Designing Zero-Hunger, Zero-Carbon Food Systems: Unpacking the Implementation and Sustainability Challenges of Small-Scale Agrivoltaic Grids in Bihar.

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Abstract:

This report examines the promise and challenges of scaling agrivoltaic systems in Bihar, India, through the lens of the Tata-Cornell Institute's pilot projects in Nawada. Agrivoltaics—a dual-use model integrating clean energy production with agricultural output—offers a potential solution to simultaneously address climate change and food insecurity. Focusing on Bihar's smallholder-dominated agricultural sector, the report analyzes key barriers, including financial constraints, technical limitations, policy gaps, and the absence of national standards and definitions. It concludes by proposing strategic policy pathways such as creating a national framework, improving financing models, investing in technical capacity, and adjusting subsidy structures to support agrivoltaics' sustainable and inclusive growth in Bihar and beyond.

Section I: Introduction

A. **Background**

To quote former United Nations Secretary-General Ban Ki-moon, "Energy is the golden thread that connects economic growth, social equity, and environmental sustainability." This insight underscores the need for integrated approaches to development and sustainability. Within the Republic of India, we face two urgent challenges: climate change and food insecurity. India hosts some of the world's leading pollution emitters in urban settings, including Delhi and Mumbai. Meanwhile, around 200 million people are undernourished, amongst whom 43% of children suffer chronically. As per National Family Health Survey 5, 57% of women (15-49 years) and 67.1% of children (6-59 months) suffer from anemia (a medical condition marked by hemoglobin deficiency). Currently, India's agricultural sector is undergoing a period of transformation where there is a need to simultaneously enhance food security nationally while decarbonizing energy systems. Looking at this context gives an understanding of why India requires a solution addressing both these sectors while simultaneously enhancing the status of sustainable energy. A relatively recent model comes under the term agrivoltaics, also known as agri-photovoltaics, a transformative dual-use model where solar panels are installed in croplands to simultaneously produce food through providing a clean energy supply for irrigation while producing sustainable 'Green energy.'

B. **Why Bihar?**

The question must be asked - why is the focus of this report tailored to the Indian state of Bihar? Looking externally, about 50% of global greenhouse gas emissions from global croplands come from flooded rice cultivation. India is responsible for producing 22% of global rice and leading rice-related methane emissions. Although Bihar is responsible for 3.3% of India's national greenhouse gas emissions, it is an interesting case for agrarian innovation for emission reduction. Agriculture is the backbone of Bihar's economy, with over 70% of the populace engaged in agrarian activities. Persistent developmental challenges signify how Bihar suffers from vast underinvestment in rural infrastructure and electrical systems. The combination of these factors makes the state vulnerable to the impacts of climate change and a fantastic testing site for innovative agrivoltaic solutions, as taken up by the Tata Cornell Institute.

C. **Report Goals and Focus**

This report will focus on effectively presenting the innovative solution of agrivoltaics while more specifically analyzing key challenges before installation through the recent pilot project of the Tata Cornell Institute in Bihar. The primary challenges identified within this report regarding agrivoltaic systems include financial barriers, technical obstacles on the ground, data deficits, lack of standards, definitions, and regulatory clarity, alongside a range of post-implementation risks.

Section II: Agrivoltaics within the Zero-Hunger, Zero-Carbon Vision

A. **The Zero-Hunger, Zero-Carbon Initiative**

As previously mentioned, this report analyzes agrivoltaics through the lens of the Tata-Cornell Institute (TCI), a research institution developing and assessing food-system-based approaches in addressing poverty, nutrition, sustainability, and key societal issues within an Indian context. The key vision under which agrivoltaics is encompassed is TCI's flagship initiative: 'Zero-Hunger, Zero-Carbon.' Zero-hunger, Zero-Carbon food systems include three significant components: Reducing cattle herd size and livestock emissions, achieving sustainable rice cultivation, and using agrivoltaics to boost solar energy production for agricultural products and electricity. The combination of these strategies addresses TCI's fundamental goals for the project: Reducing net agricultural emissions while improving productivity and farmers' livelihoods in Bihar. This project serves as a model for smallholder farmers - one to be replicated across other Indian states if deemed a success.

B. **Agrivoltaics and International Case Studies**

Agrivoltaics is viewed as a solution that leads the path to creating climate-resilient food systems with an inherent focus on social equity and sustainability. They are a system that aims to integrate solar infrastructure with water-efficient technologies, including drip and sprinkler irrigation, to produce sustainable solar-powered energy and promote crop cultivation simultaneously. Although TCI's own research and development is grounded within India's smallholder-dominated agricultural sector, it draws key inspiration from other successful international models that have proven successful. A key comparison can be seen in Germany, where a study by the Karlsruhe Institute of Technology and others determined that agrivoltaics could effectively contribute 80% of Germany's photovoltaic energy targets by 2030. In the case of the United States, alternatively, research by the Department of Energy suggests that solar energy could supply up to 40% of national energy demands by 2035, while the agrivoltaics market is expected to reach up to $800 million by 2032, reflecting an 11.8% annual compound growth rate from today.

C. **India's Context-Specific Agrivoltaics**

Of course, it is important to acknowledge that India has drastically different climatic conditions, economic conditions, soil types, and situations for implementing agrivoltaics compared to the case studies provided. As per an evaluation of the Center for Study of Science, Technology, and Policy (CSTEP), some of the implementation criteria specific to India should include proximity within 10 km of road or rail, a slope less than 8 degrees, and a distance from a substation of less than 25 km, amongst other recommendations. TCI's approach differs in terms of being on a smaller scale and having different ambitions. Fitting agrivoltaics into resource-constrained and generally decentralized farming systems yields its fair share of challenges, explored below:

Challenge I: Financial Barriers

A. Bihar's financial struggles

One of the most significant challenges to scaling Agrivoltaics within the agricultural sector in smallholder contexts for Bihar is financial challenges, often resulting from high capital costs for installation. For further context, Bihar is already one of India's poorest states, as indicated by its ridiculously low GDP per capita of INR 60,337, the lowest in the country, as per the Reserve Bank of India (RBI). Furthermore, according to the Press Information Bureau, Bihar ranks as the fourth lowest state in farmer income, with an average monthly income of INR Rs. 7,542 per agricultural household. The data only justifies why agrarian practitioners in Bihar require external assistance and support for agrivoltaic implementation on the financial side.

B. Agrivoltaic expenses through comparison

Although TCI's official agrivoltaics costs are not public, the Indian government's PM Kusum source within the Ministry of New and Renewable Energy gives further clarity through appropriate comparative data of differing solar components. 'Component A' - Grid-connected solar power plants cost up to Rs. 65,000 per acre per year if farmers install plants by taking loans. The average smallholder farmer's land is around 5 acres. Despite government-provided subsidies, including Rs. 6.60 lakhs/MW/year or 30% subsidies for grid-connected solar pumps, the inherently expensive nature of implementing Agrivoltaics is there to be seen. Since agrivoltaic systems cannot be ground-mounted and require far more than simple solar panels (including irrigation infrastructure and control panels), they can also drive material and labor costs beyond the given estimates.

C. Ownership models

In the case of the Nawada pilot model, TCI employed a relatively healthy model relying on some smallholder ownership and shared governance. However, all major models have differing consequences on the financial and ownership side. In the case of corporate ownership, where large companies cover significant initial investments, they are primarily concerned with implementing agrivoltaics for energy production, not necessarily crop cultivation. Lack of farmer ownership reduces the incentive to optimize agricultural outcomes while stripping independence. On the other hand, smallholder owners independent of developers often lack enough financial resources and technical capacity to operate solar panels effectively in the long run, even with external subsidies and capacity building.

D. Requirement for continued financing and partnerships

In the case of TCI, a developer looking to exit the agrivoltaics project in a few years, farmers in the Nawada pilot model will likely struggle financially in the future without the developer's continued financial and technical support. The economic indicators, current models, and TCI's case highlight the requirement to build better agrivoltaic financing plans and ownership/financing models to sustainably promote agrivoltaics while balancing crop cultivation with solar power production.

Challenge II: Technical Obstacles on the Ground

A. Scaling limits of Agrivoltaics

Agri-photovoltaics (APV) represent not just a dual-solution but a technological innovation. As with any new technology, there are a variety of challenges to be faced across various fronts. Taking a step past financial challenges, the clear step is to evaluate technical obstacles within the field. Application-based obstacles are far easier to overcome than gaining capital, overcoming financial challenges, and addressing overarching regulatory and policy issues. Large-scale, uniform solar installations are often far more cost-efficient on a per-unit basis due to greater electricity production than small-scale microgrids, such as in TCI's Nawada pilot project. Moving forward, it is unlikely that smallholder farmers will have the support of partners such as those within the Nawada project, who will gain support from TCI's technical partner, Jain Irrigation Systems, which is responsible for solar power installation and irrigation infrastructure.

B. Electrical systems and Grid conversion

A different obstacle exists throughout electrical systems and the transformations required to convert small-scale agrivoltaic systems into more efficient and effective systems. For one thing, solar panels generate power for the DC or Direct Current system. However, most agricultural equipment and general household appliances - whether in irrigation systems or mills run on an Alternating Current AC. Therefore, an issue is raised - the conversion of produced energy into AC or the conversion of the grid into the DC system. This conversion requires much maintenance, technical expertise, technologies such as transformers, and further capital, exacerbating the challenge. An additional issue conversion raises is that farmers who wish to sell excessive (generated) electricity will find it extremely difficult without the aforementioned support and transformers.

C. Capital, Expertise, and Collaboration

As previously mentioned, Agrivoltaics are extremely capital-intensive due to the upfront investment in installing solar panels, irrigation systems, support structures, and a variety of infrastructure. Revisiting the financial challenges, these technical challenges are much more likely to arise for smallholder farms without the support of developers or owning companies, adding an argument for corporate ownership and dual farmer-developer models. This stems from the lack of technical expertise, such as dealing with the electrical grids, and the lack of capital. Agrivoltaics is a new system that farmers are not familiar with and are largely incapable of taking care of, thus engendering the need for partners such as Jain Irrigation Systems within TCI's initiative. In addition to the given obstacles, existing pumping systems in rural agricultural communities, such as in Bihar, are often outdated and possibly incompatible with solar power. Smallholder farms need more tailored panel layouts for agrivoltaic, often due to smaller plot spaces and potentially differing crops, different from standardized macro-grid farms. Within India, arable land is fragmented, and smaller, scattered land makes Agrivoltaic construction harder on a larger, commercial scale.

D. Summary of arguments and possible solutions

These concerns raise the need for field-appropriate electrical systems, alongside technical experts' assistance, to ensure that small-scale grids can function properly within rural agrarian communities. Additionally, building technical capacity at the grassroots level through technical training for farmers and agricultural practitioners will likely reduce their dependence on technical experts and improve their trust in these systems.

Challenge III: Current Government Policies

A. Agricultural electricity subsidies

A prominent challenge among current government policies is the reduction of incentives through current electrical subsidies in the agricultural sector. Currently, the Indian government provides electrical subsidies, up to 85% of the average supply cost, as per the University of California at Davis in 2012, to encourage agrarian output and economic growth. While seemingly positive, the implication of this policy is a lack of incentivization for farmers to transition their energy sources from traditional coal-powered electricity to solar-powered sources. When electricity is cheaper and use is encouraged by the government, it raises questions about why a farmer would need Agrivoltaics, as it is unlikely they share significant environmental concerns. Despite key government efforts targeted towards solar energy generation, such as through the 'PM: Surya Ghar' scheme, current electrical subsidies pose a far bigger challenge to their renewable energy goals. Therefore, current pathways deter farmers from Agrivoltaics and sustainable energy sources, thus demonstrating how the policy impacts key decisions.

B. Lack of Outreach and Visibility

A factor that works in combination with electrical subsidies is a lack of knowledge about agrivoltaics. When there is a lack of knowledge, it leads to a lack of action and possible distrust. The lack of proof of concept in agrivoltaic implementation in India has led to a deficiency in data. Therefore, there is no feasible way to prove to farmers on a large scale that Agrivoltaics is an optimal solution for cultivation and sustainable energy production. This leads to a need for gathering sufficient data, such as data on the efficiency of agrivoltaic systems and the implementation of awareness campaigns targeted towards farmers to improve the implementation of agrivoltaic systems not just in Bihar but on a national level.

C. Policy mismatch between the central and state governments

The final policy challenge to explore is the slight discrepancy between central and state governments, such as in the case of Bihar and the central government in New Delhi. The state and central government systems' inefficiencies are evident in the context of imposing such agricultural policies. An example is the Indian government's 'PM Kusum' program, which is meant to increase the successful solar grid and plant pumps nationwide. In the case of Bihar, no advancements have been made whatsoever through this program across grid-connected solar pumps or other alternatives. Agrivoltaics are hybrid systems that do not fit into any current agricultural or energy schemes, thus creating a disconnect given a lack of categorization, leading to further delays in execution and regulatory confusion. Overall, advancing agrivoltaic systems on a larger scale in states such as Bihar requires the bridging of gaps between central and state governments.

Challenge IV: Lack of Standards and Definitions

A. Absence of a uniform legal definition

On a conceptual level, a significant roadblock to scaling the production of agrivoltaics within the agriculture sector is the prominent Absence of a standardized definition within India. The ideas regarding what constitutes an agrivoltaic system differ across agencies and developers due to differing interpretations. The absence of uniformity can lead to confusion in goals, designs, and measured outcomes. A critical example is a pioneer of agrivoltaics in Germany, where, as per the German Institute for Standardization, "Agricultural photovoltaics (agrivoltaics) is the combined use of the same area of land for agricultural production as the primary use, and for electricity production using a PV system as a secondary use." In order to build a key framework for future policy, regulation, and programs, a standardized definition is critical. That being said, although a key definition is important, it is important to keep definitions broad enough to fit acceptable differing models as agrivoltaic systems. However, having no definition hinders the development of commercial and large-scale agrivoltaic systems in the future.

B. Lack of consistent technical standards

An issue accompanying the Absence of a definition is a lack of national or state-level policy standards across India. Research institutions such as TCI and the public sector are dominating agrovoltaic promotion across the board. However, the commercial adoption of agrivoltaics will likely be contingent on clearly defined standards. The main challenge to this development is the absence of a universal agrivoltaics model due to a wide range of designs and piloted configurations. Current parameters for standards could include "change in the effective area of cropping." The importance of the standard is creating the criteria for such projects, opening up independent developers to government support (through possible subsidies), and enhancing understanding of the technology and accepted model. Additionally, the deficiency in standards risks 'greenwashing' in the future, a phenomenon where developers implementing regular solar plants receive unduly incentives, per the International Institute for Sustainable Development. It is, therefore, critical for the central government and different states to collaborate with other pioneer countries to adequately develop standards and definitions tailored to the agricultural conditions of the Indian subcontinent.

Section III: Strategic Policy Pathways

A. Establishing a national legal definition and framework

This would include getting the central government, in partnership with individual states, to create a universal definition for agrivoltaics (similar to those implemented in France and Germany) alongside a national framework with a specific set of criteria to determine all specific aspects of agrivoltaics and specific models. This would further improve the policy and incentivize more commercial partners into the space by setting a defined standard without ambiguity.

B. Creating Agrivoltaic information campaigns

The best way to increase the success rate of agrivoltaics is to improve the average farmer's understanding of them. In order to do this, government officials could host a national agrivoltaic scheme with information sessions in major agrarian towns and villages targeted toward farmers. These would stress the importance of agrivoltaics, advertise potential economic benefits through subsidies, and eventually increase small-scale grid implementation for smallholder farmers.

C. Creating stable financial pathways

From a financial perspective, it is critical to make agrivoltaics accessible to farmers. The manner to achieve this could be through various subsidies, such as those given for 'PM Kusum' solar panels, and securing financial credits to get loans from mainstream banks at an easier rate. Creating such stable pathways is likely to pave the way for the implementation of further agrivoltaic grids.

D. Increasing technical capacity from a grassroots level

Even after the information and awareness stage, a pressing issue to address is the lack of familiarity farmers have with the technical aspects of agrivoltaic grids. Farmer confidence to operate and maintain systems effectively is critical. The government could invest in regional capacity-building centers to offer training on system installation, operation, and maintenance, among other possibilities.

E. Electricity subsidy adjustments

As previously mentioned, current agricultural subsidies favor coal-powered electricity generation. In order to shift the electricity source to agri-photovoltaic powered sources, the government should consider slightly reducing subsidies on electricity over a long period in favor of agri-voltaic subsidies and investments in contracts with technical experts. With the intent of further agrivoltaic expenditure or different pathways within sustainable energy, this shift is likely to reduce emissions going forward in favor of increasing sustainable energy usage.

Section IV: Conclusion

The exploration of Bihar's scenario throughout the report demonstrates that scaling agrivoltaic systems within a smallholder, resource-constrained landscape, in the case of small-grids, faces numerous challenges, even with potentially upcoming successes. Agrivoltaics represents an effective dual solution system, simultaneously addressing food insecurity and sustainable energy. Despite potential benefits, financial barriers, technical obstacles, current legislative policies, and a lack of standards and definitions significantly curtail the progression of agrivoltaics as a usable technology. These challenges help underscore the vast requirements for coordinated intervention from many stakeholders - governments, project developers, and farmers. Consequently, agrivoltaics will likely remain a conceptual framework instead of a transformative agricultural and energy innovation without targeted efforts along multiple fronts.

These efforts can manifest into numerous possibilities, ranging from a national definition and framework to better financial opportunities, information campaigns, technical capacity investments, and electrical subsidy adjustments. It is not any individual amendment but a combination of changes in policy, legislation, and approach that will assist in the transformation of agrivoltaics on a scale from the Tata Cornell Institute's pilot projects in Nawada into large-scale, sustainable, and productive systems formed through mutually beneficial partnerships between the aforementioned stakeholders.

In conclusion, the lessons from Bihar necessitate the criticality of addressing these challenges and developing healthy models in financing and ownership to fuel the sustainable development and implementation of agrivoltaics throughout states such as Bihar and the whole of India. If combined with the variety of recommendations and a better support system, Agrivoltaics can play a defining role in India's and Bihar's journey towards a Zero-Hunger, Zero-Carbon future.

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