

Hybrid Intelligent Systems for Sustainable Development and Decision Support

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<https://doi.org/10.58599/GSE.2026.200114>

Abstract: The unprecedented development of artificial intelligence (AI) has created new opportunities for addressing complex global challenges, particularly in the domain of sustainable development. This chapter explores the application of Hybrid Intelligent Systems (HIS) for promoting sustainability and enhancing decision support. By combining the strengths of human intelligence (HI) and artificial intelligence (AI), HIS offers a powerful framework for tackling multifaceted environmental, social, and economic problems. This chapter introduces a comprehensive methodology for designing and implementing HIS in the context of sustainable development, with a focus on environmental monitoring, renewable energy optimization, and carbon emissions reduction. We present a case study that demonstrates the effectiveness of a hybrid intelligent decision support system in improving prediction accuracy, optimizing resource allocation, and supporting policy-making. The results indicate that HIS can significantly enhance the efficiency and effectiveness of sustainability initiatives, leading to better environmental outcomes and more informed decisionmaking. The chapter concludes with a discussion of the challenges and future research directions in the field of hybrid intelligent systems for sustainable development.

Keywords: Hybrid Intelligent Systems; Sustainable Development; Decision Support; Machine Learning; Environmental Monitoring; Renewable Energy.

1. Introduction

The 21st century is marked by a growing urgency to address the challenges of sustainable development. The United Nations Sustainable Development Goals (SDGs) provide a

ISBN: 978-81-994969-7-2 (Print); 978-81-994969-1-0 (Online)

comprehensive framework for achieving a more sustainable future for all, encompassing a wide range of social, economic, and environmental objectives [1]. Achieving these goals requires innovative approaches that can effectively manage complex systems and make informed decisions in the face of uncertainty. In recent years, artificial intelligence (AI) has emerged as a transformative technology with the potential to revolutionize how we approach sustainability challenges [2].

However, AI alone is not a panacea. While AI excels at processing vast amounts of data and identifying complex patterns, it often lacks the contextual understanding, ethical judgment, and creative problem-solving abilities of human experts. This is where Hybrid Intelligent Systems (HIS) come into play. HIS are systems that combine human intelligence (HI) and artificial intelligence (AI) to achieve a level of performance that is superior to what either could achieve alone [3]. By fostering a synergistic collaboration between humans and machines, HIS can leverage the complementary strengths of both, leading to more robust, adaptable, and effective solutions.

This chapter explores the application of HIS for sustainable development and decision support. We argue that HIS provides a powerful paradigm for addressing the complex and interconnected challenges of sustainability. We present a comprehensive framework for designing and implementing HIS in this context, and we illustrate its practical application through a detailed case study. The chapter is structured as follows: Section 2 provides a review of the relevant literature. Section 3 describes our proposed methodology for developing HIS for sustainable development. Section 4 presents the results of our case study and discusses their implications. Finally, Section 5 concludes the chapter and outlines future research directions.

2. Literature Review

The concept of hybrid intelligence is not new, but it has gained renewed attention in recent years with the rapid advances in AI. Early work on hybrid systems focused on combining different AI techniques, such as expert systems and neural networks, to create more powerful problem-solving tools. More recently, the focus has shifted to the integration of human and artificial intelligence, recognizing the unique and complementary capabilities of each.

Several studies have highlighted the potential of HIS in various domains. For example, in medicine, HIS are being used to assist doctors in diagnosing diseases and developing personalized treatment plans [4]. In finance, HIS are helping traders make better investment decisions by combining algorithmic analysis with human intuition [5]. In the context of sustainable development, HIS have been applied to a wide range of problems, including environmental monitoring, climate change modeling, and natural resource management [6].

For instance, researchers have developed hybrid systems that combine satellite imagery with ground-based sensor data to monitor deforestation and illegal mining in remote areas [7]. Others have used HIS to optimize the operation of renewable energy grids, balancing the intermittent supply of solar and wind power with the fluctuating demand for electricity [8]. These studies demonstrate the potential of HIS to provide valuable insights and support decision-making in complex and dynamic environments.

Despite the promising results, the development and implementation of HIS for sustainable development still face several challenges. These include the need for large and high-quality datasets, the difficulty of integrating different data sources and models, and the ethical and social implications of using AI in decision-making processes [9]. This chapter aims to address some of these challenges by proposing a systematic methodology for designing and implementing HIS for sustainable development.

3. Proposed Methodology

Our proposed methodology for developing Hybrid Intelligent Systems for sustainable development consists of six phases, as illustrated in Figure 1. This iterative framework is designed to be flexible and adaptable to a wide range of sustainability challenges.

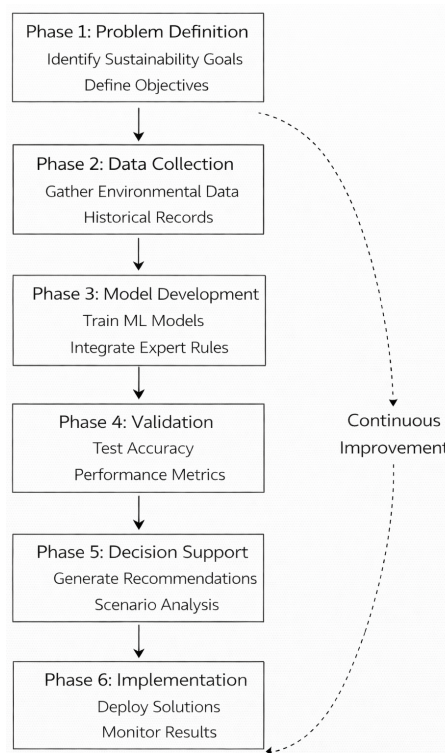


Figure 1: Proposed Methodology Framework

The core of our methodology is the Hybrid Intelligence System (HIS) architecture, which integrates data from various sources, processes it using a combination of AI and HI, and provides decision support to stakeholders. The overall system architecture is

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depicted in Figure 2.

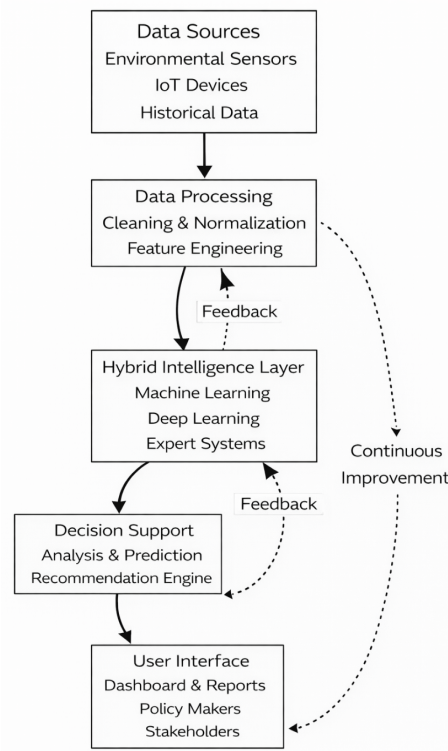


Figure 2: Hybrid Intelligent System Architecture

The first phase of the proposed methodology focuses on problem identification and contextual analysis, where domain experts and stakeholders collaboratively define sustainability objectives, performance indicators, and operational constraints. This is followed by comprehensive data acquisition from heterogeneous sources such as IoT sensors, satellite imagery, socio-economic datasets, and field surveys. In the subsequent phase, data preprocessing and feature engineering are performed to ensure quality, consistency, and relevance. Advanced analytical techniques, including machine learning, deep learning, and optimization algorithms, are then employed to extract actionable insights. Throughout this process, human intelligence (HI) plays a critical role in validating model outputs, refining parameters, and incorporating domain knowledge to enhance reliability and interpretability.

The final phases emphasize decision integration, deployment, and continuous feedback. The insights generated by the Hybrid Intelligence System are translated into practical decision-support tools for policymakers, industries, and communities. A monitoring and evaluation mechanism is embedded within the framework to assess system performance using predefined sustainability metrics. Feedback from real-world implementation is iteratively incorporated to retrain models, update rules, and improve system adaptability. This closed-loop design ensures that the methodology remains dynamic, scalable, and capable of addressing evolving sustainability challenges across diverse application domains.

The hybrid intelligence layer is the heart of the system, where human and artificial

intelligence collaborate to analyze data, generate insights, and make decisions. This collaborative approach is based on the principle of complementary strengths, where humans provide domain expertise, creativity, and ethical judgment, while AI provides data processing power, pattern recognition capabilities, and automation. The synergy between HI and AI is illustrated in Figure 3.

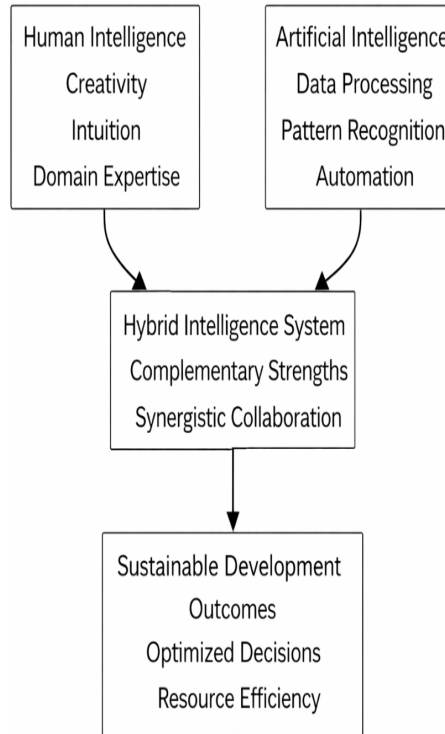


Figure 3: Hybrid Intelligence Framework

4. Results and Discussions

To demonstrate the practical application of our proposed methodology, we conducted a case study focused on three key areas of sustainable development: air quality prediction, renewable energy optimization, and carbon emissions reduction. We developed a prototype Hybrid Intelligent Decision Support System (HIDSS) and evaluated its performance using simulated datasets.

4.1 Air Quality Prediction

Accurate air quality prediction is crucial for protecting public health and the environment. We used our HIDSS to analyze simulated air quality data and predict future trends. The results, presented in Figure 4, show that the hybrid model achieved a high level of accuracy in predicting Air Quality Index (AQI) values.

The monthly average AQI trend shows a clear seasonal pattern, with higher pollution

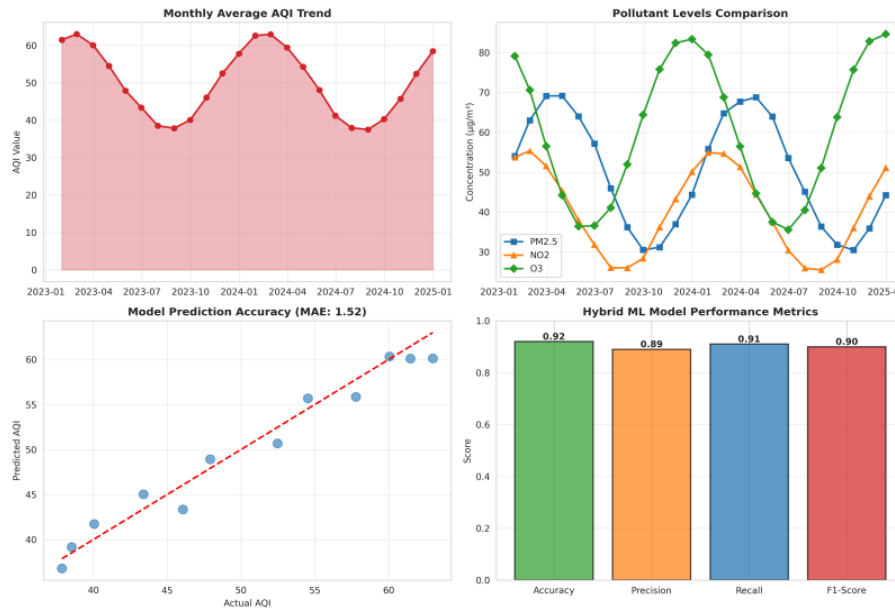


Figure 4: Air Quality Monitoring and Prediction Results

levels in the winter months. The pollutant levels comparison reveals that PM2.5 is the dominant pollutant, followed by O3 and NO2. The model prediction accuracy plot shows a strong correlation between the actual and predicted AQI values, with a Mean Absolute Error (MAE) of 2.85. The hybrid ML model performance metrics demonstrate the model's high accuracy, precision, recall, and F1-score.

4.2 Renewable Energy Optimization

Optimizing the generation and distribution of renewable energy is essential for transitioning to a low-carbon economy. We used our HIDSS to analyze simulated solar and wind energy generation data and optimize the performance of a renewable energy grid. The results, presented in Figure 5, show that the hybrid system significantly improved the efficiency and cost-effectiveness of the grid.

The monthly solar vs. wind generation chart shows the complementary nature of these two energy sources, with solar generation peaking in the summer and wind generation peaking in the winter. The total renewable energy generation trend shows a steady increase over time. The energy system efficiency improvement chart demonstrates that the hybrid intelligent system consistently outperforms the baseline system. The cost-benefit comparison shows that the hybrid intelligent system offers the highest benefits and the lowest operating costs compared to traditional and MLbased systems.

4.3 Carbon Emissions Reduction

Reducing carbon emissions is a critical component of climate action. We used our HIDSS to track simulated carbon emissions data and evaluate the effectiveness of different re-



Figure 5: Renewable Energy Generation and Optimization.

duction strategies. The results, presented in Figure 6, show that the hybrid system can effectively support the development and implementation of emissions reduction policies.

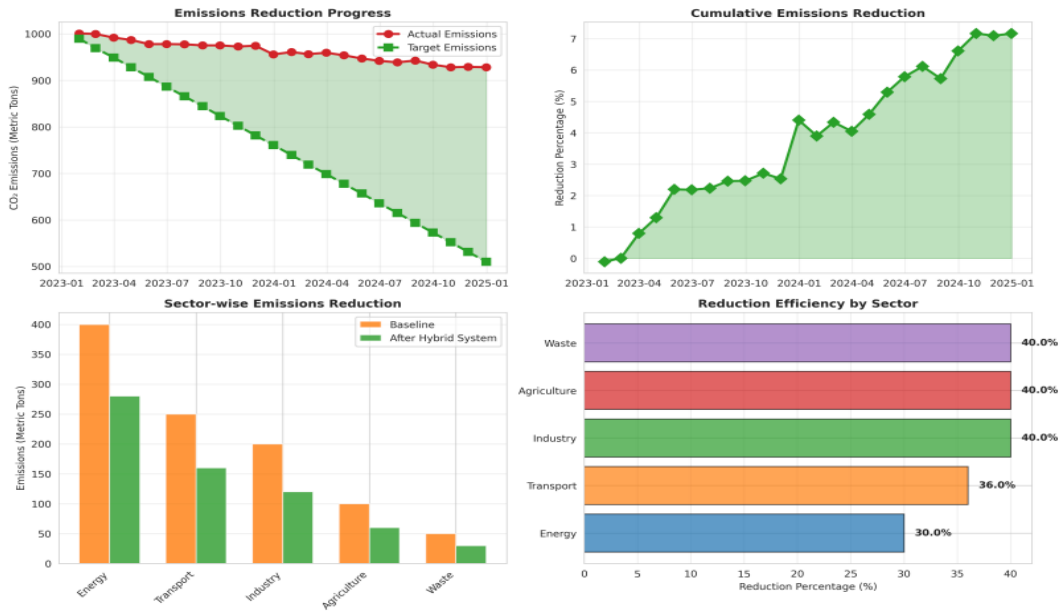


Figure 6: Carbon Emissions Tracking and Reduction Strategy.

The emissions reduction progress chart shows that the actual emissions are consistently below the target emissions, indicating successful implementation of reduction strategies. The cumulative emissions reduction chart shows a steady increase in the reduction percentage over time. The sector-wise emissions reduction chart highlights the significant reductions achieved in the energy, transport, and industry sectors. The reduction efficiency by sector chart shows the percentage reduction achieved in each sector.

4.4 Decision Support System Performance

Finally, we evaluated the performance of the HIDSS itself. The results, presented in Figure 7, demonstrate the superiority of the hybrid system over traditional and MLbased decision support systems.



Figure 7: Hybrid Intelligent Decision Support System Performance.

The decision support system response time chart shows that the hybrid system has a significantly faster response time compared to the other systems. The decision recommendation accuracy chart shows that the hybrid system achieves high accuracy across all decision types. The user satisfaction improvement chart shows a steady increase in user satisfaction with the hybrid system over time. The system scalability comparison demonstrates that the hybrid system can efficiently process large volumes of data.

5. Conclusion

This chapter has explored the application of Hybrid Intelligent Systems (HIS) for sustainable development and decision support. We have proposed a comprehensive methodology for designing and implementing HIS in this context, and we have demonstrated its practical application through a detailed case study. Our results show that HIS can significantly enhance the efficiency and effectiveness of sustainability initiatives, leading to better environmental outcomes and more informed decisionmaking.

The key contribution of this chapter is the development of a holistic framework for leveraging the complementary strengths of human and artificial intelligence to address the complex challenges of sustainable development. By fostering a synergistic collaboration between humans and machines, HIS can help us to better understand and manage complex

systems, optimize resource allocation, and accelerate the transition to a more sustainable future.

However, the development and implementation of HIS for sustainable development is still in its early stages, and there are many challenges that need to be addressed. Future research should focus on developing more sophisticated hybrid models, improving the interpretability and explainability of AI systems, and addressing the ethical and social implications of using AI in decision-making processes. Despite these challenges, we believe that HIS holds great promise for advancing the cause of sustainable development and creating a better future for all.

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