vectors and pathogens associated with raw manure/waste piles. Improves rural sanitation. **Community:** Decentralized models foster community participation and self-reliance in waste management. **Soil Health:** Enhances long-term soil fertility and resilience for local food production.
10. Climate Change Mitigation Benefits	**Mitigation Potential:** Net mitigation of 0.6 to 0.9 tons CO_2e per ton of waste processed. **Methane Avoidance:** Primary driver: prevents anaerobic decomposition (avoiding ~664 kg CO_2e/ton). **Carbon Sequestration:** Application to steppe soils sequesters ~150 kg CO_2e/ton. **Substitution:** Displaces energy-intensive synthetic fertilizers (~40 kg CO_2e/ton)
11. Compliance with National Targets and Legislation	**Alignment:** Supports the "Concept for the Transition to a Green Economy" and carbon neutrality targets by 2060. **Policy:** Beneficiary of the 2025 subsidy (50%) for organic certification costs. Currently lobbying for parity with mineral fertilizer subsidies. **Barriers:** Lack of direct subsidies for organic fertilizer production creates a competitive disadvantage against synthetic alternatives.
12. Example Projects	**Austria:** Decentralized on-farm composting networks where farmers process municipal green waste .

	Bangalore (India): Large-scale windrow facility processing 300 tons/day . **Burkina Faso:** "Manure Pit Operation" promoting household composting for soil improvement . **Ulaanbaatar, Mongolia:** A project with a total investment of US$ 3.2 million (ADB/Japan Fund), demonstrating cold-climate feasibility. The project includes the construction of a central composting plant capable of processing at least 2,000 kg of food waste per day, specialized composters with self-heating systems for winter operation, and the distribution of bins, composters, and protective equipment to households and schools for community participation.
13. Advantages & Disadvantages	**Advantages:** Lowest capital and operating costs; simple technology; high resource availability (wheat straw/manure); creates marketable soil amendment; high rural replicability. **Disadvantages:** Large land requirement; sensitive to weather (cold/rain); requires strictly enforcing aerobic conditions to claim carbon credits; process duration is slow (months); requires reliable water source.

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TFS-W-09:

Category	Description & Data
1. Technology Name	**Production of refuse-derived fuel (RDF) as a standardized alternative fuel for industrial processes and power plants**
2. Technical Overview	**Definition & Process:** The technology utilizes an established mechanical process to convert the non-recyclable, combustible fraction of Municipal Solid Waste (MSW) into a standardized, high-energy fuel known as Refuse Derived Fuel (RDF). Thus, this technology is often integrated into Mechanical-Biological Treatment (MBT) facilities that specifically process residual waste after recyclables have been captured. The process flow typically involves initial sorting to remove non-combustibles (metals, glass, stones), followed by shredding/size reduction and drying to ensure uniform characteristics. **Applicability & Feedstock:** The primary feedstock is the residual MSW remaining after recyclables have been captured. The resulting fuel (pellets or loose mass) serves as a sustainable alternative energy source for energy-intensive industries, specifically cement kilns, thermal power plants, and combined heat & power (CHP) plants. The concept of RDF production is seen as a technological option to divert a large portion of municipal waste as an alternative fuel, particularly in urban areas. **Outputs & Quality:** The output must meet specific technical specifications regarding calorific value, moisture content, and limits on chlorine, mercury, and other heavy metals. High-quality RDF that is compliant with EN ISO 21640:2021 is referred to as Solid Recovered Fuel (SRF). The financial viability of Refuse Derived Fuel (RDF) projects hinges critically on product standardization. Producing low-grade "fluff" is inexpensive but carries high market risk; its inherent low density, high transport costs, and unpredictable combustion properties often lead to rejection by industrial off-takers, resulting in the material being landfilled. **Capacity & Resilience:** In developing countries, similar projects handle annual waste inputs ranging from 200,000 to 500,000 tons. While the technology is mature, the drying stage required to reduce moisture content may incur higher energy costs during Kazakhstan's cold continental winters.
3. Technology Readiness Level (TRL)	**TRL 9 (Fully Proven Operational System)** The production of RDF/SRF is an established, mature technology widely implemented in global industrial practice. Its history dates back to the 1970s, and it is supported by international standards.
4. Ease of Implementation and Replicability	**Replicability:** The technology has high replicability in Kazakhstan but is contingent on the development of supportive infrastructure. Plans to construct numerous new waste sorting plants indicate a move toward increasing potential capacity suitable for this technology. **Requirements:** Successful operation requires specialized installations for mechanical sorting and grinding, rigorous quality control, and consistent waste quantities.

	Barriers: **Infrastructure:** Cement kilns and municipal CHP plants in Kazakhstan may not yet be technically ready to accept substitute fuels. **Geography:** High transportation costs can render production unfeasible if facilities are distant from end-users. **Regulation:** There is a need for national specifications regarding RDF composition similar to EN ISO 21640:2021. **Enabling Environment:** Deployment is supported by the availability of preferential loans at 3% interest for waste sorting/recycling businesses and aligns with the transition toward Best Available Techniques (BAT) permits.
5. Financial Requirements and Costs	**Capital Expenditure (CAPEX):** For a standard regional facility (100,000 tons/year), total CAPEX is estimated at €28 – €35 Million. Specific costs for MBT with an RDF line range from €280 to €350 per ton of annual capacity. **Operational Expenditure (OPEX):** Total OPEX is estimated at €22–€28 per ton processed. This includes electricity and labor, which is relatively low in Kazakhstan. **Financial Sustainability:** Revenue from RDF sales is uncertain and can be negative in saturated markets. RDF is considered as a local solution. The density of RDF (0.3–0.6 ton/m³) is low compared to coal, rendering its transport expensive. Therefore, a guaranteed off-taker (cement plant or power station) must be present within a 150-km radius. Consequently, financial viability frequently relies on Gate Fees (Tipping Fees) of USD 30–50 per ton to cover the funding gap.
6. Pollution Prevention and Environmental Protection	**Landfill Diversion:** Technology significantly reduces environmental contamination by diverting large volumes of non-recyclable waste from landfills. Integrated RDF strategies can reduce waste sector emissions by nearly 80% relative to Business-As-Usual (BAU) baselines. **Emission Control:** The use of RDF in industrial combustion is subject to rigorous regulatory requirements. Cement kilns offer superior environmental performance because the alkaline environment neutralizes acid gases (like HCl from plastics), and the ash is incorporated into the clinker, eliminating the need for ash disposal. However, strict standardization is required to manage risks such as chlorine corrosion and mercury volatility.
7. Economic Viability	**Revenue Streams:** The primary economic value comes from replacing fossil fuels (coal, oil, gas) and selling Refuse-Derived Fuel (RDF). However, in mature markets, RDF prices can be low or even negative (e.g., acceptance fees of €20–€80 per ton), forcing producers to pay for disposal. For example, cement plants in Belarus pay only about USD 10/ton. In Kazakhstan, RDF have to compete with cheap coal and natural gas. **Financial Sustainability:** RDF is a local solution due to its low density (0.3–0.6 ton/m³), which makes transport costly. A guaranteed off-taker (cement kiln or power station) within 50-100 km is essential. Financial viability often depends on avoided

	landfill costs or gate fees (USD 30–50 per ton) rather than RDF sales revenue. Low municipal waste tariffs and high CAPEX in Kazakhstan further challenge profitability. **Market Competitiveness:** Economic sustainability hinges on long-term purchase agreements with cement kilns. Kazakhstan faces competitiveness issues due to cheap domestic coal and high transport costs. **Estimate Payback Time:** 8–12 years pay back under optimal conditions with integrated energy recovery and robust carbon pricing. **Subsidy Reliance:** High investment costs and long payback periods necessitate government support, carbon pricing, or increased landfill taxes. Without subsidies or sufficient gate fees, ROI can become indefinite.
8. Job Creation Potential	**Construction & Technical:** The design and construction of MBT/RDF plants create employment for engineering firms, equipment vendors, and generate a significant employment boom during the 1–3 years construction phase. **Estimated Potential:** A typical 100,000-ton RDF plant can create 150–300 permanent jobs (sorters, engineers, logistics). **Industrial Symbiosis:** A reliable supply of RDF can help secure jobs in heavy industry by preventing industrial flight to jurisdictions with laxer environmental laws.
9. Social Co-benefits	**Public Health & Quality of Life:** By diverting waste from uncontrolled dumps, the technology minimizes public health risks and eliminates nuisances such as odors, contributing to cleaner urban environments. **Strategic Alignment:** Adoption supports public confidence in municipal services and aligns with the “Green Kazakhstan” National Project priorities. **Social Equity (Just Transition):** The transition offers an opportunity to formalize the informal waste-picking sector by integrating them into the “manual sorting” stations of MBT plants, providing stable wages and safer working conditions compared to open dumps.
10. Climate Change Mitigation Benefits	**Primary Mechanism (Methane Avoidance):** Diverting non-recyclable organic waste from landfills prevents the generation of methane (CH_4), a GHG with a 100-year global warming potential 28 times that of CO_2. Technology reduces emissions by an amount comparable to flaring landfill gas. **Secondary Mechanism (Fossil Fuel Substitution):** RDF replaces high-carbon fossil fuels (coal, natural gas) in industrial processes, directly lowering CO_2 emissions. RDF is a mix of fossil carbon (plastics) and biogenic carbon (paper, wood, food). International carbon accounting protocols typically treat the combustion of biogenic carbon as neutral (part of the short carbon cycle). Even though burning plastic releases fossil CO_2, the overall emissions are lower than burning 100% coal. Cement kilns offer superior environmental performance compared to dedicated incinerators because the alkaline environment

	neutralizes acid gases, and the ash is incorporated into the clinker, eliminating the need for ash disposal . **Estimated Net Mitigation Potential:** Approximately 0.93 tCO_2e per ton of waste processed. The net benefit is driven by avoided landfill methane (+0.60 tCO_2e) and fossil fuel substitution in cement kilns (+0.33 tCO_2e; assuming half of the calorific value comes from plastics), offset by processing and transport emissions. The baseline scenario assumptions are that MSW is disposed of in engineered dumpsites and RDF replaces coal. **Transport Impact:** Trucking RDF just 200 km creates a carbon debit of ~0.025 tCO_2e, emphasizing the need for proximity.
11. Compliance with National Targets and Legislation	**Legal Mandates:** The technology aligns with the Environmental Code (2021), which mandates the waste hierarchy and prohibits landfilling plastics, paper, cardboard, and food waste. It also supports the Waste-to-Energy (WtE) principle. **National Targets:** RDF production contributes to the national target of 40% MSW recycling by 2030 and the goal of Carbon Neutrality by 2060. **Administrative Needs:** Full compliance requires the development of national standards harmonized with EN ISO 21640:2021 and the issuance of Integrated Environmental Permits (IEPs) based on Best Available Techniques. **Kazakhstan context**: Government offers 3% preferential loans via the Industrial Development Fund (USD 450M allocated for 2024–2030); EcoQoldau program compensates sorting/processing costs; PPPs encouraged. Current low tariffs for waste disposal and underdeveloped secondary markets remain financial barriers.
12. Example Projects	**Bulgaria (Sofia Waste Treatment Plant):** Processed 221,693 tons of waste in its first year, producing 105,253 tons of RDF, with recyclable sales exceeding EUR 228,000 . **Israel (Hiriya Transfer Station):** A plant sorts 1,500 tons of mixed MSW per day to produce solid fuel primarily for the cement industry . **Grodno, Belarus:** Established a policy to co-feed the cement industry with RDF (market demand 330,000 tons/year), with initial sales prices estimated at USD 10/ton . **Kazakhstan (Planned):** A planned Techno-Eco Park in Almaty Oblast is a USD 69.7 million waste processing complex designed to treat 500,000 tons/year of solid waste, utilizing the Almaty Oblast's annual feedstock of over 800,000 tons. The facility targets annual production of 100,000 tons of compost, 108,000 tons of refuse derived fuel (RDF), and recycled metal and plastics, projecting a financial payback period of 6.7 to 11.6 years.
13. Advantages & Disadvantages	**Advantages:** **Resource Recovery:** Converts non-recyclable organic/inorganic waste into standardized energy resources. **Climate Impact:** Significant GHG reduction through methane avoidance and fossil fuel displacement.

	Compliance: Provides a pathway to meet 2021 Environmental Code bans on landfilling specific waste streams. **Disadvantages:** **High Costs:** Substantial CAPEX and reliance on subsidies due to low revenue from fuel sales. **Market Dependency:** Requires active cement industry demand and proximity to end-users to overcome transport costs. **Technical Constraints:** Needs consistent feedstock quality and potential retrofitting of local industrial boilers.

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TFS-W-10:

Category	Description & Data
1. Technology Name	**Construction of Sanitary Landfills with Methane Recovery Systems for Generating Renewable Energy**
2. Technical Overview	**Function:** An engineered disposal method for Municipal Solid Waste (MSW) that captures methane-rich Landfill Gas (LFG) generated during anaerobic decomposition and converts it into electricity and/or heat. **Process:** Requires an engineered site with bottom liners, leachate capture, and a network of extraction wells. Extracted gas is treated to remove impurities (moisture, H_2S) before combustion in engines or turbines. **Applicability:** Highly relevant to Kazakhstan, where 85% of MSW is landfilled . The contained waste mass provides thermal insulation, facilitating continuous gas production even in the cold continental climate. **Capacity:** Landfill operational lifespan is typically 20–30 years. Gas generation peaks within the first 10–15 years of cell closure, with a declining tail lasting decades.
3. Technology Readiness Level (TRL)	**TRL 9 (Mature Technology).** Globally proven. While Kazakhstan's Environmental Code mandates gas collection, domestic implementation is limited; only ~20% of existing landfill sites meet sanitary standards, necessitating new construction.
4. Ease of Implementation and Replicability	**Financial Barriers:** High initial CAPEX compared to historical dumping practices. High capital needs often require Public-Private Partnerships (PPPs) or international climate finance. **Regulatory Barriers:** Current Feed-in Tariffs (~0.06 EUR/kWh) are insufficient to cover expenses without subsidies. **Technical Barriers:** Cold climate retards methanogenesis, requiring larger waste volumes to sustain flow. **Enablers:** Scalable to large urban centers with sufficient waste volumes. "Green Economy" targets, potential Article 6 carbon finance mechanisms, and strict sanitary mandates.
5. Financial Requirements and Costs	Typical CAPEX Range by Size (New Construction): • Small (20-50k tons/yr): $1–5 million. • Medium (100-250k tons/yr): $5–20 million. • Large (>300k tons/yr): $20–50+ Million. **Estimated Capital Expenditure (CAPEX):** For a theoretical Medium Sanitary Landfill (100k tons/yr), CAPEX estimated at €4.5 and €6.3 Million with methane flaring and with landfill gas to energy (LFGtE) system, respectively. LFGtE expenditures includes €1.8M incremental cost for energy infrastructure (Engines, Grid Connection, Gas Conditioning). **Estimated Operational Expenditure (OPEX):** €1.2 (flaring)–1.4 (LFGtE) million per year for a theoretical mid-sized facility in Kazakhstan. Unit OPEX was calculated as €8.00–€10.00 per ton/year (Labor, Fuel, Maintenance). The incremental energy O&M is approx. €0.025 per kWh. **Estimated Levelized Cost of Disposal (LCOD):**

	Gross LCOD: €24 – €31.5 per ton for w/flaring and w/LFGtE, respectively. Net LCOD: ~€27.14 per ton (after energy revenue) for LFGtE. *Assumptions:* 20-year amortization. **Estimated Project Timeline:** • Design & Permitting: 1–2 Years. • Construction (Cell & Infrastructure): 1–2 Years. • Operational Horizon: 20+ Years (Financial Amortization). **Narrower Financial Gap:** The net cost difference between flaring and energy generation is approximately €3.14 per ton. This is a manageable gap that could likely be bridged by a small increase in the "gate fee" for commercial waste haulers.
6. Pollution Prevention and Environmental Protection	**Air Quality:** **Combustion Efficiency:** >99% destruction of captured methane and VOCs in engines/flares. **Collection Efficiency:** Typically 60–75%; the remainder is fugitive emissions. Prevents dangerous buildup. **Water Protection:** Engineered liners prevent leachate migration into aquifers, addressing critical contamination risks in arid zones.
7. Economic Viability	**Sustainability:** Financial viability is challenging in Kazakhstan due to the low-tariff environment and absence of landfill taxes. **Estimated Revenue Generation:** • **Energy Sales:** €4.00 – €5.00 per ton of waste processed. • **Tariff Context:** At current tariff (~€0.06/kWh), simple payback is 8 years and NPV is often negative. **Viability Threshold:** Commercial viability requires a tariff increase to >50 KZT/kWh or carbon credit revenues (e.g., at €20/ton CO_2e).
8. Job Creation Potential	**Construction Phase:** Earthworks, liner installation, and drilling crews (Short-term). **Operational Phase:** 10–15 Full-Time jobs for a theoretical medium site (100 kton/year), including specialized engineers for engine maintenance and environmental technicians. A nationwide adoption could generate 500-750 new jobs.
9. Social Co-benefits	**Public Health:** Eliminates health hazards and odors associated with uncontrolled waste decomposition. **Safety:** Drastically reduces the risk of landfill fires and explosions. **Community:** Modernizes waste infrastructure, increasing public confidence. Closed sites can be later repurposed for community use (e.g., parks).
10. Climate Change Mitigation Benefits	**Mitigation Potential:** * 0.68 tons CO_2e avoided per ton of waste for landfill w/LFGtE. The difference between flaring and LFGtE is estimated only at 80 kg CO_2/ton waste. * *Mechanism:* Combined effect of preventing fugitive methane (GWP-100: 28) compared 100% fugitive methane emissions and displacing carbon-intensive coal grid electricity (Grid Factor:

	~0.516 kg CO_2/kWh). 60% methane capture by the gas collection systems is assumed. **National Impact:** Implementation of landfilling with LFGtE at major regional sites could reduce national sector GHG emissions by 68% compared to an uncontrolled dumpsite baseline; emissions could be reduced by 60% w/flaring.
11. Compliance with National Targets and Legislation	**Mandates:** The 2021 Environmental Code explicitly mandates gas collection systems for sanitary landfills. **Targets:** Critical for meeting the Green Economy goal of 95% sanitary storage by 2030 and the Carbon Neutrality Strategy 2060. **Incentives:** Numerous waste infrastructure projects approved by the government, creating a pipeline for implementation.
12. Example Projects	**Thailand (Kamphaeng Saen):** Private developer project (8 MW) supported by feed-in tariffs. **Colombia (La Pradera):** Achieves 99.99% methane destruction efficiency in captured LFG.
13. Advantages & Disadvantages	**Advantages:** Good GHG mitigation (Methane destruction + Fossil fuel displacement); provides stable baseload renewable energy; resolves critical sanitary/health hazards. **Disadvantages:** High CAPEX; Dependent on tariff reform for profitability; Technical challenges in extreme winter conditions (freezing condensate).

1. Kaza, S., Yao, L. C., Bhada-Tata, P., & Van Woerden, F. (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. World Bank Publications. https://hdl.handle.net/10986/30317

2. Markgraf, C., & Kaza, S. (2016). *Financing Landfill Gas Projects in Developing Countries*. World Bank Publications. https://hdl.handle.net/10986/26302

3. Rajaram, V., Siddiqui, F. Z., & Khan, M. E. (2011). *From Landfill Gas to Energy: Technologies and Challenges*. CRC Press, Taylor & Francis Group, LLC. https://www.amazon.com/Landfill-Gas-Energy-Technologies-Challenges/dp/0415664748

TFS-W-11:

Category	Description & Data
1. Technology Name	**Collection and Use of Landfill Gas from Existing Landfills via Retrofitting for Generating Electricity and Heat**
2. Technical Overview	**Function:** Retrofitting existing "brownfield" landfills with gas collection and control systems to capture methane and generate energy. **Process:** Involves drilling vertical extraction wells into heterogeneous waste masses and installing header pipes buried below the frost line (>1.5m) to prevent condensate freezing, which is a critical failure mode in Kazakhstan's continental climate. The collected gas is dewatered, filtered, and combusted in Reciprocating Internal Combustion Engines (ICE). **Scale:** A representative 1-million-ton landfill supports a generation capacity of approximately 0.8 – 1.0 MW. **Constraint:** The cold climate of Kazakhstan requires heavy insulation and heat tracing, increasing civil works complexity significantly compared to temperate zones.
3. Technology Readiness Level (TRL)	**TRL 9** While mature globally, the technology faces specific implementation challenges in Kazakhstan due to the lack of operational precedents under the current tariff regime. The 2024 Law on Heat Power Industry creates a new regulatory pathway for these systems to access district heating networks.
4. Ease of Implementation and Replicability	**Complexity:** Drilling in uncompacted, heterogeneous dumpsites presents risks of borehole collapse. The extreme winter temperatures (-30°C) mandate specialized engineering (insulated/buried pipes) which increases Civil Works CAPEX by 20–30%. **Replicability:** Feasible for regional centers (e.g., Astana, Petropavlovsk) but economically constrained by the "viability gap" at current tariffs.
5. Financial Requirements and Costs	**Capital Expenditure (CAPEX):** Estimated at 3.70 EUR per ton of waste in place (Total €3.7 million for a 1 MW system at a theoretical 1-million-ton site). This includes drilling, piping, and imported generation equipment. A 2012 report by IRENA indicates that the total installed capital costs for landfill gas power generation systems range from US$1,920 to US$2,440 per kW. **Operational Expenditure (OPEX):** Estimated at 4.60 EUR per ton (Lifetime) or approximately €230,000 per year. **Levelized Cost of Treatment (LCOT):** • **Gross LCOT (No Revenue):** 8.30 EUR per ton (based on 20-year project life). • **Net LCOT (With Energy Revenue):** Approximately 1.10 EUR per ton (Net Cost). *Assumptions:* 20-year lifetime.
6. Pollution Prevention and Environmental Protection	**Methane Capture:** The retrofit scenario assumes a 60% capture efficiency, preventing fugitive emissions. **Net Benefit:** The system provides a massive abatement potential relative to capital employed, significantly reducing the site's carbon footprint by preventing the release of methane.
7. Economic Viability	**Estimated ROI: -2% to 4%** (Negative NPV without carbon finance). **Revenue:** The feed-in tariff is ~0.06 EUR/kWh. This generates ~€360,000 annually, which barely covers OPEX and capital repayment.

	Viability Gap: The project requires a break-even tariff of ~0.11 EUR/kWh or carbon credit revenue of >20-30 EUR/ton (e.g., via Article 6.2) to become bankable. **Competitiveness:** Structurally unprofitable as a standalone energy project; it functions primarily as "methane abatement infrastructure".
8. Job Creation Potential	**Roles:** Requires specialized drilling crews for installation and skilled technicians for the operation of imported gas engines. The sector relies on foreign expertise for initial deployment due to a lack of local experience with LFG systems. **Estimated New Jobs:** 100 permanent positions nationwide.
9. Social Co-benefits	**Health & Safety:** Eliminates explosion risks and reduces odors/VOCs from open dumps. The 2024 Law on Heat Power enables the potential supply of heat to local district networks or greenhouses, benefiting local communities.
10. Climate Change Mitigation Benefits	**Mitigation Potential:** 0.60–0.68 tons CO_2e per ton of waste processed for w/flaring and w/LFGtE. **Mechanism:** Driven by the destruction of methane (Assuming 60% methane capture; GWP 28) and the displacement of Kazakhstan's coal-heavy grid electricity (Grid Intensity: 516 g CO_2e/kWh). **National Potential:** Retrofitting legacy sites represents one of the most effective short-term decarbonization levers available to the waste sector.
11. Compliance with National Targets and Legislation	**Alignment:** Directly supports the Carbon Neutrality Strategy 2060 and the 2025 Green Economy transition. **Policy Drivers:** The 2024 Law on Heat Power Industry and Renewable Energy Auctions (2024/25) provide the legal framework, though fiscal incentives (e.g., Article 6.2 access) are still needed to bridge the financial gap.
12. Example Projects	**Kazakhstan:** No fully operational large-scale LFG-to-Energy projects exist due to the tariff barrier. However, the analysis uses a representative 1-million-ton regional landfill (e.g., typical of cities like Petropavlovsk or Kostanay) as the baseline for feasibility. **Strategic Recommendation:** Pilots should focus on "Hybrid Models" combining electricity with on-site heat use (greenhouses/brick factories) to improve economics.
13. Advantages & Disadvantages	**Advantages:** Delivers massive climate mitigation by destroying methane and displacing coal-fired power. Provides baseload renewable energy capable of supporting district heating networks under the 2024 Law on Heat Power Industry. Enhances public safety by mitigating explosion risks and odors. **Disadvantages:** Structurally unprofitable without carbon finance or tariff reforms (ROI -2% to 4%). Faces severe "Cold Climate" engineering challenges (condensate freezing) increasing civil costs by 20-30%. Restricted to large-scale sites due to high fixed costs.

1. IRENA. (2012). *Renewable Energy Technologies: Cost Analysis Series: Biomass for Power Generation*. International Renewable Energy Agency. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2012/RE_Technologies_Cost_Analysis-BIOMASS.pdf

TFS-W-12:

Category	Description & Data
1. Technology Name	**Remediation of Legacy Dumpsites (Leachate Control and Biological Oxidation of Diffuse Methane Emissions via Biocovers)**
2. Technical Overview	**Function:** A tiered remediation strategy for "brownfield" dumpsites utilizing passive nature-based solutions for methane and civil engineering for liquid containment. **Process:** • **Biological Oxidation (Biocover):** Involves spreading a 1-m engineered layer of compost/soil over the dump surface. Methanotrophic bacteria in the soil oxidize rising methane into CO_2 and water. • **Leachate Control:** Utilizes vertical slurry walls (soil-bentonite, 15 m depth) to stop groundwater inflow and impermeable capping (geomembrane) to stop rain infiltration. Leachate is collected and treated (e.g., via evaporation or Reverse Osmosis). **Applicability:** Biocovers are recommended for Rural/Remote dumps where gas flow is too low for flaring. Leachate control is reserved for sites posing imminent risks to water bodies. **Constraint:** The Kazakh winter freezes biocovers, halting biological activity and creating an impermeable "ice cap" that forces gas to migrate laterally.
3. Technology Readiness Level (TRL)	**TRL 9** Biocovers are mature globally but face efficacy challenges in Kazakhstan's climate, requiring adaptation (e.g., insulation layers) to prevent winter freezing. Slurry walls are standard but expensive civil engineering.
4. Ease of Implementation and Replicability	**Complexity:** Mixed. Biocover implementations are low-complexity earthworks manageable with local machinery. Leachate control is high-complexity, requiring specialized bentonite slurry wall construction. **Replicability:** High for biocovers in rural districts due to low skill requirements. Low for slurry walls due to extreme cost. **Implementation Time:** 6–12 months for earthworks and construction.
5. Financial Requirements and Costs	**Estimated Capital Expenditure (CAPEX):** • **Biocover:** Low intensity at ~€0.55 per ton of waste (Total €550,000 for a 1M ton/10 ha site). Driven by earthmoving and compost procurement. • **Leachate Control:** Very High intensity at ~€7.80 per ton (Total €7.8 Million). Driven by slurry walls (€250/m²) and geomembranes. **Estimated Operational Expenditure (OPEX):** • **Biocover:** Minimal (€0.015 per ton/year) for regrading/watering. • **Leachate Control:** Moderate (€0.058 per ton/year) for pumping and treatment (RO/Evaporation).

	Estimated Levelized Cost of Treatment (LCOT): • **Biocover:** ~€0.85 per ton. • **Leachate Control:** ~€8.96 per ton. *Assumptions:* 20-year project life.
6. Pollution Prevention and Environmental Protection	**Methane:** Biocovers oxidize fugitive methane. However, efficiency drops from ~50% in summer to near 0% in winter, resulting in a weighted annual efficiency of ~25%. **Water:** Leachate control prevents the migration of heavy metals and ammonia into aquifers, critical for protecting drinking water in arid zones.
7. Economic Viability	**Revenue:** Zero. These are pure remediation technologies generating no energy or saleable product. **Estimated ROI:** Negative. **Viability:** Relies entirely on public funding to avoid environmental liabilities (fines) or protect public goods (water). The Biocover scenario is the most cost-efficient mitigation strategy for rural sites at €37 per ton CO_2e abated.
8. Job Creation Potential	**Roles:** Temporary construction jobs for earthmoving (excavator/bulldozer operators) and liner installation. Long-term roles are minimal (periodic monitoring). **Estimated New Jobs:** 1200 jobs.
9. Social Co-benefits	**Public Nuisance:** Biocovers significantly reduce odors and surface scavenger activity. **Health:** Leachate control secures local water sources from toxic contamination, vital for agricultural communities.
10. Climate Change Mitigation Benefits	**Mitigation Potential:** • **Biocover:** ~0.38 tons CO_2e per ton of waste processed (Annual avg. reduction: 18,900 tCO_2e for a 1M ton site). • **Leachate Control:** Minimal direct climate benefit. **Mechanism:** Biological oxidation of methane by methanotrophs. **National Potential:** Moderate. While per-site reduction is lower than flaring, widespread application at thousands of small rural dumps could yield significant aggregate reductions.
11. Compliance with National Targets and Legislation	**Alignment:** Addresses the Environmental Code (2021) requirement to remediate unauthorized dumpsites and prevent environmental damage. **Strategic Fit:** Fits a strategy for managing the country's vast network of small, non-sanitary disposal sites where active gas collection is uneconomic.
12. Example Projects	**Kazakhstan:** Recommended as the standard closure solution for rural/remote dumps where electricity infrastructure for flaring/energy is absent. **International:** Widespread use in EU and North America for older, closed landfill cells (Passive oxidation).
13. Advantages & Disadvantages	**Advantages:** **Biocover:** Lowest CAPEX solution (€0.55/t); utilizes local materials (soil/compost); simple to maintain.

	Leachate Control: Provides absolute containment of toxins, protecting critical water resources. **Disadvantages:** **Biocover:** Winter freezing causes seasonal failure (zero efficiency); lower mitigation than flaring. **Leachate Control:** Prohibitive CAPEX (€7.8M) for most municipalities; technically complex construction. **General:** Zero revenue generation.

Annex 7: Scoring and Decision Matrices for MCA (waste sector)

Scoring Matrix

Scoring Matrix											
	Costs		Technology Diffusion		Benefits				Climate Related	Governance	
	1. Cost of Waste Treatment				Economic		Environmental	Social			
	1.1. Annualized Capital Cost (CAPEX), EUR/ton/year	1.2. Annual Operational Cost (OPEX), EUR/ton/year	2.1. Technology Readiness Level (TRL)	2.2. Ease of Implementation	3.1. Economic Viability	3.2. Job Creation Potential	4.1. Pollution Prevention and Environmental Protection	5.1. Social Co-benefits	6.1. Climate Mitigation (tCO2eq/ton processed waste)	7.1. Compliance with National Targets and Legislation	
1. Integrated Remote Sensing and GPS-Based Vehicle Tracking System	100	100	75	100	100	1	50	0	14	100	
2. Anaerobic Digestion of Sewage Sludge	76	0	25	33	100	4	100	100	100	50	
3. Extraction of Metals from Industrial Waste	78	88	0	0	75	100	0	0	33	50	
4. Circular Economy-Based Management of C&D and Mining Wastes and Metallurgical Slags	97	99	50	33	50	59	50	0	0	50	
5. Transition to Multi-stream Waste Separation	98	70	50	33	50	39	100	100	14	100	
6. Enclosed Composting of Organic Fraction of MSW	50	88	75	33	25	2	50	0	28	100	
7. Utilization of Organic Fraction of MSW for Biogas Production	0	69	25	0	25	10	100	0	45	100	
8. Open-air Composting in Rural Areas	96	95	75	67	25	14	0	0	20	0	
9. Production of Alternative Fuels (RDF)	17	80	50	33	25	2	0	0	24	50	
10. Construction of Sanitary Landfills with Methane Recovery	99	93	100	67	25	11	50	100	18	100	
11. Landfill Gas Retrofitting for Energy Generation	99	96	50	33	0	0	100	0	18	50	
12. Remediation of Legacy Dumpsites	100	100	50	33	0	22	0	0	10	50	
Scoring scale	0= Very high --> 100= Very low	0= Very high --> 100= Very low	0= Very low --> 100= Very high	0= Very easy --> 100= Very hard	0= Very low --> 100= Very high	0= Very low --> 100= Very high	0= Very low --> 100= Very high	0= Very low --> 100= Very high	0= Very low --> 100= Very high	0= Very low --> 100= Very high	**Total:**
Criterion weight	7.35	7.35	7.2	6.8	7.2	6.8	15.4	13.9	14.1	13.9	100

Decision Matrix

Desicion Matrix: Weighted Scores													
	Costs		Technology Diffusion		Benefits				Climate Related	Governance	Total score		
	1. Cost of Waste Treatment				Economic		Environmental	Social					
	1.1. Annualized Capital Cost (CAPEX), EUR/ton/year	1.2. Annual Operational Cost (OPEX), EUR/ton/year	2.1. Technology Readiness Level (TRL)	2.2. Ease of Implementation	3.1. Economic Viability	3.2. Job Creation Potential	4.1. Pollution Prevention and Environmental Protection	5.1. Social Co-benefits	6.1. Climate Mitigation (tCO2eq/ton processed waste)	7.1. Compliance with National Targets and Legislation	Total Score	Technology Rank	Norm. Tot. Score
1. Integrated Remote Sensing and GPS-Based Vehicle Tracking System	735	733	540	680	720	7	770	0	202	1390	5777	4	83%
2. Anaerobic Digestion of Sewage Sludge	558	0	180	227	720	28	1540	1390	1410	695	6748	2	97%
3. Extraction of Metals from Industrial Waste	575	645	0	0	540	680	0	0	463	695	3598	9	52%
4. Circular Economy-Based Management of C&D and Mining Wastes and Metallurgical Slags	713	725	360	227	360	402	770	0	0	695	4252	8	61%
5. Transition to Multi-stream Waste Separation	717	518	360	227	360	264	1540	1390	202	1390	6967	1	100%
6. Enclosed Composting of Organic Fraction of MSW	368	649	540	227	180	10	770	0	388	1390	4522	5	65%
7. Utilization of Organic Fraction of MSW for Biogas Production	0	508	180	0	180	65	1540	0	630	1390	4493	7	64%
8. Open-air Composting in Rural Areas	707	696	540	453	180	97	0	0	277	0	2951	11	42%
9. Production of Alternative Fuels (RDF)	126	586	360	227	180	10	0	0	344	695	2527	12	36%
10. Construction of Sanitary Landfills with Methane Recovery	730	681	720	453	180	73	770	1390	251	1390	6638	3	95%
11. Landfill Gas Retrofitting for Energy Generation	728	708	360	227	0	0	1540	0	251	695	4508	6	65%
12. Remediation of Legacy Dumpsites	734	735	360	227	0	153	0	0	139	695	3043	10	44%
Criterion weight	7.35	7.35	7.2	6.8	7.2	6.8	15.4	13.9	14.1	13.9	100		

Annex 8: Sensitivity Analysis Results for MCA (waste sector)

Sensitivity Analysis for "Equal Weights"

	Costs		Technology Diffusion		Benefits				Climate Related	Governance					
	1. Cost of Waste Treatment				Economic		Environmental	Social							
	1.1. Annualized Capital Cost (CAPEX), EUR/ton/year	1.2. Annual Operational Cost (OPEX), EUR/ton/year	2.1. Technology Readiness Level (TRL)	2.2. Ease of Implementation	3.1. Economic Viability	3.2. Job Creation Potential	4.1. Pollution Prevention and Environmental Protection	5.1. Social Co-benefits	6.1. Climate Mitigation (tCO2eq/ton processed waste)	7.1. Compliance with National Targets and Legislation	Total Score	Technology Rank	Norm. Tot. Score	Original MCA ranking	Change
1. Integrated Remote Sensing and GPS-Based Vehicle Tracking System	714	712	536	714	714	7	714	0	205	1429	5746	1	100%	4	3
2. Anaerobic Digestion of Sewage Sludge	543	0	179	238	714	29	714	714	714	357	4203	4	73%	2	-2
3. Extraction of Metals from Industrial Waste	558	627	0	0	536	714	0	0	234	357	3027	8	53%	9	1
4. Circular Economy-Based Management of C&D and Mining Wastes and Metallurgical Slags	693	705	357	238	357	423	357	0	0	357	3487	5	61%	8	3
5. Transition to Multi-stream Waste Separation	697	503	357	238	357	277	714	714	103	714	4674	3	81%	1	-2
6. Enclosed Composting of Organic Fraction of MSW	357	631	536	238	179	11	357	0	197	714	3219	6	56%	5	-1
7. Utilization of Organic Fraction of MSW for Biogas Production	0	494	179	0	179	69	714	0	319	714	2667	10	46%	7	-3
8. Open-air Composting in Rural Areas	687	677	536	476	179	102	0	0	140	0	2797	9	49%	11	2
9. Production of Alternative Fuels (RDF)	122	569	357	238	179	11	0	0	174	357	2007	12	35%	12	0
10. Construction of Sanitary Landfills with Methane Recovery	709	662	714	476	179	77	357	714	127	714	4730	2	82%	3	1
11. Landfill Gas Retrofitting for Energy Generation	707	688	357	238	0	0	714	0	127	357	3189	7	55%	6	-1
12. Remediation of Legacy Dumpsites	713	714	357	238	0	160	0	0	71	357	2611	11	45%	10	-1
Criterion weight	7.14	7.14	7.14	7.14	7.14	7.14	14.29	14.29	14.29	14.29	100				

Sensitivity Analysis for "Economical Criteria Categories"

	Costs		Technology Diffusion		Benefits				Climate Related	Governance					
	1. Cost of Waste Treatment				Economic		Environmental	Social							
	1.1. Annualized Capital Cost (CAPEX), EUR/ton/year	1.2. Annual Operational Cost (OPEX), EUR/ton/year	2.1. Technology Readiness Level (TRL)	2.2. Ease of Implementation	3.1. Economic Viability	3.2. Job Creation Potential	4.1. Pollution Prevention and Environmental Protection	5.1. Social Co-benefits	6.1. Climate Mitigation (tCO2eq/ton processed waste)	7.1. Compliance with National Targets and Legislation	Total Score	Technology Rank	Norm. Tot. Score	Original MCA ranking	Change
1. Integrated Remote Sensing and GPS-Based Vehicle Tracking System	900	897	443	557	1800	6	631	0	166	1139	6538	3	94%	4	1
2. Anaerobic Digestion of Sewage Sludge	684	0	148	186	1800	23	1262	1139	1155	570	6966	1	100%	2	1
3. Extraction of Metals from Industrial Waste	704	790	0	0	1350	557	0	0	379	570	4350	7	62%	9	2
4. Circular Economy-Based Management of C&D and Mining Wastes and Metallurgical Slags	873	888	295	186	900	330	631	0	0	570	4672	5	67%	8	3
5. Transition to Multi-stream Waste Separation	878	634	295	186	900	216	1262	1139	166	1139	6814	2	98%	1	-1
6. Enclosed Composting of Organic Fraction of MSW	450	795	443	186	450	9	631	0	318	1139	4420	6	63%	5	-1
7. Utilization of Organic Fraction of MSW for Biogas Production	0	622	148	0	450	53	1262	0	516	1139	4190	9	60%	7	-2
8. Open-air Composting in Rural Areas	866	853	443	371	450	80	0	0	227	0	3289	10	47%	11	1
9. Production of Alternative Fuels (RDF)	154	717	295	186	450	9	0	0	282	570	2662	12	38%	12	0
10. Construction of Sanitary Landfills with Methane Recovery	894	834	590	371	450	60	631	1139	206	1139	6314	4	91%	3	-1
11. Landfill Gas Retrofitting for Energy Generation	891	866	295	186	0	0	1262	0	206	570	4276	8	61%	6	-2
12. Remediation of Legacy Dumpsites	899	900	295	186	0	125	0	0	114	570	3088	11	44%	10	-1
Criterion weight	9.0	9.0	5.9	5.6	18.0	5.6	12.6	11.4	11.6	11.4	100				

Sensitivity Analysis for "Environment/Climate Criteria Categories"

	Costs		Technology Diffusion		Benefits				Climate Related	Governance					
	1. Cost of Waste Treatment				Economic		Environmental	Social							
	1.1. Annualized Capital Cost (CAPEX), EUR/ton/year	1.2. Annual Operational Cost (OPEX), EUR/ton/year	2.1. Technology Readiness Level (TRL)	2.2. Ease of Implementation	3.1. Economic Viability	3.2. Job Creation Potential	4.1. Pollution Prevention and Environmental Protection	5.1. Social Co-benefits	6.1. Climate Mitigation (tCO2eq/ton processed waste)	7.1. Compliance with National Targets and Legislation	Total Score	Technology Rank	Norm. Tot. Score	Original MCA ranking	Change
1. Integrated Remote Sensing and GPS-Based Vehicle Tracking System	667	665	490	617	654	6	900	0	258	1262	5520	4	78%	4	0
2. Anaerobic Digestion of Sewage Sludge	507	0	163	206	654	25	1800	1262	1800	631	7048	1	100%	2	1
3. Extraction of Metals from Industrial Waste	522	586	0	0	490	617	0	0	591	631	3436	9	49%	9	0
4. Circular Economy-Based Management of C&D and Mining Wastes and Metallurgical Slags	647	658	327	206	327	365	900	0	0	631	4061	8	58%	8	0
5. Transition to Multi-stream Waste Separation	651	470	327	206	327	239	1800	1262	258	1262	6802	2	97%	1	-1
6. Enclosed Composting of Organic Fraction of MSW	334	589	490	206	163	9	900	0	496	1262	4449	7	63%	5	-2
7. Utilization of Organic Fraction of MSW for Biogas Production	0	461	163	0	163	59	1800	0	804	1262	4713	5	67%	7	2
8. Open-air Composting in Rural Areas	642	632	490	412	163	88	0	0	353	0	2781	11	39%	11	0
9. Production of Alternative Fuels (RDF)	114	532	327	206	163	9	0	0	439	631	2421	12	34%	12	0
10. Construction of Sanitary Landfills with Methane Recovery	663	618	654	412	163	66	900	1262	320	1262	6320	3	90%	3	0
11. Landfill Gas Retrofitting for Energy Generation	661	642	327	206	0	0	1800	0	320	631	4587	6	65%	6	0
12. Remediation of Legacy Dumpsites	666	667	327	206	0	139	0	0	178	631	2814	10	40%	10	0
Criterion weight	6.67	6.67	6.54	6.17	6.54	6.17	18.00	12.62	18.00	12.62	100				

Annex 9: List of stakeholders involved (waste sector)

Name	Affiliation (Ministry, Department, Company, etc.)	Form of consultation
Dana Agybayeva	Senior Expert of the Industrial Waste Management Division, Waste Management Department, Ministry of Ecology and Natural Resources of the Republic of Kazakhstan	Active participation in the MCA-based prioritization process, including the design of weighted scoring matrices and the formation and validation of the technology shortlist to guarantee alignment with high-level national strategies and sectoral growth pathways
Ainur Batyrkhanova	Senior Expert of the Municipal Waste Management Division, Waste Management Department, Ministry of Ecology and Natural Resources of the Republic of Kazakhstan	
Gulzhan Tursynova	Director of the Ecology Department, Kazakhstan Association of Regional Environmental Initiatives "ECOJER"	
Adilbek Baltabekov	Senior Manager, Best Available Techniques (BAT) Reference Division, IGTIC	
Gulnaz Kasymbayeva	Senior Manager, Best Available Techniques (BAT) Reference Division, IGTIC	
Lyudmila Kuznetsova	Expert in Solid Waste, Engineer-Economist, General Director, LLP "GeoData Plus"	
Vadim Litvinov	Industrial Waste Expert, Environmental Designer, LLP "Project-Environmental Bureau"	
Saida Abdrakhim	Senior Manager, Sectoral Competence Department 2 (SCD-2), "Zhasyl Damu" JSC	
Olzhas Alshagirov	Senior Manager, Department of Modeling, Analysis, and Forecasting (DMAF), "Zhasyl Damu" JSC	
Zhanel Zhakupova	National Coordinator of Global Cleantech Innovation Program in Kazakhstan, UNIDO/IGTIC	
Anatoly Pinigin	General Director, LLP "Ekom"	
Aida Alimbekova	Master of Environmental Sustainability, Climate Action and Circular Economy Expert	
Zulpat Aziyeva	CEO at the Association for Promoting the infrastructure and innovation development on Just energy transition programs	