

# Modeling Path Dependence in Jordan's Water-Energy Nexus: The Geo-Institutional Proxy Analysis (GIPA) Framework

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## Abstract

This research investigates the systemic drivers of policy resistance within Jordan's Water-Energy nexus. It aims to quantify how macroeconomic fiscal constraints—termed here as the “Structural Fiscal Veto”—translate into technical operational deficits, necessitating a strategic shift toward domestic technical resilience. The study introduces the original Geo-Institutional Proxy Analysis (GIPA) framework, utilizing verifiable financial metrics as quantifiable proxies for institutional capacity. A System Dynamics model is developed to map the interplay of legacy fiscal burdens and innovation cycles, utilizing the “Shifting the Burden” archetype to evaluate the transition from donor-dependency to self-sustaining modernization. Empirical application of the GIPA framework to baseline data (2022-2025) yields an Innovation Allocation Efficiency Index of ~14.43. This diagnostic value reveals an “Innovation Trap”, where fiscal structures are predominantly oriented toward administrative sustainability, leaving technical modernization vulnerable to external funding fluctuations. The results highlight the precariousness of relying on external grants for up to 80% of research operations, as evidenced by the 2025 JD 257 million liquidity shock. To break the self-reinforcing loops of dependency, the study proposes a shift toward Output-Based Financing and Technical Sovereignty. Key recommendations for 2026-2030 include establishing a centralized WEFE Nexus Authority and integrating a “Solar-Rail Backbone” to stabilize the operational baseline. By targeting these deep leverage points, Jordan can decouple its strategic infrastructure projects, such as the National Conveyance Project, from external shocks and transform its globally superior scientific output into a catalyst for self-reliant technological leadership.

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## Keywords

GIPA Index, System Dynamics, WEF Nexus, Innovation Trap, Reinforcing Decay Loop, Shifting the Burden, Technical Sovereignty, Donor-Dependency, Jordan

## 1. Introduction

The transition of the Jordanian energy sector toward a sustainable, technology-driven future is not merely a technical objective but a systemic imperative defined by the intersection of macroeconomic stability, resource scarcity, and deep-seated institutional structures. As of late 2025, the Hashemite Kingdom of Jordan faces a complex duality: a resilient economy achieving a real **Gross Domestic Product** (GDP) growth rate of 2.8% in Q3 2025 (*The Jordan Times, 2025a*), reflecting a steady upward trajectory from 2.5% in 2024, despite the severe regional shocks generated by ongoing conflicts.

This resilience is largely attributed to robust performance in the manufacturing sector, which contributed a significant 0.89 percentage points to growth, and the mining sector, which expanded by 7.4%. However, this growth remains insufficient to outpace the accumulation of public debt. The total public debt (excluding the Social Security Investment Fund holdings) reached approximately JD 35.36 billion, standing at 90.9% of the national **GDP** by the end of Q2 2025 (*Ministry of Finance, 2025*). The fiscal deficit, which reached 5.0% of **GDP** in the January-May period of 2025, underscores the limitations of the current economic model, which serves as a primary driver affecting the operational equilibrium (*Central Bank of Jordan, 2025*). These macroeconomic dynamics are further detailed in **Table 1**.

**Table 1.** Key economic indicators (2025).

Key Economic Indicator (2025)	Value/Metric	Source
Real <b>GDP</b> Growth (Q3 2025)	2.8%	<i>The Jordan Times, 2025a</i>
Total Public Debt (Excl. SSIF <sup>a</sup> )	JD 35.36 Billion (90.9% of <b>GDP</b> )	<i>Ministry of Finance, 2025</i>
Net External Debt (Excl. SSIF <sup>a</sup> )	JD 19.82 Billion	<i>Ministry of Finance, 2025</i>
Fiscal Deficit (Jan-May 2025)	JD 780.2 Million (5.0% of <b>GDP</b> )	<i>Central Bank of Jordan, 2025</i>
Manufacturing Contribution to <b>GDP</b>	17.7%	<i>The Jordan Times, 2025a</i>
Mining Sector Growth	7.4%	<i>The Jordan Times, 2025a</i>

a. *Social Security Investment Fund.*

The core analytical problem lies in identifying the endogenous mechanisms that translate these fiscal constraints into persistent deficits in human and technical capital. This study hypothesizes that Jordan's energy sector is governed by a Structural Fiscal Veto—a consumption mechanism where high-cost, long-

term liabilities, such as legacy **Power Purchase Agreements** (PPAs), structurally restrict the funding necessary for productive investments in **Research and Development** (R&D) and specialized workforce training. The fiscal position remains acutely vulnerable; the combined fiscal pressures at the **National Electric Power Company** (NEPCO) and the **Water Authority of Jordan** (WAJ) were a key component of the overall public sector deficit in 2024 (del Mar Logrono Narbona, 2025). Much of this fiscal burden is tied to rigid legacy **PPA** contracts, exemplified by substantial legal fees incurred in disputes such as the Attarat power project.

This financial bottleneck fuels a Structural Innovation Deficit, directly compromising the security of vital national infrastructure. While strategic initiatives like the **NCP** are essential for resource security, their long-term viability depends on local **Operational Technology** (OT) Skills Proficiency to mitigate escalating cyber risks (Abdulhaleem, 2025). This is particularly critical given the 80% increase in cyber incidents reported against national infrastructure in 2023, necessitating a strategic shift from debt-servicing to technical-capacity building.

The methodological contribution lies in the introduction of the **Geo-Institutional Proxy Analysis** (GIPA). Since institutional capacity and meritocracy are often unobservable latent variables, **GIPA** utilizes verifiable financial and operational metrics as quantifiable proxies to dynamically track the effects of governance constraints within the Water-Energy nexus (Liu et al., 2024). **System Dynamics** (SD) modeling allows for the development of computer-supported frameworks that portray non-linear processes of accumulation and feedback. By mapping the structure responsible for policy resistance, this study identifies the high-leverage points capable of inducing the systemic change required for the energy transition (Korhonen-Kurki et al., 2024; Meadows, 2026).

The significance of this research lies in providing a proactive framework that aligns with Jordan's Economic Modernization Vision. By modeling the intricate relationship between fiscal variables and technical capacities, this study seeks to offer strategic pathways for enhancing institutional sustainability. The value of this analysis is rooted in its ability to transform operational challenges into growth opportunities, particularly within the water and energy sectors. By proposing mechanisms to strengthen "Institutional Meritocracy", the research aims to safeguard national infrastructure while maximizing the impact of the Kingdom's highly skilled human capital.

## 2. Methodology

### 2.1. The GIPA Framework and Institutional Proxies

**GIPA** framework is an original methodological contribution designed to quantify latent institutional variables through verifiable financial metrics. **GIPA** utilizes these proxies to evaluate "**Institutional Capacity on Meritocracy**" (ICM) and the efficiency of resource allocation. The **GIPA** Index (**Equation 1**) formalizes the dynamic relationship between administrative sustainability and the capacity

for technical modernization, substantiated by the high-fidelity data points in **Table 2**.

$$\text{GIPA Index} = \frac{\text{Operational Baseline (OB)}}{\text{Strategic Investment (SI)} \times \text{Skills Proficiency (SP)}} \quad (1)$$

Where:

- **Operational Baseline (OB)**: The fiscal commitment required for personnel stability and administrative continuity.
- **Strategic Investment (SI)**: The effective allocation directed toward core R&D and innovative technical outputs.
- **Skills Proficiency (SP)**: The measured proficiency in specialized OT.

**Table 2.** GIPA Framework Data Points (2023-2025).

GIPA Proxy Indicator	Institutional Phenomenon	Value/Metric	Source
Electricity as % of Water O&M	Structural Fiscal Veto	40.2% - 43.8%	Talozi et al., 2025
GERD as % of GDP	Structural Innovation Deficit	0.7%	WIPO, 2025
National Agricultural Research Center (NARC) Budget to Salaries	Administrative Concentration	~84% - 90%	General Budget Law, 2022
OT Skills Index (Proficiency)	Human Capital Gap	~58% (Specialized)	Abdulhaleem, 2025
GII Ranking (2025)	Innovation Paradox	65th (2nd in Papers)	WIPO, 2025

## 2.2. SD Modeling: Causal Loops and Archetypal Behavior

The core SD analysis is based on modeling the interplay of Reinforcing Loops (R) and Balancing Loops (B) (Braun, 2002; Team EACPDS, 2015).

### 2.2.1. Reinforcing Loop R1 (The Operational Decay Loop)

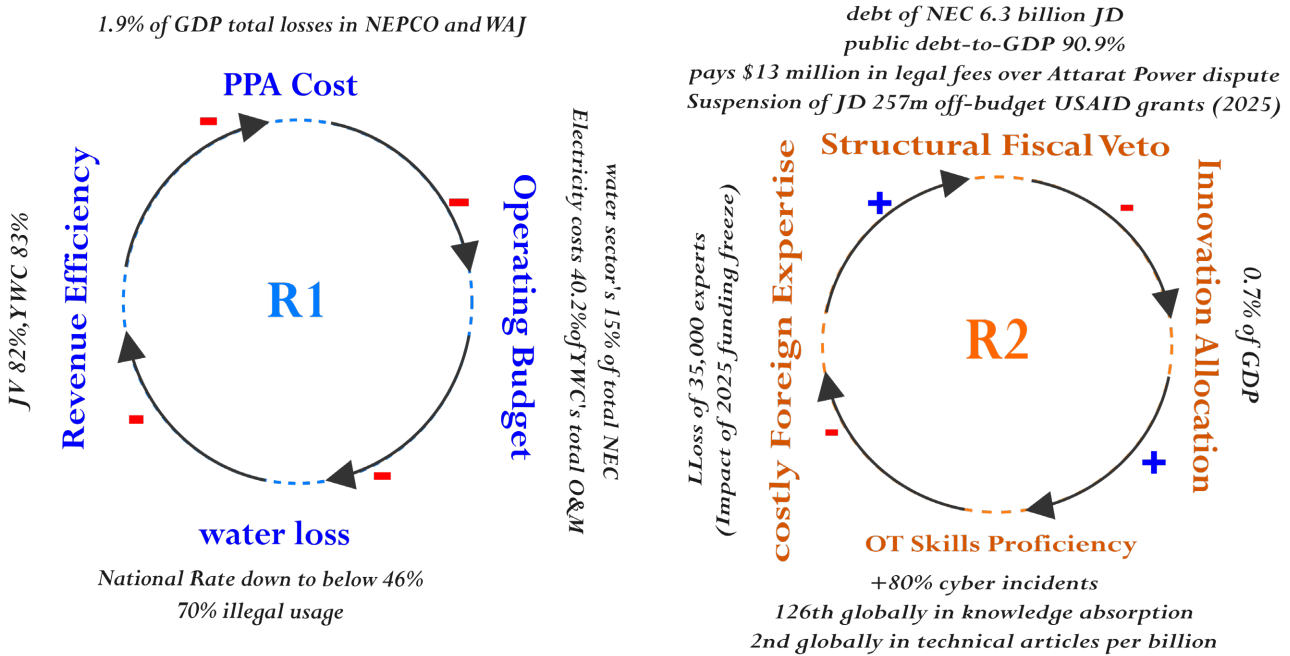
- **High PPA Cost constraint** → (-) Operating Budget: High debt servicing reduces cash flow available for maintenance.
- Operating Budget *limits* → (-) Water Loss (**Non-Revenue Water (NRW)**): Underfunding leads to physical asset decay.
- Water Loss *erodes* → (-) Revenue Efficiency: Physical losses translate into financial inefficiency.
- Revenue Efficiency *exacerbates* → (-) **High PPA Cost**: Reduced collection and revenue increase the utility's reliance on debt and government guarantees, closing the R1 loop.

### 2.2.2. Reinforcing Loop R2 (The Innovation Trap)

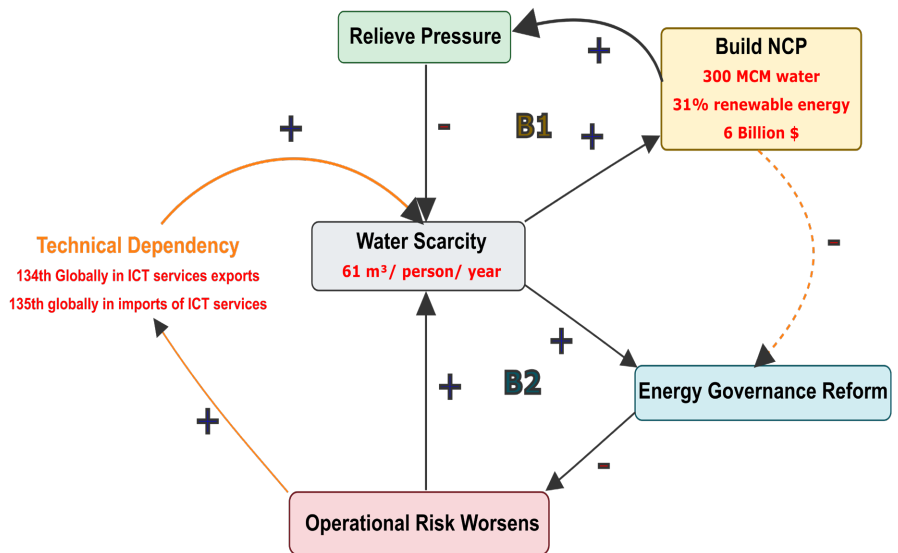
- **Structural Fiscal Veto restricts** → (-) Innovation Allocation (GERD): Fiscal pressure limits R&D investment.
- Innovation Allocation *drives* → (+) OT Skills Proficiency: R&D investment is a direct input to technical proficiency.
- OT Skills Proficiency *displaces* → (-) Costly Foreign Expertise: Higher local mastery reduces the need for expensive foreign consulting.
- Costly Foreign Expertise *reinforces* → (+) **Structural Fiscal Veto**: Reliance on high-cost external help reinforces the sovereign debt burden.

### 3. Results

The **GIPA** framework recognizes that in a complex system, information feedback characteristics are more influential than individual stock levels (Liu et al., 2024). By mapping the “Reinforcing Decay Loop” (R1) and the “Reinforcing Deficit Loop” (R2), shown in **Figure 1**, this research identifies how high electricity costs in water pumping directly throttle the **OB** available for maintenance. In the case of the Yarmouk Water Company, these costs represent over 40% of **O&M** expenditures, leading to high **NRW** rates (del Mar Logrono Narbona, 2025).



**Figure 1.** The “Reinforcing Decay Loop” (R1) and the “Reinforcing Deficit Loop” (R2).



**Figure 2.** The “Shifting the Burden” archetype models Jordan’s reliance on symptomatic fixes.

The analysis utilizes the “Shifting the Burden” archetype (**Figure 2**) to model Jordan’s strategic response to water scarcity. This archetype illustrates a critical systemic tension:

**The Symptomatic Fix (Loop B1):** Water scarcity ( $61 \text{ m}^3/\text{person}/\text{year}$ ) is addressed through large-scale supply-side infrastructure, specifically the \$6 billion **NCP**. While the **NCP** is essential for providing 300 MCM of water annually, **Figure 2** highlights that this “Relief of Pressure” is temporary if it remains a standalone measure.

**The Fundamental Solution (Loop B2):** The model suggests that long-term stability requires Energy Governance Reform. Without this reform, the high energy intensity of desalination and pumping leads to a “Side Effect” where Operational Risk Worsens, further increasing Technical Dependency.

**Strategic Insight:** **Figure 2** visually confirms that relying solely on the **NCP** without optimizing the **GIPA** Index variables (specifically **SP** and **SI**) creates a reinforcing loop of dependency. The orange arrows in **Figure 2** demonstrate how low ICT service rankings (134th globally) exacerbate technical dependency, thereby increasing the systemic pressure back on water scarcity.

A critical component of the \$6 billion **NCP** shown in **Figure 2** is the strategic integration of 31% renewable energy into its operational matrix. This planned renewable energy share is a high-leverage intervention designed to mitigate the ‘Side Effect’ of escalating energy costs. By decoupling nearly one-third of the **NCP**’s power requirements from the conventional grid, Jordan can stabilize the **OB** and reduce the systemic pressure on electricity tariffs. This 31% integration serves as a technical bridge toward the Fundamental Solution (Loop B2), provided it is supported by the governance reforms and **SP** necessary to manage such complex, hybrid energy-water systems.

### 3.1. The Empirical Application: NARC Diagnostic Case

The proxy for Administrative Resource Concentration is empirically grounded in the financial allocations of the National Agricultural Research Center (**NARC**). According to the General Budget Law of 2022, the ‘Current Expenditures’—primarily salaries and social security for 789 employees—amounted to JD 7,869,000, representing 83.7% (0.837) of the total program budget. When adjusted for administrative overheads, the effective allocation for core **R&D** activities **SI** is estimated at 10% (0.10).

Applying Equation 1 to the **NARC** baseline data ( $OB = 0.837$ ,  $SI = 0.10$ ,  $SP = 0.58$ ), the resulting **GIPA Index is ~14.43 in bold**. This value serves as a mathematical diagnostic tool, identifying the strategic opportunity to transition toward ‘Output-Based Financing’. This baseline quantifies the potential to enhance institutional impact by optimizing the allocation toward **SI** and **SP**, thereby achieving a sustainable equilibrium between administrative stability and technical modernization (*General Budget Law, 2022*).

This fiscal rigidity is compounded by an acute vulnerability to external funding fluctuations. Historically, **NARC** relies on external grants (primarily from USAID

and the EU) to fund up to 80% of its effective research operations (IFPRI & NCARE, 2014). The precariousness of this model was highlighted in January 2025, when the abrupt freeze of JD 257 million in off-budget USAID development assistance triggered a liquidity shock that impacted donor-funded R&D initiatives (Essaid, 2026).

### 3.2. The Jordanian Innovation Paradox and GIPA Validation

The 2025 Global Innovation Index (GII) reveals that Jordan ranks 2nd globally in “Scientific and Technical Article Publications”, yet 126th in “Knowledge Absorption” (Table 3). This “Translation Gap” is effectively modeled by the **GIPA Index (14.43 for NARC)**. The diagnostic result proves that while intellectual output is high, the transition toward the “Fundamental Solution” shown in Figure 2 requires increasing **SI** and **SP** to reduce the “Technical Dependency” illustrated in the archetype.

**Table 3.** Global innovation index specific indicator rank (2025).

GII Pillar	Specific Indicator Rank	Value/Metric	Source
Institutions (52nd)	Policy Stability for Business	29th	WIPO, 2025
Knowledge/Tech (60th)	Scientific/Technical Articles	2nd	WIPO, 2025
Infrastructure (87th)	Government Online Services	63rd	The Jordan Times, 2025b

The “Reinforcing Deficit Loop” (R2) (Figure 1) further substantiates Figure 2 by illustrating how the shortage of specialized skills leads to a reliance on costly foreign expertise. This reliance reinforces the sovereign debt burden (90.9% of GDP), making the “Symptomatic Fix” of infrastructure projects more financially precarious unless coupled with merit-based resource allocation **ICM** to secure national assets like the NCP.

### 3.3. Modeling the Water-Energy Nexus and Socio-Technical Transitions

Jordan’s renewable water availability has reached a critical level of 61 cubic meters per year (Table 4) (Al-Rkebat, 2026). This necessitates energy-intensive pumping with intensities reaching 7.11 kWh/m<sup>3</sup> (Talozi et al., 2025).

**Table 4.** Jordan water budget (2023).

Water Budget Component	Volume (MCM)/%
Total Rainfall Volume	8508.4 MCM (100%)
Evaporation Loss	8029.5 MCM (93%)
Groundwater Recharge	304.3 MCM (4.5%)
Floods and Runoff	174.6 MCM (2.4%)

The “Reinforcing Decay Loop” (R1) (Figure 1) is fueled by the mismatch between electricity tariffs and water revenue. While electricity prices have generally

risen, water tariffs only cover approximately 60% of the real cost of production (Talozi et al., 2025; del Mar Logrono Narbona, 2025). This shortfall leads to chronic underfunding for maintenance, which manifests as high **NRW** rates (47.6% for Yarmouk Water) and collection inefficiencies (83.0% for Yarmouk Water) (del Mar Logrono Narbona, 2025). **Table 5** shows the energy performance of Jordan’s water utilities (MWI, 2023)

**Table 5.** Energy performance of Jordan water utilities (2023).

Utility	Electricity as % of <b>O&amp;M</b>	Revenue (Collection) Efficiency	<b>NRW</b> (National Rate)
Miyahuna	39.2%	90.0%	44.7%
Aqaba Water	20.3%	90.0%	33.8%
Yarmouk (YWC)	40.6%	83.0%	47.6%

## 4. Discussion

The transition toward a sustainable Water-Energy Nexus is facilitated by addressing key institutional factors. Enhancing financial inclusion and adopting “Social Capital Finance” models can overcome traditional collateral barriers for innovative managers. Success in this transition requires targeting “deep leverage points”, such as institutionalizing resource management goals and fostering collaborative governance. These measures ensure that large-scale projects like the NCP are supported by a resilient and inclusive socio-technical framework.

### 4.1. Comparative Institutional Analysis

Jordan’s governance structure remains a central pillar for national development, with current efforts focusing on bridging the gap between policy alignment (90%) and institutional capacity (73%) (Abdulhaleem, 2025). This disparity is often observed in operational processes, such as solar project licensing, which could benefit from streamlined “One-Stop Shop” models similar to regional benchmarks like Morocco’s MASEN agency (International Trade Administration, 2024).

Furthermore, the UAE’s “Shams Dubai” program provides a benchmark for “Smart Grid Integration” by utilizing AI-driven management to reduce approval times while significantly adding to grid capacity (Dubai Electricity & Water Authority (PJSC), 2025). For Jordan, these regional successes suggest that sustained progress requires a “Holistic Integration” of infrastructure, legislation, and human capital—moving from being a technology consumer to a strategic industry partner. This transition is essential to fully leverage Jordan’s intellectual potential, which currently ranks 2nd globally in scientific and technical publications (WIPO, 2025).

### 4.2. Future Technology Scenarios

To achieve this “Fundamental Solution” pathway, the strategic deployment of three key technology clusters is necessary: Vehicle-to-Grid (V2G) systems, smart

grid modernization, and the electrified **Jordan National Railway Project (JNRP)**.

#### 4.2.1. Vehicle-to-Grid and Grid Resilience

Electrifying the transport sector offers a transformative opportunity to enhance grid stability. V2G technology converts Electric Vehicles (EVs) into mobile energy storage units, critical given Jordan’s current 50 MW battery storage gap (*International Trade Administration, 2024*).

**Cost Savings:** V2G integration can reduce EV Total Cost of Ownership (TCO) by up to 19% through grid support rewards.

**Grid Stability:** Managed V2G programs significantly reduce peak load impacts.

**Revenue Efficiency:** Smart charging aligns EV demand with available grid capacity, helping utilities avoid billions in otherwise necessary network investment costs.

To further enhance Revenue Efficiency and support the expansion of the renewable energy market, there is a strategic opportunity to evolve current regulatory frameworks. For instance, transitioning toward a more flexible net-metering model and streamlining certification processes for bidirectional inverters—similar to the successful “Shams Dubai” initiative—could act as a significant catalyst. Implementing smart metering mandates as part of a holistic implementation strategy would bridge the current gap and accelerate Jordan’s transition toward becoming a regional leader in smart grid technology (*Central Bank of Jordan, 2025; HOMECUBES, 2025*).

#### 4.2.2. The JNRP and the Energy-Transport Nexus

The \$2.3 billion **JNRP** is a high-leverage “Fundamental Solution” as it reduces energy intensity by 50% - 80% compared to trucking and accommodates renewable-powered traction, reducing dependency on imported fuel (**Table 6**).

**Table 6.** Railway project transaction specifications.

Railway Project Parameter	Specification	Source
Total Investment Value	\$2.3 Billion (UAE Package)	Ministry of Investment, 2026
Network Length (Total)	897 km	Jordanian Railway Network, 2025
Freight Capacity (2030)	~40 Million Tonnes	The Ministry of Transport, 2011
Energy Intensity Reduction	50% - 80% (vs. Trucking)	The Ministry of Transport, 2011
Operational Date (Target)	2030	Ministry of Investment, 2026
Key Economic Impact	16% Internal Rate of Return (EIRR)	World Bank, 2023

### 4.3. Breaking the “Innovation Trap” through Capacity Building

The current institutional equilibrium within **NARC** is an organic byproduct of “Structural Funding Dependency”, illustrated in the Reinforcing Deficit Loop (R2). While the national budget ensures personnel stability through baseline salaries, the January 2025 freeze of approximately JD 257 million in off-budget assistance demonstrated the systemic vulnerability of donor-dependent **R&D**

models.

This disruption temporarily impacted technical implementation and highlighted the critical importance of local **OT Skills Proficiency**. To mitigate the need for “Costly Foreign Expertise”, which acts as a “Structural Fiscal Veto” on the 90.9% debt-to-GDP ratio—Jordan must scale successful domestic models. The **European Bank for Reconstruction and Development (EBRD)**, **NEPCO**, and **Al-Hussein Technical University (HTU)** apprenticeship program, which produced ISO/AHK-certified technicians in 2024, provides a scalable blueprint. Enhancing the **ICM** through such accredited up-skilling is essential for operational resilience and managing the 80% increase in national cyber risks reported in 2023.

## 5. Conclusion

The analysis of future technology deployment confirms that Jordan stands at a structural crossroads. While the economy showed resilience with 2.8% **GDP** growth in 2025, the escalating demands of the Water-Energy-Food-Ecosystems (WEFE) necessitate fundamental governance shifts. The system currently faces “Policy Resistance”, where fiscal lock-ins and the Innovation Trap act as self-reinforcing loops.

To transform these cycles into loops of renewal, the following tangible recommendations are proposed for 2026-2030.

### 5.1. Establishment of a National WEFE Nexus Authority

Jordan should transition to a centralized “One-Stop Shop” authority to manage the WEFE nexus. This authority should consolidate permitting processes, aiming to reduce solar and V2G licensing from nine months to 30 days, mirroring successful regional models like Morocco’s MASEN. This shift will enhance institutional agility and ensure that resource management is governed by strictly merit-based performance metrics.

### 5.2. Implementing a V2G “National Resilience Buffer” Program

To bridge the 50 MW electricity storage gap, a national V2G incentive program is recommended. This includes VAT exemptions for bidirectional chargers and a “100% Feed-in-Tariff” for grid discharge during peak hours. This would transform Jordan’s growing EV fleet into a decentralized storage asset, stabilizing the grid and reducing reliance on costly peaker plants.

### 5.3. Mandated OT-Skill Certification and Meritocratic Up-Skilling

The government should formalize the EBRD/HTU accreditation model as the national standard for energy sector technicians. By 2030, 100% of technical roles in NEPCO and **WAJ** should be filled through an independent, accredited certification process. This will ensure the human capacity exists to manage smart grids and mitigate the 80% increase in cyber risks reported in 2023.

#### 5.4. Decoupling Agricultural Innovation from Asset Ownership

The Agricultural Credit Corporation (ACC) and commercial banks should launch “Social Capital Finance” products. By using group-lending models instead of traditional land collateral, Jordan can mobilize the potential of rural managers and women, facilitating the adoption of technologies that could save an estimated 10 - 20 MCM of water annually.

#### 5.5. Strategic Integration of the “Solar-Rail Backbone”

The \$2.3 billion **JNRP** should serve as a physical spine for a high-voltage renewable energy corridor. Utilizing the 897 km railway right-of-way for solar arrays can provide decentralized power for energy-intensive water pumping and mining operations, significantly reducing the Structural Fiscal Burden.

Without these shifts, Jordan’s “Innovation Paradox” will persist, leaving its exceptional scientific output (2nd globally) as a “Trapped Asset”. By targeting the deep leverage points identified in this **SD** analysis, Jordan can transform resource scarcity into a catalyst for institutional renewal and technological leadership in the MENA region.

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#### Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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