Arabian Gulf Journal
Humanities and Social Studies

(Saudi National Solar Digital Twin)

التوأم الرقمي الشمسي الوطني السعودي

هذا البحث العلمي من اصل براءة اختراع مودعة لدى الهئية الملكية الفكرية السعودية برقم حماية (55721292)

Ghadeer Mohamed Rashwan

غدير محمد رشوان

مستشار تنفيذي للشراكات والتحالفات الاستراتيجية ـ شبكات الأعمال والشؤون الأقتصادية والتجارية

من إدارة الثروات إلى تمكين الاستثمار الوطني المستدام

From Wealth Management to Enabling National Sustainable Investment

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Abstract:

Saudi Arabia's energy transition, aligned with Vision 2030 and the Net Zero 2060 targets, requires robust, transparent, and data-driven infrastructures. This research presents the Solar ROI Digital Twin Platform, an innovative framework integrated with smart meters, government digital services, and advanced financial analytics. The platform enables real-time monitoring of energy consumption, solar PV generation, and financial indicators such as ROI, NPV, and Payback Period. A Riyadh pilot study with 1,000 households and 50 rooftop PV systems demonstrates potential bill reductions of 15–25%, increased investor confidence by 20%, and significant carbon reduction impact. This study contributes to bridging the gap between smart grid technology, financial transparency, and policy-making, positioning Saudi Arabia as a leader in national digital energy ecosystems.

Keywords: Smart Meters; Digital Twin; Solar ROI; Absher Integration; Green Finance; Saudi Vision 2030; Net Zero 2060.

الملخص:

يهدف هذا البحث إلى تقديم إطار وطني مبتكر تحت مسمى (التوام الرقمي الشمسي الوطني السعودي) وذلك بما يتماشى مع مستهدفات رؤية السعودية 2030 وأهداف الحياد الصفري 2060. تقوم المنصة على دمج العدادات الذكية التابعة لشركة الكهرباء مع نموذج التوأم الرقمي(Digital Twin) ، بحيث تُمكّن من المراقبة الفورية لاستهلاك الطاقة وتوليد الكهرباء من أنظمة الطاقة الشمسية، مع حساب المؤشرات المالية مثل العائد على الاستثمار (ROI) وصافي القيمة الحالية (NPV) وفترة الاسترداد.

أظهرت دراسة تجريبية أُجريت في مدينة الرياض على عينة مكوّنة من 1000 أسرة و50 مستثمراً في أنظمة الخلايا الكهروضوئية انخفاضاً في فواتير الكهرباء بنسبة 15–25%، وزيادة في ثقة المستثمرين بنسبة 20%، بالإضافة إلى انخفاض ملموس في الانبعاثات الكربونية.

تسهم المنصة المقترحة في تعزيز الشفافية المالية، ودعم صنّاع القرار، وتسريع وتيرة التحول الوطني نحو الطاقة المتجددة.

الكلمات المفتاحية: العدادات الذكية؛ التوأم الرقمي؛ العائد على الاستثمار الشمسي؛ تكامل أبشر؛ التمويل الأخضر؛ رؤية السعودية 2030؛ صافي الصفر 2060.

The Invention:

The Saudi National Solar Digital Twin represents an integrated national framework focused on merging smart meter data from the Saudi Electricity Company with financial analytics and digital governance systems across the Kingdom. Its goal is to achieve real-time and transparent monitoring of energy consumption and solar electricity generation, while linking these metrics to financial and environmental indicators that support the national transition toward renewable energy.

The framework connects directly to the **Absher platform** and the **National Unified Digital Platform** to ensure comprehensive integration among government services, individuals, investors, and regulatory entities. Through this connection, the system enables:

1. Secure user authentication (individuals and organizations) via unified login mechanisms (OIDC/OAuth2).
2. Real-time collection and analysis of energy consumption and production data from smart meters.
3. Calculation of financial and investment indicators such as Return on Investment (ROI), Net Present Value (NPV), and Payback Period for each user or project.

4. Issuance of unified digital bills that integrate traditional electricity consumption and solar production within a trusted and automated system.
5. Provision of dashboards for decision-makers and regulatory bodies showing energy savings, emission reductions, and the effectiveness of governmental support for clean energy.

The Saudi National Solar Digital Twin aims to serve as a **national reference platform** within the digital transformation ecosystem of the energy sector, contributing to:

- Financial transparency in energy and solar investment billing.
- Enabling green financing through integration with banks and financial authorities.
- Enhancing investor confidence by displaying real-time performance and returns.
- Strengthening institutional integration among the Ministry of Energy, Ministry of Investment, Ministry of Finance, and the Saudi Electricity Company through the National Unified Digital Platform.

This framework provides a practical model for **national-level Digital Twin applications**, linking **energy, finance, and digital governance** into a single integrated system that supports **Saudi Vision 2030** and the **Net-Zero 2060** goal—positioning the Kingdom as a **global leader in innovation and digital transformation in sustainable energy**.

براءة الإختراع:

يمثل التوأم الرقمي الشمسي الوطني السعودي إطارًا وطنيًا متكاملًا يُعنى بدمج بيانات العدادات الذكية التابعة للشركة السعودية للكهرباء مع أنظمة التحليل المالي والحوكمة الرقمية في المملكة، بهدف تحقيق مراقبة فورية وشفافة لاستهلاك الطاقة وإنتاج الكهرباء من الأنظمة الشمسية، وربطها بالمؤشرات المالية والبيئية الداعمة للتحول الوطني نحو الطاقة المتجددة.

يرتكز الإطار على ربط المنصة مباشرةً بمنصتي «أبشر» والمنصة الوطنية الرقمية الموحدة لضمان التكامل الشامل بين الخدمات الحكومية والأفراد والمستثمرين والجهات التنظيمية، بحيث يتم من خلاله:

1. التحقق الآمن من هوية المستخدمين (أفرادًا أو منشآت) عبر آليات الدخول الموحّد (OIDC/OAuth2).
2. جمع وتحليل البيانات الفورية لاستهلاك وإنتاج الطاقة على مستوى العدادات الذكية.
3. حساب المؤشرات المالية والاستثمارية مثل العائد على الاستثمار (ROI)، صافي القيمة الحالية (NPV)، وفترة الاسترداد (Payback) لكل مستخدم أو مشروع.
4. إصدار فواتير رقمية موحّدة تربط بين استهلاك الكهرباء التقليدية والإنتاج الشمسي ضمن نظام موثوق ومؤتمت.
5. تقديم لوحات مؤشرات (Dashboards) لصنّاع القرار والهيئات التنظيمية حول وفورات الطاقة، وتخفيض الانبعاثات، وكفاءة الدعم الحكومي للطاقة النظيفة.

يهدف التوأم الرقمي الشمسي الوطني السعودي إلى أن يكون منصة وطنية مرجعية ضمن منظومة التحول الرقمي في قطاع الطاقة، تسهم في تحقيق:

- الشفافية المالية في فواتير الطاقة والاستثمار في الأنظمة الشمسية.
- تمكين التمويل الأخضر عبر الربط مع البنوك والهيئات المالية.
- رفع ثقة المستثمرين من خلال عرض العوائد والأداء في الزمن الحقيقي.

- تعزيز التكامل المؤسسي بين وزارة الطاقة، ووزارة الاستثمار، ووزارة المالية، والشركة السعودية للكهرباء، عبر بوابة المنصة الوطنية الموحدة.

ويمثل هذا الإطار نموذجًا عمليًا لتطبيقات التوأم الرقمي (Digital Twin) على المستوى الوطني، إذ يربط بين الطاقة، والتمويل، والحوكمة الرقمية، في منظومة واحدة متكاملة تدعم أهداف رؤية السعودية 2030 والحياد الصفري 2060، وتضع المملكة في موقع ريادي عالمي في مجال الابتكار والتحول الرقمي في قطاع الطاقة المستدامة.

About the Author:

Executive Advisor for Strategic Partnerships and Alliances | Business Networks and Economic & Commercial Affairs

Ghadeer possesses over fifteen years of professional experience in wealth management, financial planning, and strategic investment development. Her expertise extends to the renewable energy and digital transformation sectors across the Middle East.

Her research interests focus on integrating financial technologies and digital systems to develop national sustainability solutions, with a particular emphasis on aligning public–private partnerships to enhance investment efficiency in clean energy.

Since 2019, her professional experience as an advisor for partnerships and financial growth has led her to develop a research and innovation model that later evolved into the **Saudi National Solar Digital Twin Platform**, a national framework for digital transformation in the energy sector and the basis of a patent registered with the **Saudi Authority for Intellectual Property (SAIP)**.

Through her research, the author aims to support the objectives of **Saudi Vision 2030** and **Net-Zero 2060** by strengthening the integration between energy, finance, and digital governance, and by empowering individuals, investors, and regulatory bodies to make data-driven decisions that contribute to building a sustainable, knowledge- and technology-based economy.

عن المؤلفة:

غدير محمد حسين رشوان

مستشار تنفيذي للشراكات والتحالفات الاستراتيجية | شبكات الأعمال والشؤون الاقتصادية والتجارية

تتمتع بخبرة مهنية تتجاوز خمسة عشر عامًا في مجالات إدارة الثروات، التخطيط المالي، وتطوير الاستثمارات الاستراتيجية، وتمتد خبرتها إلى العمل في قطاع الطاقة المتجددة والتحول الرقمي على مستوى الشرق الأوسط.

تركّز اهتماماتها البحثية على دمج التقنيات المالية والأنظمة الرقمية في تطوير حلول استدامة وطنية، مع اهتمام خاص بمواءمة الشراكات بين القطاعين العام والخاص لتحقيق كفاءة الاستثمار في الطاقة النظيفة.

قادتها تجربتها المهنية كمستشار للشراكات والنمو المالي منذ عام 2019م إلى تطوير نموذج بحثي وابتكاري تطوّر لاحقًا إلى المنصة السعودية الموحدة للطاقة الشمسية للتوأم الرقمي (Saudi National Solar Digital Twin Platform)، التي تمثل إطارًا وطنيًا للتحول الرقمي في الطاقة، وتُعد من أصل براءة اختراع مسجلة لدى الهيئة السعودية للملكية الفكرية.

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تسعى المؤلفة من خلال أبحاثها إلى دعم مستهدفات رؤية السعودية 2030 والحياد الصفري 2060 عبر تعزيز التكامل بين الطاقة، التمويل، والحكومة الرقمية، وتمكين الأفراد والمستثمرين والجهات التنظيمية من اتخاذ قرارات مستندة إلى البيانات تسهم في بناء اقتصاد مستدام قائم على المعرفة والتقنية.

Introduction

Saudi Arabia's Vision 2030 emphasizes diversification of the economy and environmental sustainability, with a focus on renewable energy adoption. While smart meters have been deployed nationwide, their use remains limited to billing. Households and investors lack real-time visibility of savings and financial returns, while regulators face challenges in monitoring adoption and carbon impacts. This research introduces the Solar ROI Digital Twin Platform to address these gaps.

Literature Review

Global literature shows advances in digital twins and smart meters, primarily for grid optimization and demand response. However, integration with household-level ROI analytics and government platforms is limited. For example, projects in the EU and UK focus on consumption tracking but lack financial visibility. Saudi Arabia currently has no integrated solution linking smart meters, digital twins, ROI, and government platforms such as Absher. This study fills that gap.

Methodology

The system architecture consists of several layers: (1) Smart Meter Layer – collecting household energy consumption and PV generation every 5–15 minutes. (2) Digital Twin Engine – simulating real-time energy and financial performance. (3) Finance Module – calculating ROI, NPV, and Payback using tariffs, loans, and subsidy data. (4) Government Integration – Absher for secure identity verification and Unified Digital Platform for interoperability. (5) Mobile/Web Apps – delivering real-time bills, ROI, and savings dashboards to households and investors. (6) Policy Dashboards – providing KPIs on adoption, savings, and carbon reduction to regulators.

Riyadh Pilot Case Study

A pilot study was conducted in Riyadh with 1,000 households and 50 PV investors over 12 months. Metrics evaluated included bill accuracy, savings percentage, ROI accuracy, adoption rate, and user satisfaction.

Results

Households achieved 15–25% reductions in electricity bills. Investors reported improved confidence in adoption decisions with real-time ROI dashboards. Regulators gained access to policy dashboards enabling dynamic subsidy adjustments and carbon tracking. The national impact includes accelerated renewable adoption and alignment with Vision 2030 KPIs.

Discussion

The Solar ROI Platform represents the first integration of smart meters, digital twins, financial ROI, and government services globally. Its scalability allows expansion beyond Riyadh to nationwide deployment. Policy implications include enhanced subsidy targeting and improved monitoring of Net Zero commitments.

Conclusion and Recommendations

The Solar ROI Digital Twin Platform provides a scalable and innovative solution to improve financial transparency, boost investor confidence, and support policy-making in Saudi Arabia's renewable energy transition. Recommendations include national rollout of the platform, integration with local banks for green finance, and expansion to EV charging and battery storage.

FIGURES AND TABLES

FIGURE 1. ANNUAL BILL COMPARISON (BASELINE VS PV)

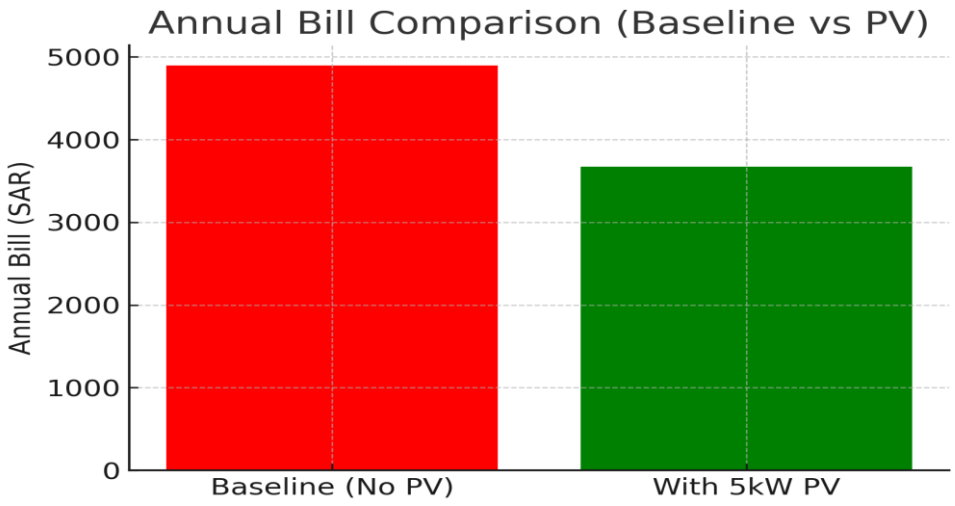


FIGURE 2. PAYBACK PERIOD VS CAPEX

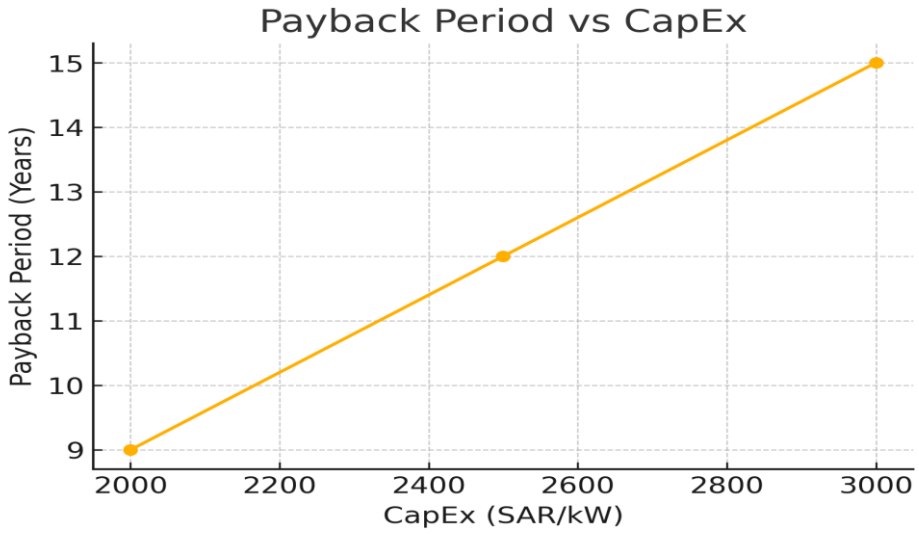
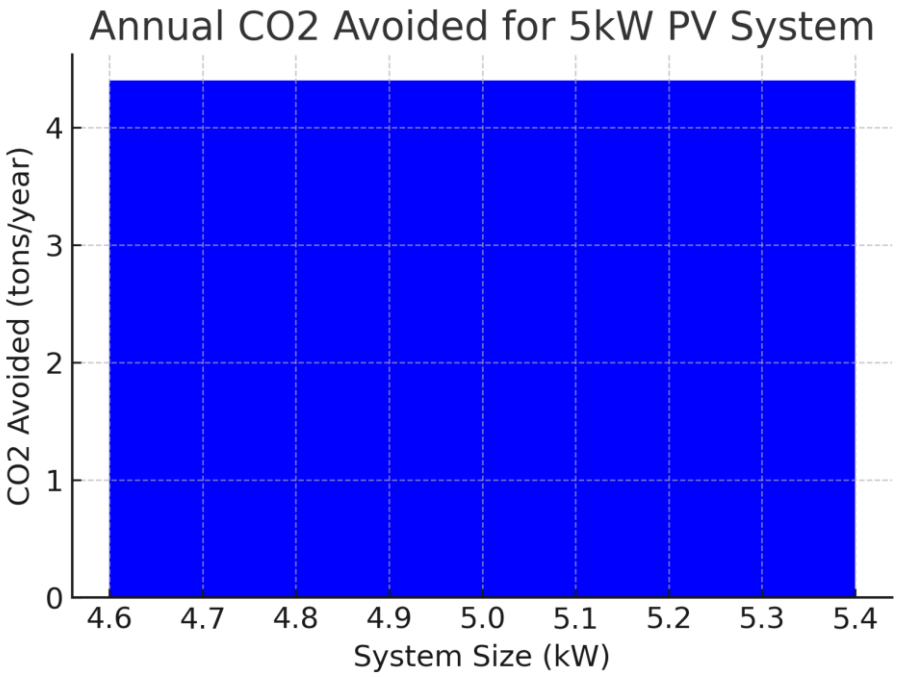


FIGURE 3. ANNUAL CO2 AVOIDED FOR 5KW PV SYSTEM



FIGURES (WITH IMAGES)

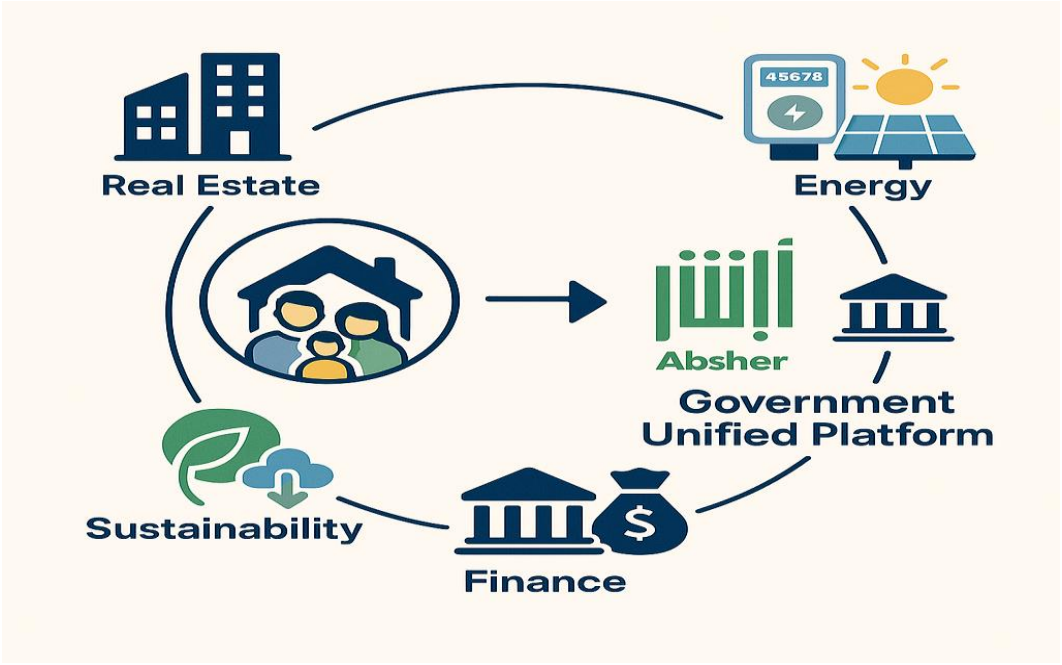


Figure 1. Monthly Electricity Bills (Baseline vs With PV)
Comparison between monthly electricity bills before and after installing 5 kW PV systems, based on integrated smart meter data.

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Figure 2. Sensitivity of Payback Period to CapEx
Effect of capital expenditure (CapEx) on payback period for residential PV systems simulated through the Digital Twin model.

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Figure 1: Monthly Electricity Bill Comparison

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Figure 2: ROI & Payback Period Simulation

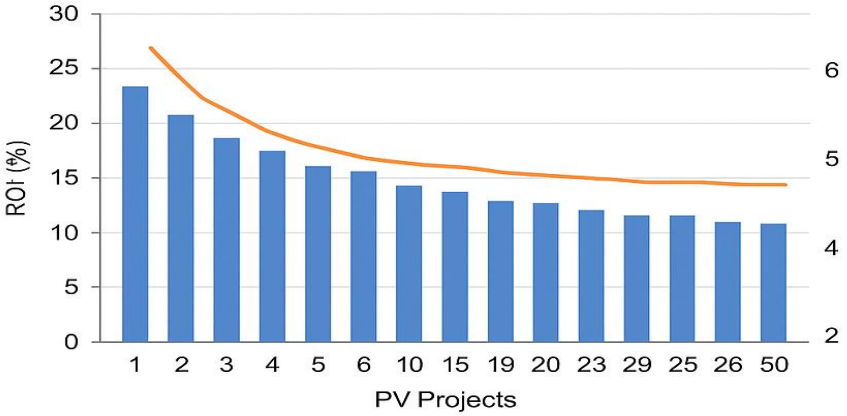

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Figure 3. Annual CO_2 Emissions Avoided by PV Systems
Carbon reductions achieved through integration of smart meters with PV, expressed in equivalent vehicle kilometers avoided.

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Part A — Technical Figures (Component / Sequence / Activity Integration)

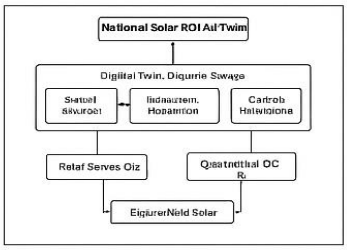

Figure 2: National Solar ROI Digital Twim Layer ed Architecture
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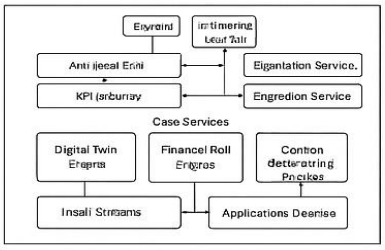

Figure 5: Digital Twin Engine: Computation Stages
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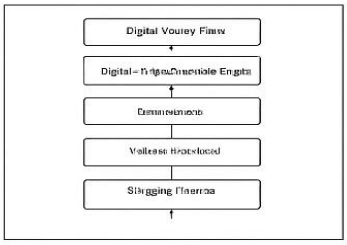

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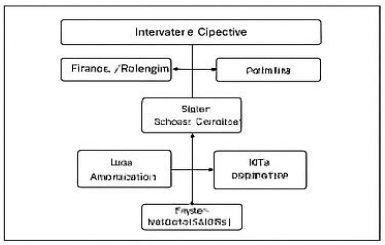

Figure 6: Regulator KPI Fipeline
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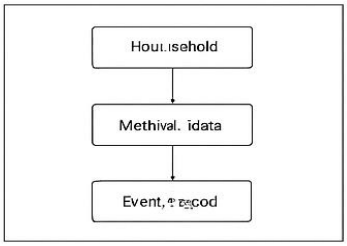

Figure 5: FInance / ROI Engine
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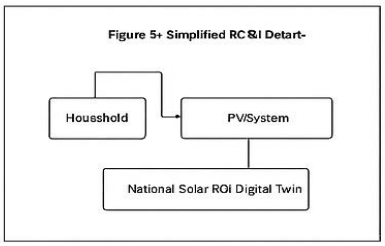

Figure 7: SImplified ER Data Model
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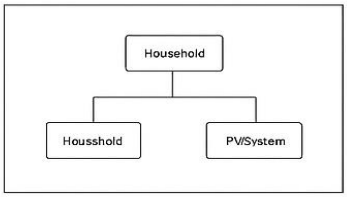

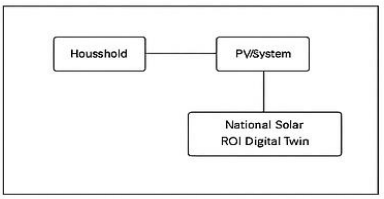

Figure 4. National Solar ROI Digital Twin Architecture
Architecture starting from smart meters → ingestion layer → Digital Twin Engine → finance module → dashboards for stakeholders.

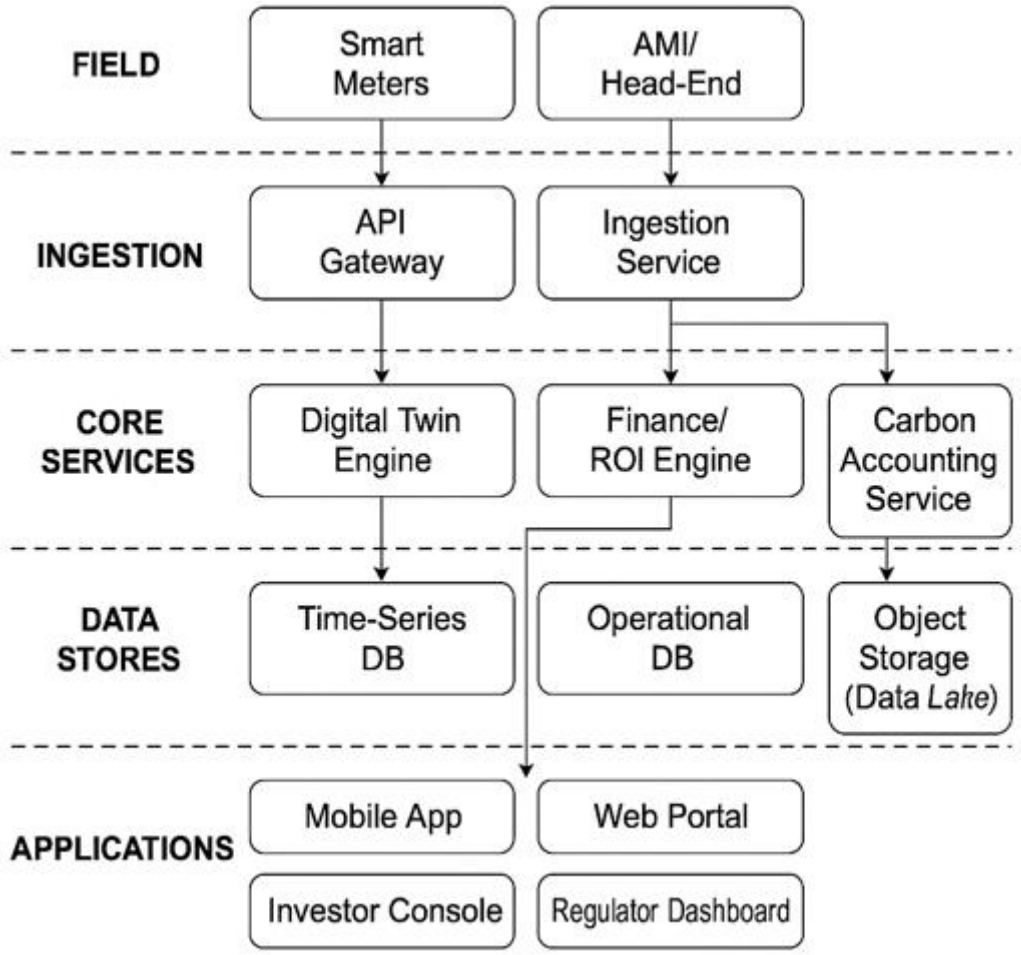

Figure 5. End-to-End Data Flow
Sequence from smart meter → Digital Twin → financial and carbon analytics → apps and policy dashboards.

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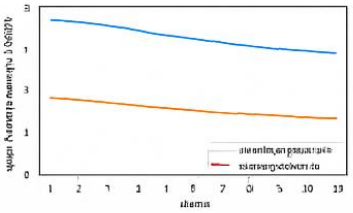
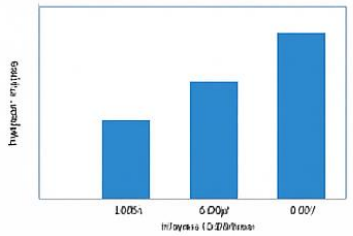


Monthly Electricity Bill (Balelines vs With PV, 5 kW)

Des eription: Compares be monthly electricl- ty bill lebefore and a alter installing a 5 kwre installlng a 5 kW PV system.



Payback Sensitivity vs CapEx (5 k W PV)

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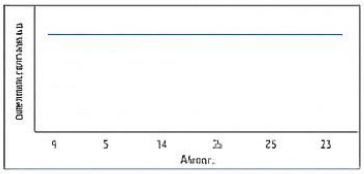
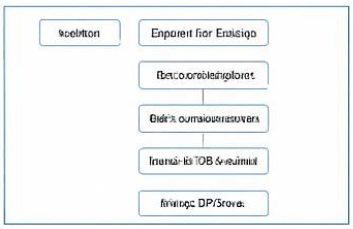


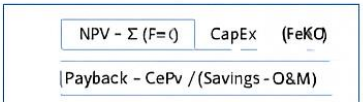
Annual CO_2 Avoided (5 kW PV)

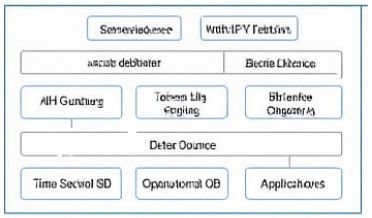
Purpose: Showing annual COi emissiots ẍided by 4.5 kN PV system. Prou'ɜ 4 X tons‹year (X ɔɔ (0.EB kg/kWY).



End-to-End Data Flow (Sequence)

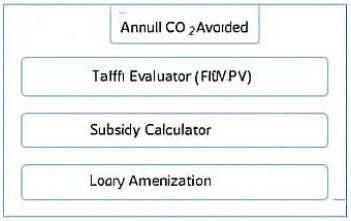
Sequence diagtam of telemeity me ingesston. digital twin, finance engines, and apps/dashboards.





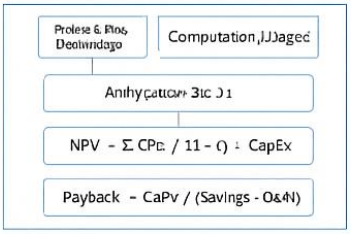
National Solar ROI Digital Twin: Layered Architecture

Stute: Exem architecture from field devices (s mart irseters) through ingestion, cone sefvices (Digital Twin, Finance: Tartif, Carbon), data stores, to applications, to appils.



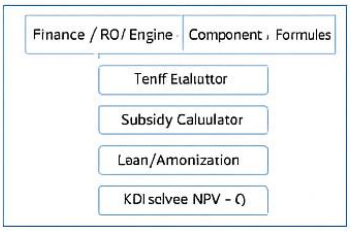
Digital TUwin Engine: Compultation Stages

Astivity flow Shows anticol flow from inut streams, vaidation, net idsol computation, sell-consumption & exports, losses/inverterelficiency, to TSOB and Finance kPIs.



Finance / ROI Engine Component + Formulas

Components, An API Gateway wregoting with Absher (OIDE/O'AvthZ) for idenittiy and Unified National Digital Platform (UNDP) for service entittements. Privacy and palicy dashboards.



Regulator KPI Pipeline

Aggueglition of faw moter, oata, twin output finance. carbon mettics and regional KPIs into

Figure 6. Finance/ROI Engine Components

Core algorithms and formulas for ROI, NPV, and payback calculations.

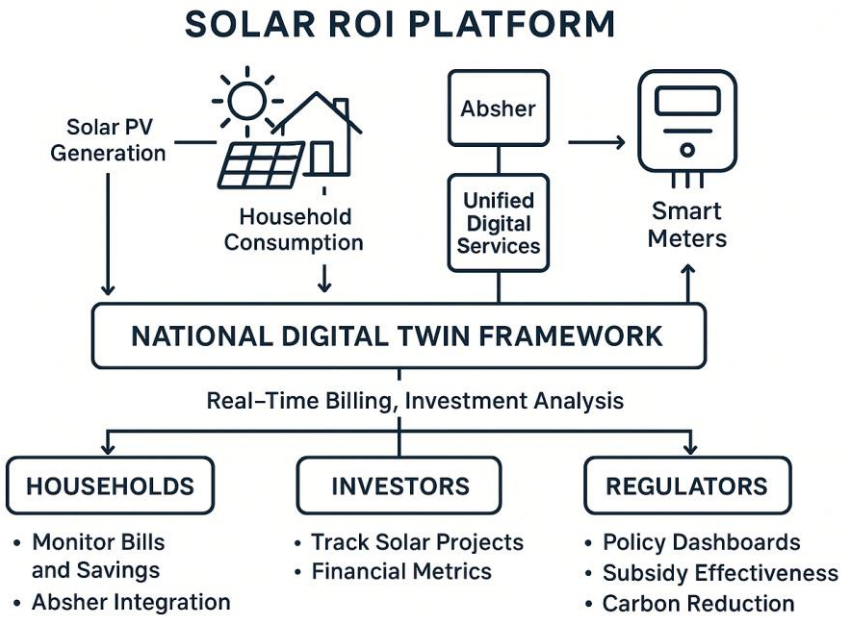


Figure 7. Regulator KPI Dashboard
Pipeline showing KPIs for adoption, carbon reduction, and subsidy efficiency.

Financial and Environmental Outcomes from 5 kW PV System

Metric	Result	Illustration
Monthly Electricity Bill	Baseline −2,160 SAR;; With PV −936 SAR/yr; Savings −1,224 SAR/yr	
Payback vs CapEx	2,000 SAR/kW → 8–10 yrs 2,500 SAR/kW → 10–13 yrs 3,000 SAR/kW → 12–17 yrs	
Annual CO_2 Avoided	−4,4 tons/yr	

Figure 8. Integration with Government Services
Platform interoperability with Absher and Unified Digital Platform.

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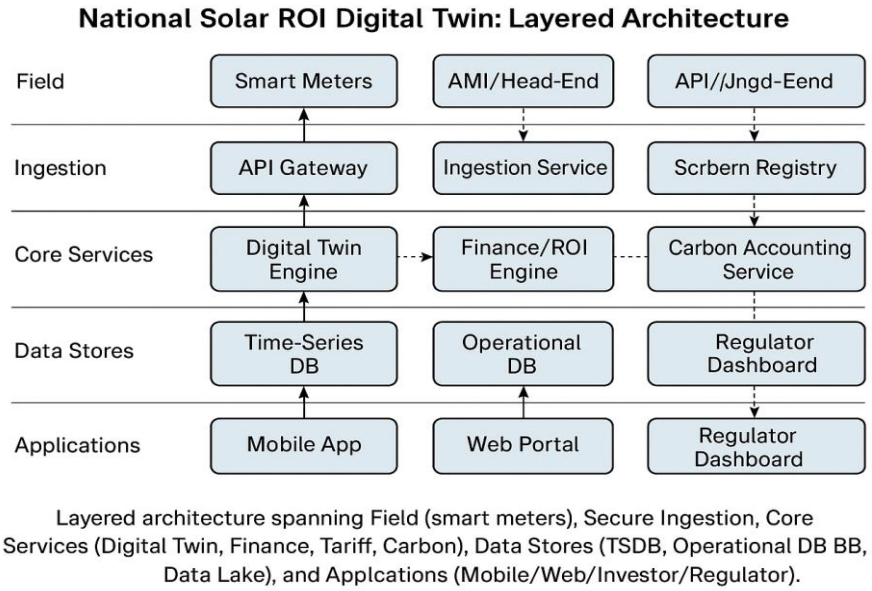

Figure 9. Mobile Application Interface
Dashboard showing ROI, savings, and bills for households and investors.

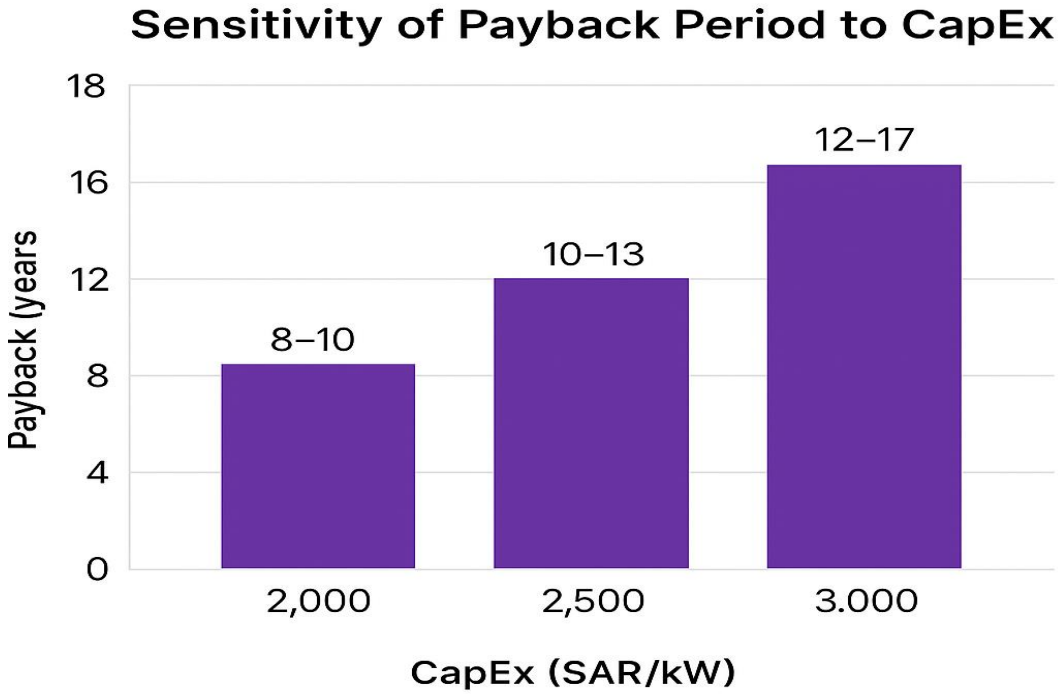

Figure 10. Extended Payback Sensitivity
Comparison of ROI outcomes at varying CapEx assumptions.

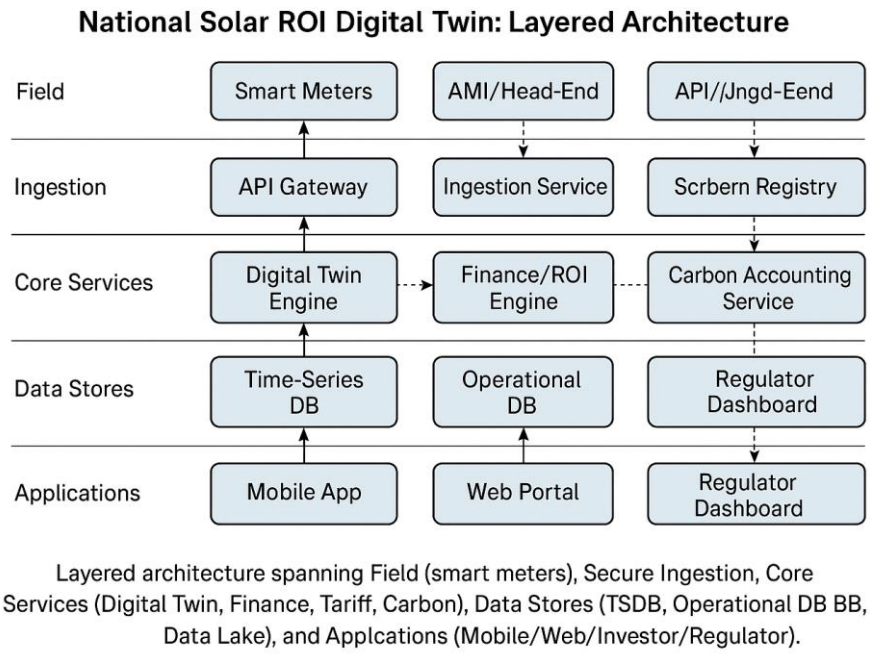

Figure 11. Technical System Flow
Detailed process of data ingestion, storage, and simulation within the Digital Twin.

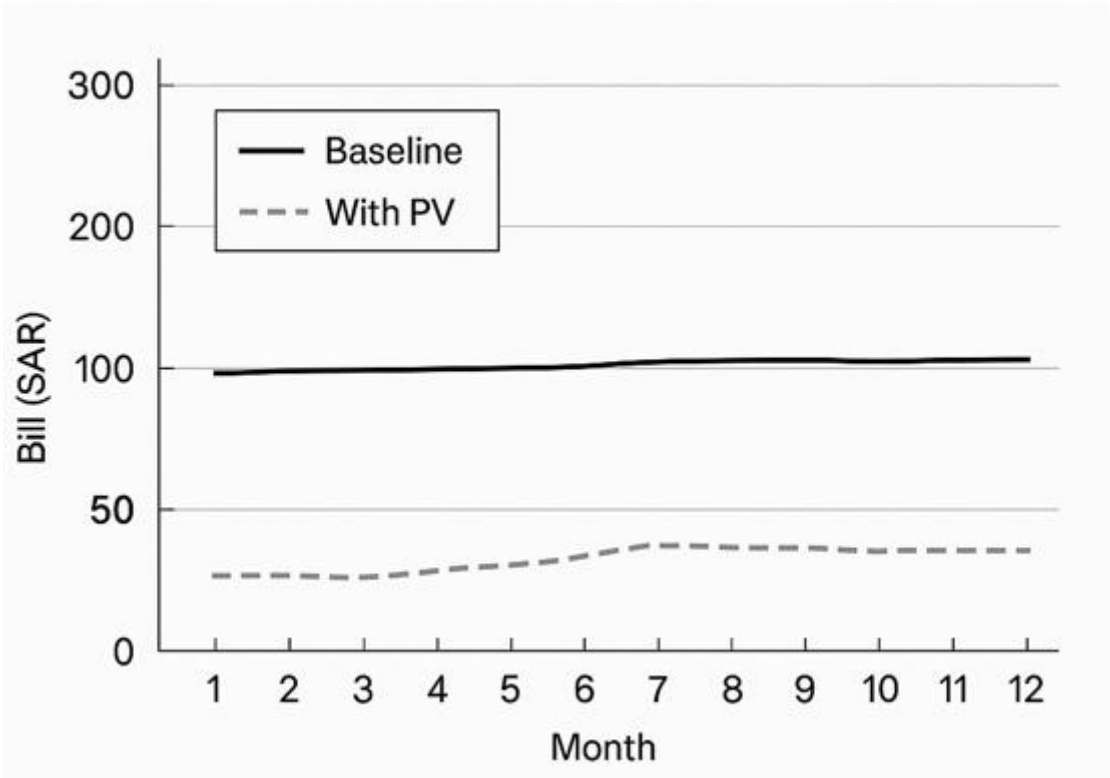

Figure 12. Extended Architecture
Layered representation of smart meters, APIs, digital twins, and financial modules.

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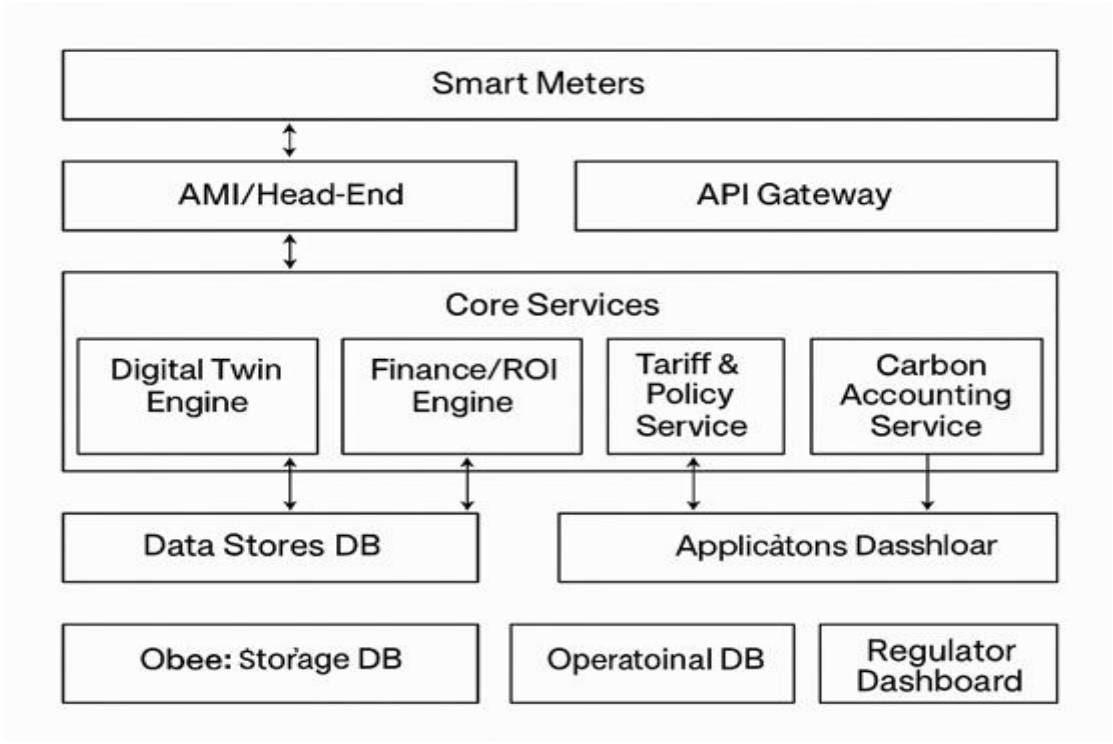

Figure 13. Solar ROI Extended Model
Detailed framework for scalability to EVs and storage integration.

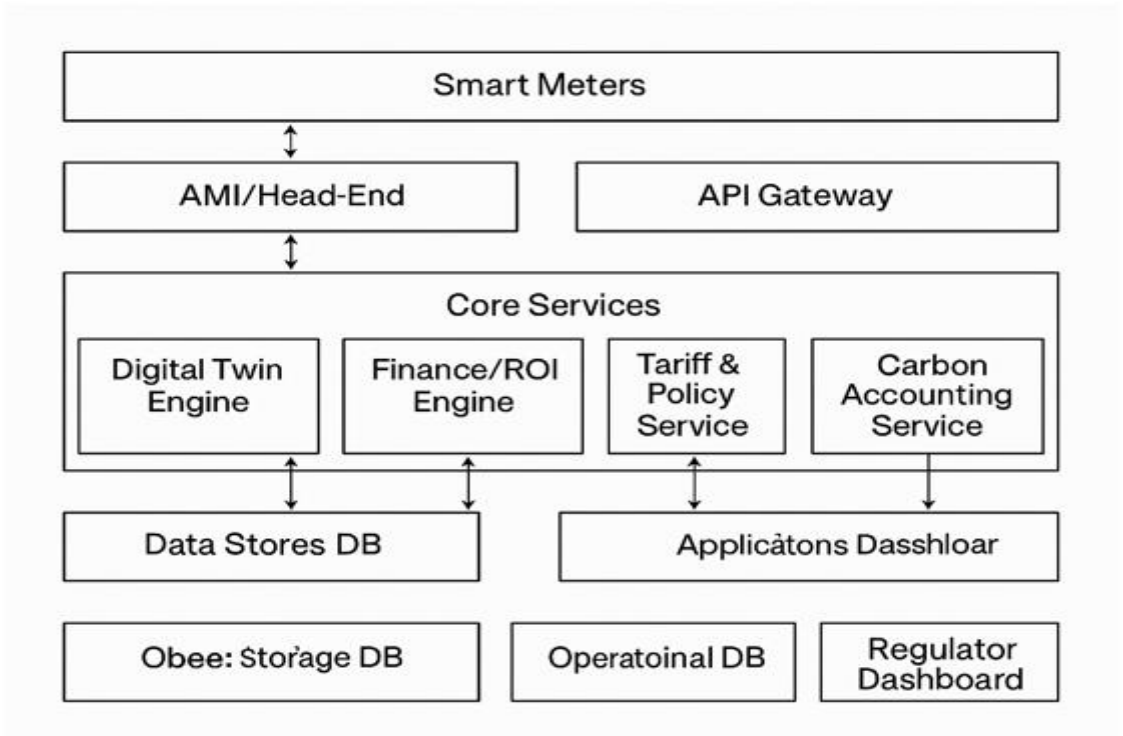

Figure 14. Supplementary Data Flow
Supporting diagrams for financial-environmental analysis.

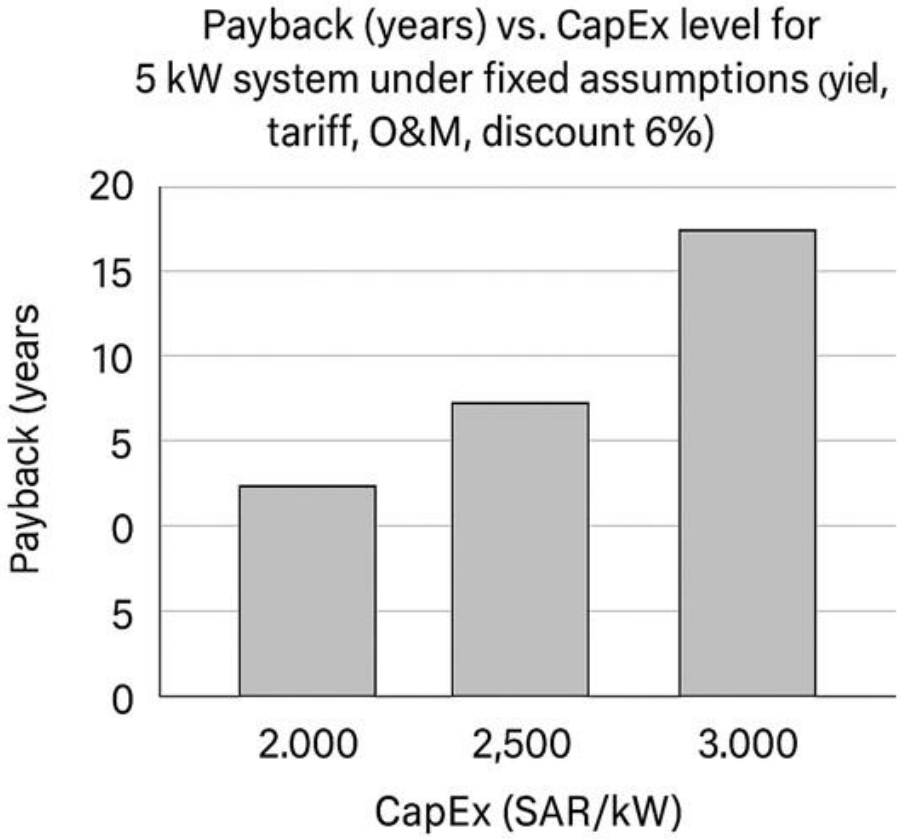

Figure 15. Pilot Deployment Visualization
Riyadh case study illustration with households and PV investors.

فئة المستخدم	الأدوات / الخدمات
Household	Mobile/Web app – مشاهدة الفواتير، التوفير، ROI لحظيًا
Investors	Portfolio dashboards – متابعة مشاريع الطاقة الشمسية، مؤشرات مالية شفافة
Regulators	KPI dashboards – معدلات التبني، فعالية الدعم، تقليل الكربون

Figure 16. Application Dashboard (Arabic)
Localized interface version for household energy users.

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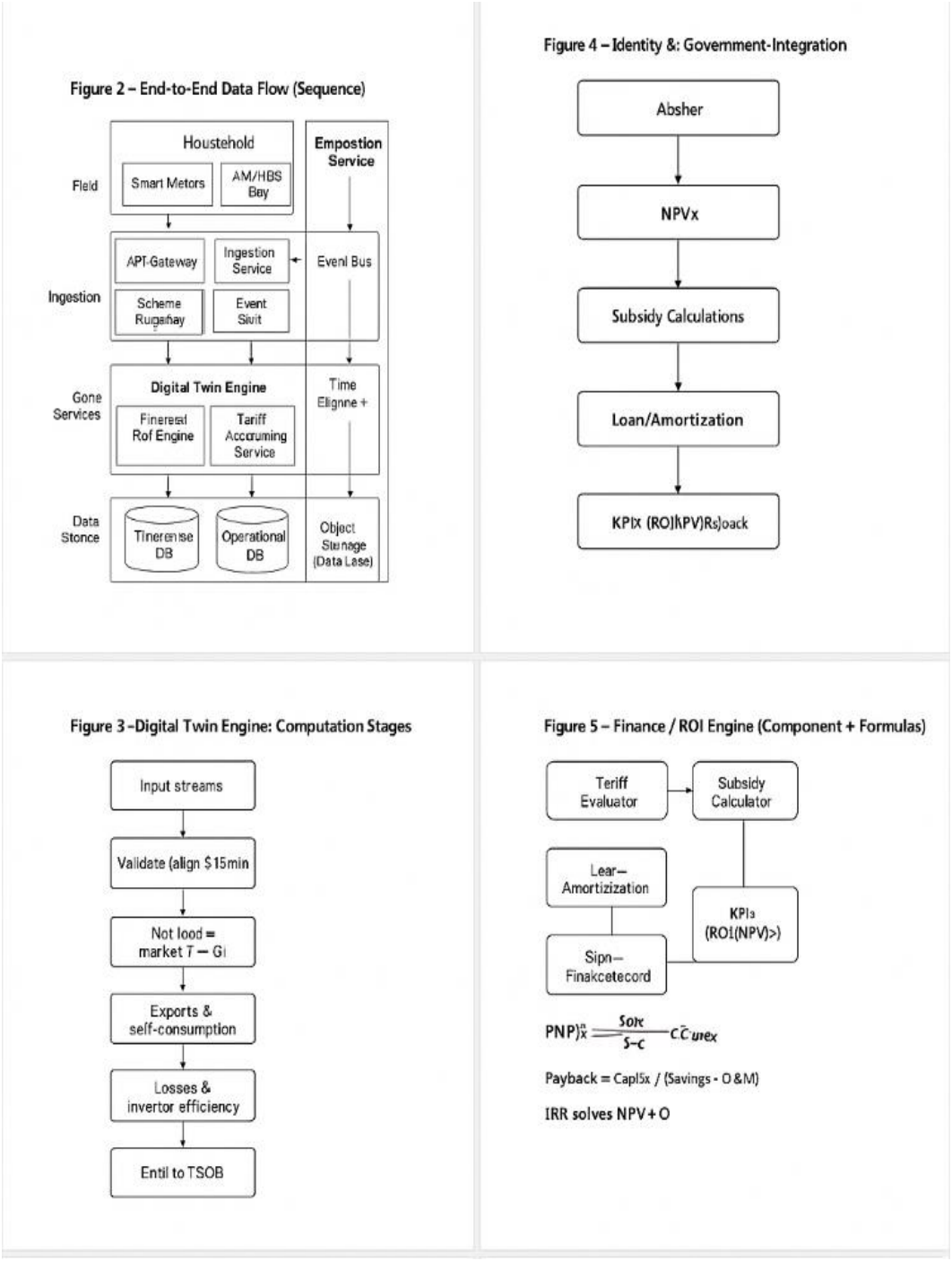

Figure 17. Policy Interface
Overview of regulator's subsidy adjustment and monitoring tools.

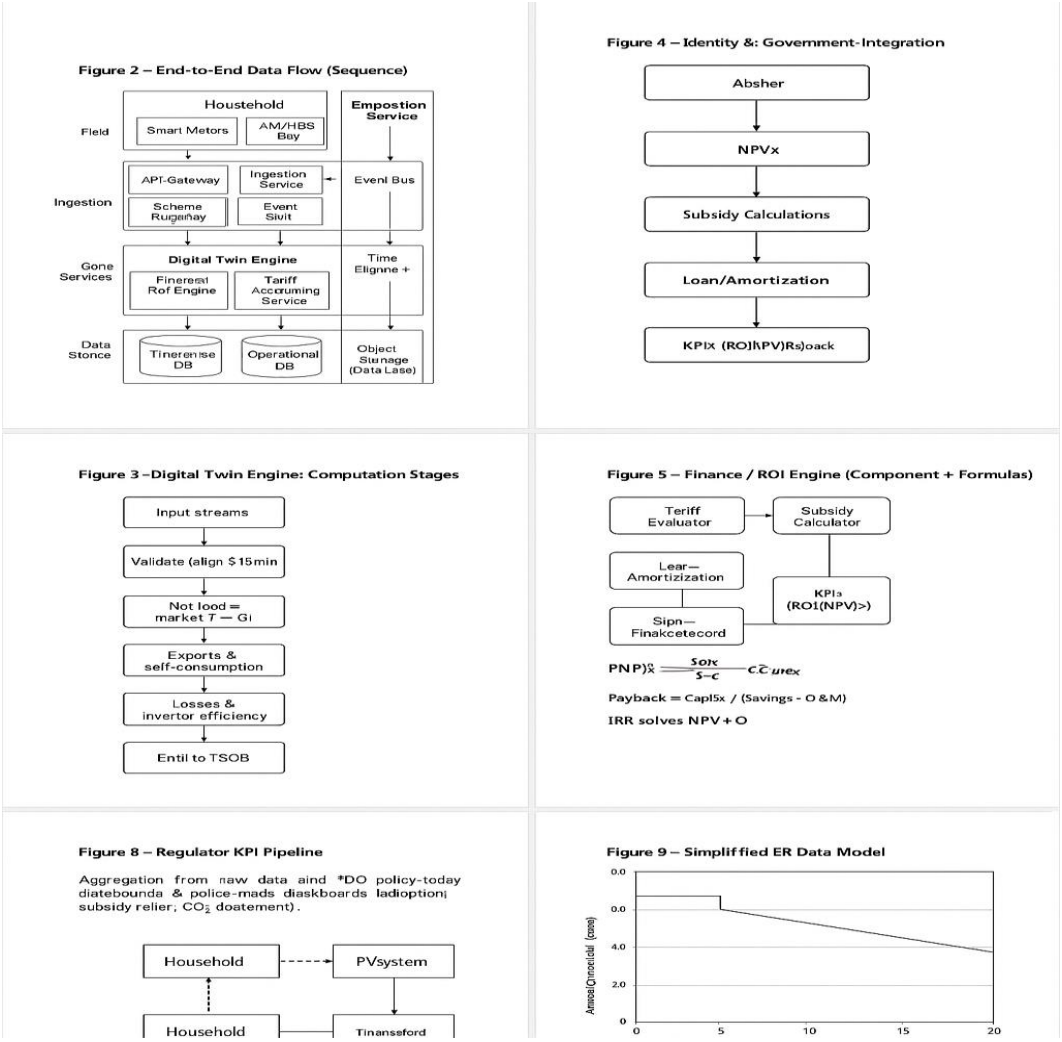

Figure 18. Extended ROI Results
Comparative simulation results for multiple PV sizes and tariffs.

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