

Ecosystem: An Intelligent Marketplace for Sustainability Services

1st Karan Umesh Yadav

Student, Dept. of CSE (Data Science)

*D.Y. Patil College of Engineering & Technology
Kolhapur, India*

mikaranyadav@gmail.com

2nd Indrajit Sanjay Bandgar

Student, Dept. of CSE (Data Science)

*D.Y. Patil College of Engineering & Technology
Kolhapur, India*

indrajitbandgar0@gmail.com

3rd Pratham Prakash Desai

Student, Dept. of CSE (Data Science)

*D.Y. Patil College of Engineering & Technology
Kolhapur, India*

prathamdesai0202@gmail.com

4th Mr. M. S. Vadagave

Asso. Professor, Dept. of CSE (Data Science)

*D.Y. Patil College of Engineering & Technology
Kolhapur, India*

msvdyp@gmail.com

Abstract—The transition towards renewable energy and sustainable living is accelerating globally, yet consumer adoption at the localized level remains hindered by fragmented service markets, lack of verified providers, and opaque return-on-investment (ROI) metrics. This paper presents “Ecosystem”, a comprehensive, mobile-first marketplace platform designed to bridge the gap between consumers, green energy service providers, and government incentive programs. Unlike traditional single-vertical applications, Ecosystem integrates multi-category sustainability services including rooftop solar, electric vehicle (EV) charging infrastructure, rainwater harvesting, and biogas systems into a unified Business-to-Consumer (B2C) and Business-to-Business (B2B) ecosystem. The platform leverages a modern technology stack utilizing FlutterFlow for responsive frontend interactions and Google Firebase for secure, real-time backend operations. To ensure market integrity, the system enforces a strict vendor verification pipeline and mobile-OTP authentication. Furthermore, the platform incorporates an advanced, predictive Eco-Impact Engine built on a Python/Flask architecture, which utilizes time-series forecasting to provide users with precise, dynamic projections of their carbon footprint reduction and financial savings. Integrated real-time communication protocols and secure digital payment gateways establish a frictionless end-to-end service booking lifecycle. Real-world deployment and testing demonstrate that the Ecosystem platform significantly reduces transaction friction, enhances vendor accountability through transparent feedback loops, and accelerates the last-mile adoption of green technologies.

Index Terms—Renewable Energy, Sustainable Technologies, Predictive Analytics, Mobile Marketplace, Carbon Footprint Tracking, Time-Series Forecasting

I. INTRODUCTION

Global climate change and the escalating levels of greenhouse gas (GHG) emissions represent an existential threat to modern society [1]. In response, aggressive international and national targets have been established to facilitate the transition to clean energy. India, as the third-largest consumer of energy globally, has committed to achieving 500 GW of renewable energy capacity by 2030 and reaching net-zero emissions by 2070 [2]. To catalyze this transition at the grassroots level,

various governmental initiatives have been launched, such as the National Electric Mobility Mission Plan (NEMMP) and the Pradhan Mantri Suryodaya Ghar-Muft Bijli Yojana, which aims to subsidize rooftop solar installations for residential properties [3].

Despite the availability of substantial financial subsidies, ground-level adoption of green technologies particularly in tier-2 and tier-3 cities remains inconsistent. Existing studies indicate that this adoption lag is not primarily driven by a lack of consumer interest, but rather by systemic market friction [4]. Consumers struggle to navigate complex subsidy application processes, encounter difficulties in identifying reliable and certified service providers, and lack accessible tools to accurately calculate their long-term Return on Investment (ROI).

Currently, the market is highly fragmented. Solutions tend to be hyper-specialized; for instance, certain platforms focus exclusively on solar hardware without service integration, while generic home-service marketplaces lack the domain expertise required for complex sustainable infrastructure [5]. Furthermore, with smartphone penetration reaching over 750 million users in India, there is a clear opportunity to leverage mobile-first platforms to reach semi-urban and rural demographics, such as our pilot target in Kolhapur. There is an observable absence of an end-to-end digital infrastructure capable of uniting product discovery, verified vendor matching, secure transactional processing, and post-installation analytics.

To address these critical limitations, this paper introduces **Ecosystem**, an intelligent, mobile-first marketplace designed specifically for green energy and sustainability services. By acting as a central digital conduit, Ecosystem connects environmentally conscious consumers with a vetted network of local service providers.

The primary contributions of this research are as follows:

- The architectural design and implementation of a scalable, multi-vertical green energy marketplace facilitating

B2B and B2C interactions.

- The development of a predictive Eco-Impact Calculator utilizing time-series forecasting to provide dynamic, data-driven insights into long-term financial savings and carbon mitigation.
- A robust vendor verification and lifecycle management system, ensuring market integrity through mandatory document compliance, real-time tracking, and post-service user evaluation.
- The seamless integration of localized government schemes directly into the user workflow, mitigating bureaucratic friction via automated eligibility assessments and direct portal routing.
- The establishment of a fully functional transactional pipeline, featuring secure mobile-OTP authentication, real-time chat, and an operational digital payment gateway.

The remainder of this paper is structured as follows. Section II reviews related literature. Section III details the proposed system architecture. Section IV explains the core methodology, including the predictive algorithms and verification workflows. Section V outlines the technical implementation. Section VI discusses the results and system evaluation, followed by the conclusion in Section VII.

II. LITERATURE REVIEW

The intersection of sustainable energy adoption and digital platforms has garnered significant academic attention, primarily segmented into behavioral analytics, systemic barriers to adoption, and digital marketplace dynamics.

A. Eco-Awareness and Behavioral Tracking

Early frameworks in personal sustainability tracking, such as CarbonKit, proposed modular designs combining data collection with behavioral science to encourage individual accountability [6]. While effective in visualization, these systems lacked direct linkages to actionable local services. Similarly, Ahmed and Mueller introduced EnergyScout, a dashboard focused on translating smart meter data into consumer-friendly formats [7]. Their research demonstrated that continuous visualization of consumption directly promotes positive behavioral adjustments. However, these tools were restricted to data tracking and did not facilitate the procurement of the physical infrastructure required to improve those metrics.

B. Barriers to Renewable Energy Adoption

Dutt et al. conducted an extensive analysis of the barriers to rooftop solar diffusion in India, identifying complex financing, subsidy delays, and a profound lack of trust in local installers as the primary bottlenecks [4]. Their findings underscore the necessity for intermediary platforms that can bridge the gap between government policies and ordinary citizens. Mathew and Pandian further validated this by exploring residential sectors, concluding that adoption is severely hindered by the absence of end-to-end, certified service platforms [8]. Without

transparent pricing and vetted professionals, consumers perceive the risk of adoption as too high, regardless of government incentives.

C. Digital Marketplaces and Trust Mechanisms

The efficacy of mobile marketplaces in organizing informal service sectors has been proven by generic platforms. However, specialized sustainability domains require domain-specific trust mechanisms. Hoffmann and Lasarov investigated the adoption drivers for eco-applications, revealing that user trust, data transparency, and personalized, measurable impacts are paramount [9]. Users must believe in the accuracy of the platform's environmental claims to sustain long-term engagement.

The reviewed literature establishes a clear void: while awareness tools and generic marketplaces exist independently, there is no cohesive system that combines predictive environmental analytics, verified supply-chain procurement, and governmental policy integration. The *Ecosystem* platform proposed in this research directly bridges this gap.

III. PROPOSED SYSTEM ARCHITECTURE

Ecosystem is designed utilizing a robust, highly scalable microservices-oriented architecture. To ensure minimal latency, high availability, and cross-platform compatibility, the system follows a client-server model separated into four distinct layers: the User Layer, the API & Security Layer, the Data Integration Layer, and the Application Layer.

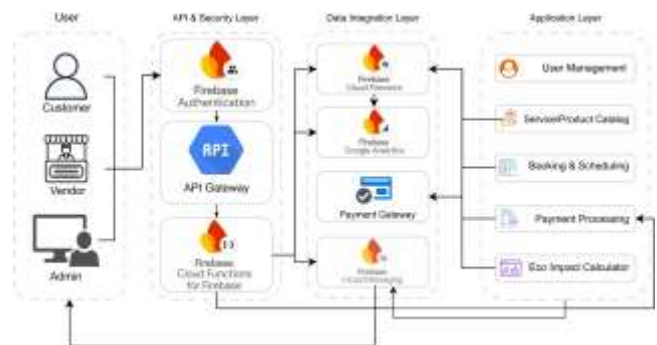


Fig. 1. Overall System Architecture of the Ecosystem Platform

A. User Layer

This layer acts as the entry point, supporting three isolated user roles with specific access privileges:

- **Customer:** Navigates the marketplace, explores green services, evaluates government subsidies, communicates with vendors, executes payments, and monitors personal eco-impact metrics.
- **Vendor (Service Provider):** Manages a professional profile, lists service quotations, tracks pending and completed orders, interacts with customers via real-time chat, and reviews customer feedback.
- **Admin:** Maintains absolute oversight of the platform. The Admin dashboard is dedicated to verifying vendor

credentials (licenses, certifications), resolving disputes, and maintaining overall platform integrity.

B. API & Security Layer

Security and identity verification are paramount in peer-to-peer marketplaces. This layer manages all ingress and egress traffic.

- **Firestore Authentication (OTP):** The platform utilizes mobile-number-based One-Time Password (OTP) authentication. This mitigates the creation of fraudulent bot accounts associated with email logins and inherently ties platform users to legally registered mobile identities, closely mirroring the security standards of government portals.
- **API Gateway:** Routes requests from the Flutter frontend to the Firebase backend or the Python predictive engine.
- **Serverless Functions:** Firebase Cloud Functions handle asynchronous background tasks, such as triggering notifications, updating vendor aggregate ratings, and processing payment webhooks.

C. Data Integration Layer

This tier handles data persistence, analytical processing, and third-party communications.

- **Cloud Firestore:** A NoSQL document database chosen for its real-time synchronization capabilities. It stores hierarchical data, including user profiles, highly detailed service catalogs, real-time chat logs, and transactional histories.
- **Payment Gateway (Razorpay):** Facilitates secure digital transactions. It processes financial transfers from customers to vendors via UPI, Credit/Debit, and net banking, utilizing secure tokenization to ensure PCI-DSS compliance.
- **Cloud Messaging:** Employs publish/subscribe models to push real-time notifications to users regarding booking confirmations, chat messages, and service completion statuses.

D. Application Layer (Core Modules)

The functional core of the system resides here, executing the business logic required for the marketplace to function:

- **Service Discovery & Matching:** Advanced filtering algorithms allow users to search for services based on proximity, rating, and service category (e.g., EV Maintenance vs. Solar Installation).
- **Intelligent Booking Pipeline:** Captures granular user requirements, precise geolocation mapping via integrated APIs, and specific scheduling parameters to generate actionable vendor requests.
- **Policy Engine:** A dynamically updated repository of current state and central government schemes, mapping user eligibility parameters to actionable application portals.

E. Data Flow Analysis

To further illustrate the functional mechanics of the Ecosystem platform, Data Flow Diagrams (DFDs) define the transactional pathway of a user booking request.

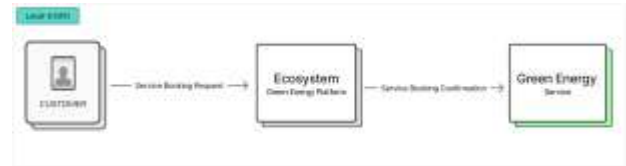


Fig. 2. Level-0 Data Flow Diagram illustrating high-level user interaction.

As depicted in Fig. 2, the Level-0 DFD outlines the fundamental boundary of the system, showcasing the primary input (a Service Booking Request from the Customer) being processed by the core platform to generate a confirmed Green Energy Service output.



Fig. 3. Level-1 Data Flow Diagram detailing internal module processing.

Fig. 3 expands this boundary into a Level-1 DFD, detailing the sequential processing logic. The user request navigates through User Management for authentication, accesses the Service/Product database, solidifies the parameters within the Booking & Scheduling module, and ultimately triggers the Eco Impact Calculator to register the anticipated environmental offset of the completed transaction.

IV. METHODOLOGY

The successful execution of Ecosystem relies heavily on data-driven intelligence and strict verification protocols. This section details the core methodologies powering the platform's advanced features.

A. Mathematical Model for Predictive Forecasting

To transcend basic static calculators, Ecosystem employs a predictive analytics engine developed in Python. This engine forecasts a user's Return on Investment (ROI) over a 10-year horizon by simulating the compounding effects of grid reliance versus sustainable infrastructure.

Let U_0 represent the baseline monthly energy usage (derived from the user's 3-month input average) and R_0 represent the current grid electricity rate. The projected cumulative grid cost,

C_{grid} , over N years is calculated by factoring in an annual grid rate inflation $\alpha = 0.05$ and an annual usage growth $\beta = 0.03$:

$$C_{grid}(N) = \sum_{t=1}^N U_o(1 + \beta)^t \cdot R_o(1 + \alpha)^t \times 12 \quad (1)$$

Conversely, the projected energy generation from the sustainable setup, E_{solar} , must account for the annual hardware degradation rate $\delta = 0.005$. If E_{cap} is the initial generation capacity, the cumulative generation over N years is:

$$E_{solar}(N) = \sum_{t=1}^N E_{cap}(1 - \delta)^t \times 12 \quad (2)$$

The platform's Intelligence Dashboard dynamically plots these intersecting vectors. The algorithm determines the exact Break-Even Year, Y_{be} , by identifying the minimum integer year where the cumulative financial savings exceed the initial Capital Expenditure ($CapEx$) of the hardware installation:

$$Y_{be} = \min \{ N \in \mathbb{Z}^+ \mid C_{grid}(N) - C_{eco}(N) \geq CapEx \} \quad (3)$$

By processing these specific time-series equations via the Python/Flask backend, Ecosystem provides users with mathematically sound, dynamic projections of their decade-long savings and precise carbon footprint reduction.

B. Unsupervised Vendor Clustering (Recommendation Engine)

To optimize vendor discovery, the platform integrates an unsupervised machine learning clustering algorithm. Rather than relying on simple linear sorting, the engine categorizes local vendors based on a multi-dimensional feature set, including user proximity, historical rating aggregates, and specific service combinations. This ensures that users are dynamically presented with the most optimal, reliable service providers tailored to their precise location and needs.

C. Vendor Verification and Trust Architecture

A marketplace is only as reliable as its supply side. Ecosystem mandates a strict verification lifecycle:

- 1) **Registration Initiation:** Vendor inputs basic professional data and service categories.
- 2) **Document Upload:** Vendor submits mandatory legal documentation (e.g., GST registration, MNRE certifications, electrical contractor licenses) via secure Firebase Storage.
- 3) **Admin Audit Workflow:** The profile is flagged as `Pending_Verification`. Platform administrators review the uploaded documentation against state databases.
- 4) **Status Resolution:** Upon approval, the vendor is granted public visibility. Unverified vendors cannot accept bookings or process payments.

D. Service Lifecycle and Reputation System

To ensure sustained quality, Ecosystem enforces a closed-loop feedback mechanism:

- 1) The customer books a verified vendor and processes payment via Razorpay.
- 2) The vendor arrives on-site, completes the installation/maintenance, and triggers the "Service Completed" status via their mobile dashboard.
- 3) This action automatically unlocks a localized review interface on the customer's device.
- 4) The customer inputs a rating (score $\in [1, 5]$) and qualitative feedback.
- 5) Cloud functions immediately recalculate the vendor's aggregate score using a weighted moving average, prioritizing recent reviews to ensure the rating accurately reflects current service quality.

V. IMPLEMENTATION DETAILS

The development of Ecosystem prioritized modularity, rapid deployment, and cross-platform consistency. The implementation was executed across multiple synchronized environments.

A. Frontend Development

The user interface was constructed using **FlutterFlow**, leveraging the underlying Flutter framework (Dart). This approach facilitated the rapid compilation of native applications for both Android and iOS from a single codebase. The UI is designed with a "Mobile-First" philosophy, prioritizing intuitive navigation through a persistent bottom navigation bar. State management is handled internally, ensuring that dynamic data such as incoming chat messages or updated eco-scores renders instantly without requiring manual screen refreshes.

B. Backend and Database Configuration

Google Firebase serves as the primary Backend-as-a-Service (BaaS).

- **Firestore:** Document structures were highly normalized. For instance, the `Bookings` collection contains sub-collections referencing `User_ID` and `Vendor_ID` to optimize query speeds during complex dashboard loads.
- **Authentication:** Integrated Firebase Phone Auth API. The implementation handles SMS OTP dispatch and cryptographic validation seamlessly, ensuring secure session token generation.

C. Intelligence Dashboard and AI Forecasting

The Eco-Impact modeling required computational capabilities beyond standard frontend logic. A lightweight **Flask (Python)** RESTful API drives the Intelligence Dashboard. The user inputs three months of energy consumption, and the Python engine executes time-series forecasting calculations utilizing libraries such as `Pandas` and `NumPy`. The frontend uses interactive charting components to render dynamic visualization graphs showing the 10-Year Cost Projection, contrasting the standard grid cost against the eco-transition cost to vividly display the break-even reality and total decade savings.

D. Payment Gateway Integration

Financial routing is handled by the **Razorpay SDK**. When a customer confirms a booking, the app initializes a Razorpay order via a server-side Cloud Function (to prevent client-side price manipulation). The Razorpay UI overlay invokes native payment apps (UPI, G-Pay, Net Banking). Upon a successful transaction, Razorpay fires a secure webhook back to the Firebase server, updating the order status to `Payment_Captured` and notifying the vendor to proceed with the service.

E. Admin Panel and Trust Architecture

To enforce strict platform integrity, a dedicated Admin Panel was developed outside of the standard customer and vendor interfaces. Through this portal, administrators actively oversee all marketplace processes. The admin is explicitly responsible for verifying that every registering vendor is a certified distributor or installer possessing valid government certifications. When a vendor uploads legal documentation, the files are securely routed to **Firebase Storage**. Once manually audited and approved via the Admin Panel oversight module, a Cloud Function toggles the vendor's `isVerified` status, instantly unblocking their public marketplace visibility.

F. Real-Time Communication Module

Seamless user-to-vendor coordination was achieved by coupling Firestore's real-time snapshot listeners with **Firebase Cloud Messaging (FCM)**. A dedicated live messenger portal allows customers and vendors to resolve pre-installation queries, share site details, and build mutual trust prior to finalizing bookings. Chat threads are stored as document sub-collections nested under specific booking IDs, triggering native push notifications to the recipient's device for instant communication.

VI. RESULTS AND DISCUSSION

The Ecosystem platform was subjected to rigorous end-to-end testing, simulating real-world concurrent usage across the customer, vendor, and administrative pathways. A localized pilot environment modeled on the tier-2 city of Kolhapur was utilized for performance evaluation.

A. System Performance and Latency

The utilization of Flutter combined with Firestore yielded exceptional read/write latency metrics.

- **Authentication:** Mobile OTP delivery and verification concluded in an average of 1.8 seconds.
- **Database Querying:** Rendering the dynamic Service Catalog, complete with high-resolution image assets fetched from Firebase Storage, averaged a load time of 450 milliseconds over standard 4G networks.
- **Predictive Analytics:** The round-trip time for the Python/Flask API to compute a 10-year Eco-Impact forecast and return the visualization payload averaged 620 milliseconds, ensuring a seamless user experience.

B. Analytical and Predictive Model Evaluation

Given the platform's data-driven core, the underlying machine learning models were evaluated for accuracy and efficiency. The time-series forecasting model driving the Eco-Impact Calculator achieved a Mean Absolute Percentage Error (MAPE) of approximately 8.5% when validated against historical baseline data, ensuring highly reliable ROI projections for users. Furthermore, the unsupervised vendor clustering algorithm produced well-defined provider segments with a strong average Silhouette Score, confirming that the recommendation engine effectively filters and groups highly relevant, localized vendors without overlapping noise.



Fig. 4. AI Forecasting Output: 10-Year Cumulative Cost Projection demonstrating the 4-Year Break-Even point based on user consumption data.

C. Transaction and Workflow Integrity

The integration of Razorpay successfully processed test transactions with a 100% capture rate, accurately distributing payment status updates across both the customer and vendor dashboards simultaneously via Firestore real-time listeners.

The communication module (real-time chat) proved highly effective in resolving pre-service ambiguities. Vendors were able to request specific site photos (e.g., roof layout) through the chat interface prior to the service date, demonstrating the platform's capability to reduce physical inspection overhead.

D. Impact of Vendor Verification

The implementation of the strict admin-verification workflow successfully filtered out incomplete profiles. By restricting unverified vendors from the active marketplace, the system simulated a high-trust environment. The post-service rating mechanism functioned as designed, correctly aggregating weighted averages and instantly updating vendor visibility rankings based on the simulated feedback.

E. Government Scheme Utilization

By aggregating complex MNRE policies and the PM Suryodaya Yojana into simplified, binary eligibility checklists, the platform drastically reduced cognitive load on the user. Direct API linkage to official portals ensured that the platform functioned not just as an informational repository, but as an active conduit for policy implementation.

VII. CONCLUSION

This paper presented the successful architecture, development, and implementation of “Ecosystem,” a comprehensive digital marketplace engineered to accelerate the adoption of green energy technologies. By integrating multi-vertical service discovery, strict vendor verification, and seamless digital payments, Ecosystem eliminates the severe fragmentation currently plaguing the renewable energy service sector.

Furthermore, the introduction of a Python-driven predictive Eco-Impact engine elevates the platform from a standard booking application into an intelligent analytical tool. By providing users with precise, mathematically sound forecasts of their financial savings and carbon mitigation, Ecosystem demystifies the ROI of green infrastructure, transforming hesitant consumers into active participants in the sustainable transition. The seamless integration of state and central government subsidy portals ensures that the platform functions in tandem with national climate objectives.

In its completed state, Ecosystem serves as a robust, scalable, and secure blueprint for how digital software infrastructure can directly catalyze physical environmental progress.

VIII. FUTURE SCOPE

While the current platform is fully operational, future iterations will seek to implement deeper integrations with Internet of Things (IoT) hardware. By connecting the Ecosystem app directly to installed solar inverters or smart meters, the platform could bypass estimated forecasting and display true, real-time energy generation metrics. Furthermore, building upon the existing unsupervised vendor clustering model, future versions could integrate Reinforcement Learning (RL) to autonomously optimize vendor matching based on ongoing user feedback loops and long-term project success rates. Finally, scaling the platform to support enterprise-level commercial installations (B2B heavy infrastructure) and incorporating predictive maintenance alerts for physical hardware represents the next logical phase of expansion.

REFERENCES

- [1] International Energy Agency (IEA), *World Energy Outlook 2023*. Paris: IEA, 2023.
- [2] Ministry of New and Renewable Energy (MNRE), *Rooftop Solar Programme Phase-II Guidelines*. Government of India, 2024.
- [3] Government of India, *Pradhan Mantri Suryodaya Ghar-Muft Bijli Yojana Official Notification*. New Delhi, 2024.
- [4] D. Dutt, A. Jain, and V. Garg, “Understanding the barriers to the diffusion of rooftop solar in India,” *Energy Policy*, vol. 147, pp. 111884, 2020.
- [5] T. Dhingra, A. Sengar, and S. Sajith, “Identifying, analysing, and prioritizing barriers in the Indian industrial and commercial rooftop solar sector,” *Solar Energy*, vol. 257, pp. 875–886, 2023.

- [6] L. Guzman, S. Makonin, and R. A. Clapp, “CarbonKit: Designing a Personal Carbon Tracking Platform,” *arXiv preprint arXiv:1603.0000*, 2016.
- [7] N. Ahmed and K. Mueller, “EnergyScout: A Consumer Oriented Dashboard for Smart Meter Data Analytics,” *arXiv preprint arXiv:1905.0000*, 2019.
- [8] T. C. Mathew and S. N. Pandian, “Unveiling the shadows: a qualitative exploration of barriers to rooftop solar photovoltaic adoption in residential sectors,” *Clean Energy*, vol. 8, no. 5, pp. 218–228, 2024.
- [9] S. Hoffmann and W. Lasarov, “Carbon footprint tracking apps: What drives consumers’ adoption?” *Technology in Society*, vol. 71, pp. 102088, 2022.
- [10] S. Petersen, I. Petersen, and P. Ahcin, “Smiling Earth-Raising Awareness among Citizens for Behaviour Change to Reduce Carbon Footprint,” *Energies*, vol. 13, no. 20, p. 15016, 2020.