Arbeitsgemeinschaft Tropische und Subtropische Agrarforschung (ATSAF) e.V.
Council for Tropical and Subtropical Agricultural Research

ATSAF Academy
Academy for International Agricultural Research for Development

Junior Scientists Tandems
Final Report

Name of student: Manuel Francisco Moreno Bustamante
German Research Institution (GRI): University of Hohenheim
Supervisor at German Research Institution (IARC): Prof. Dr. Arndt FFeuerbacher
National University (Country)
Supervisor at National University:
International Agricultural Research Center (Country): Alliance Bioversity & CIAT (Colombia)
Supervisor at IARC: Dr. Manuel Narjes
Start and end date of stay at IARC/ GRI: 01.06.2025 – 30.11.2025
Title: Household Decision-Making on the Adoption of Agrivoltaics (APV) within the Water-Energy-Forest-Food Nexus

Funded by the German Federal Ministry for Economic Cooperation and Development (BMZ)

german cooperation
DEUTSCHE ZUSAMMENARBEIT

Implemented by
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Household Decision-Making on the Adoption of Agrivoltaics (APV) within the Water-Energy-Forest-Food Nexus

Introduction

This report presents my experience and progress in developing my doctoral research proposal as part of the Junior Scientist Tandem (JST) program of the Council for Tropical and Subtropical Agricultural Research (ATSAF e.V.). Over a six-month period, I completed a research stay in Germany as a Guest Researcher at the University of Hohenheim within the Institute of Agricultural Policy and Markets, Department of Economic-Ecological Policy Modeling, under the supervision of Prof. Dr. Arndt Feuerbacher. This experience was instrumental in strengthening my doctoral proposal, which I intend to develop within the framework of the JET-AgriSOL project funded by IKI during its implementation phase. This report is divided into two sections: the first presents my experience during the JST program at the University of Hohenheim and how it contributed to identifying research gaps, which are detailed in the second section.

Experience

Before applying to the JST program, I had the opportunity to meet Nicolás Valbuena, who was completing his internship at the Alliance Bioversity International and CIAT as part of the same program. I was able to interact and collaborate with him during his six-month stay in Cali, Colombia. After his return to Germany, together with Nicolás and Dr. Manuel Narjes, my supervisor at the Alliance Bioversity International and CIAT, we discussed the possibility of completing the tandem at the University of Hohenheim with Prof. Dr. Arndt Feuerbacher. Once my proposal was accepted, Nicolás supported me before and during my arrival in Germany. The JST program enabled this collaboration, fostering mutual adaptation and making the program especially valuable by connecting researchers from different contexts. Additionally, through my work at the Alliance Bioversity International and CIAT, I reconnected with former colleagues now at the University of Hohenheim, such as Lina Ibarra and Karen Enciso.

During my stay, I became part of the Department of Economic-Ecological Policy Modeling, led by Prof. Dr. Arndt Feuerbacher—a multicultural team with diverse research profiles and interests. Being part of this environment allowed me to participate as both an assistant and presenter in the Agri-Environmental Economics and Policy Seminar sessions organized by the department. These seminars provided an excellent opportunity to meet researchers from other departments and universities, broadening my understanding of current academic discussions and inspiring my literature review. I also presented the progress of my doctoral proposal and received valuable feedback from participants, which I later incorporated into my research. Additionally, I held biweekly meetings with Prof. Dr. Feuerbacher to discuss my literature review and data analysis progress.

I also attended seminars across the University of Hohenheim, notably the presentation of doctoral work by Kelzy Jepsen from the Department of Sustainable Use of Natural Resources, led by Prof. Dr.

Verena Seufert. Interacting with Kelzy provided valuable insights on integrating gender as a central component in my proposal and on potential approaches to studying household decision-making.

Prof. Dr. Feuerbacher organized a writing retreat that brought together several PhD students from the Institute of Agricultural Policy and Markets. This retreat focused on sharing effective academic writing strategies and exchanging feedback on participants' drafts—including my doctoral proposal. It was an enriching experience that helped me refine my writing skills and connect with peers from other departments.

Following Prof. Dr. Feuerbacher's recommendation, I took part in modules from the Doctoral Certificate Program in Agricultural Economics, specifically 'Applied Choice Analysis' and 'Applied Microeconometrics and Impact Analysis'. The first module, taught by Prof. Dr. Jutta Roosen and Dr. Matthias Staudigel, enhanced my understanding of choice modeling techniques. I also had the opportunity to visit the Technical University of Munich campus in Freising. The second module, taught virtually by Prof. Dr. Johannes Sauer, Dr. Fabian Frick, and Dr. Maria Vrachioli, strengthened my knowledge of fundamental econometric techniques and experimental and quasi-experimental methods for impact evaluation. These courses expanded my methodological toolkit, which will be crucial for developing my doctoral research.

Before my stay in Germany, my colleagues and I at the Alliance Bioversity International and CIAT submitted the article "Advancing Sustainable Silvopastoral Practices for Achieving Zero Deforestation in the Colombian Amazon" to Agricultural Systems, which was officially published in October. During my stay, I collaborated with my colleagues to address reviewers' comments, which also reconnected me with researchers from the Thaer-Institute of Agricultural and Horticultural Sciences at Humboldt University of Berlin.

Research Gaps

In this section, I present some of the research gaps identified during my stay at the University of Hohenheim. Over these months, I analyzed the evolution and interconnection of the literature on agrivoltaics (APV), household decision-making, and the Water-Energy-Forest-Food (WEFF) nexus, as well as identifying useful data sources for future studies.

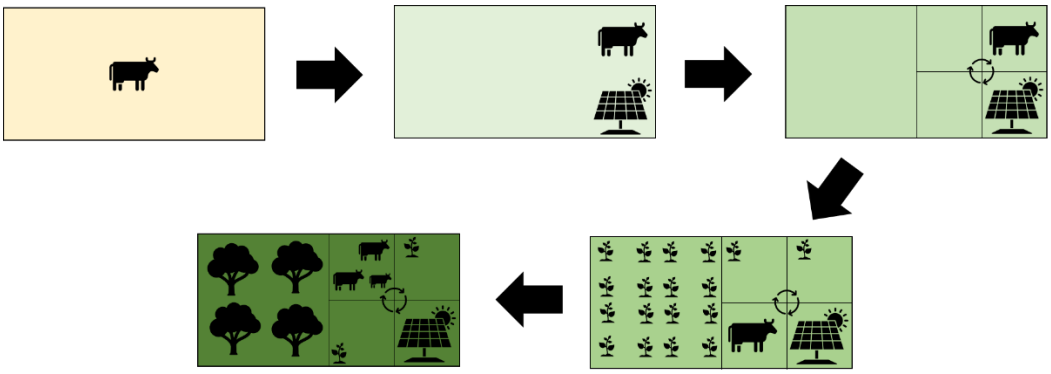
Building on Buritica et al. (2026), Silvopastoral Systems (SPS) emerge as a strategy to mitigate deforestation in the Amazon region while improving milk and livestock production. However, adoption of practices such as pasture renewal and rotation remains limited, as do the income and productivity benefits from SPS. This suggests that adoption is still relatively low, making it essential to develop strategies to enhance the uptake of sustainable practices like SPS.

A related question is how APV adoption could complement SPS to generate greater benefits without competition between systems. Agrivoltaics (APV) is a dual land-use technology that enables both agricultural and energy production (Dupraz et al., 2011). Agrivoltaics offer multiple advantages, including improved soil moisture, microclimate regulation, and water-use efficiency (Marrou et al.,

2013; Trommsdorff et al., 2021; Willockx et al., 2020). These systems are highly relevant amid the growing scarcity of agricultural land (Feuerbacher et al., 2021). Despite these advantages, adoption of APV integrated with SPS remains low, warranting further study on how the two can be effectively combined.

The integration of APV and SPS can be conceptualized within the WEFF Nexus framework (Melo et al., 2021), which emphasizes that innovations can simultaneously generate cross-sectoral benefits. Figure 1 illustrates a simplified scenario of joint adoption of APV and SPS, beginning with extensive livestock farming characterized by low stocking density and soil degradation. The process involves the sequential adoption of APV, pasture division and rotation, forage planting, and tree introduction—without reducing solar radiation for APV systems. This combined adoption leads to soil recovery, increased livestock density, improved animal welfare, and energy co-benefits that can support cooling systems or improve producers' livelihoods (Widmer et al., 2024).

Figure 1. Transformation from extensive livestock to Silvopastoral Systems including Agrivoltaics

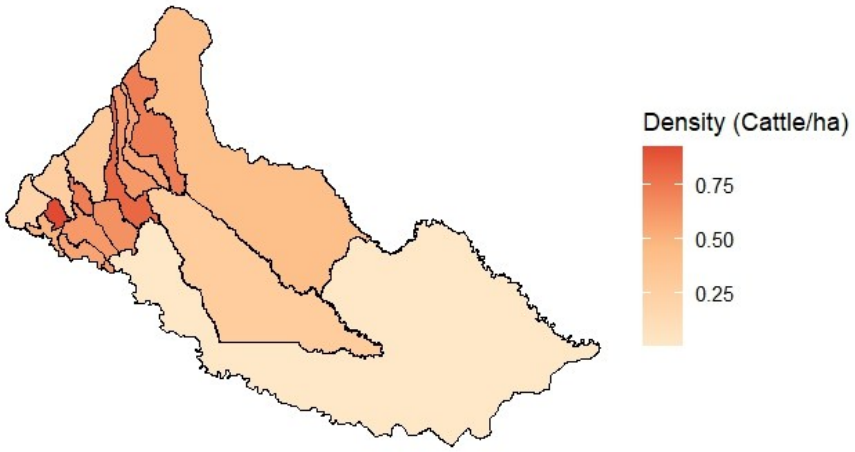


Adapted from: Buritica et al. (2026)

However, it is crucial to first understand household decision-making processes to grasp how families perceive the potential benefits of combining APV and SPS, thus situating these within the WEFF Nexus framework. A mixed-methods approach—combining qualitative and quantitative methods—could be valuable for examining these intra-household processes. Qualitative visioning exercises, for instance, have proven useful in assessing the proper implementation of just energy transition policies in recent years (Groves et al., 2023). Meanwhile, quantitative approaches such as Willingness-to-Adapt experiments have demonstrated how the adoption of SPS can be encouraged through offsets and information provision (Opdenbosch & Hansson, 2023; Stubblefield et al., 2025). In this context, it would be particularly relevant to explore how the benefits derived from APV could influence SPS adoption. Such research is especially pertinent in Latin America, where empirical evidence on APV remains limited and mostly focuses on its potential role within energy transition policies (Pena-Calzada et al., 2025). Additionally, understanding internal household dynamics can contribute to expanding the evidence base on gender dimensions within the Colombian livestock sector (Pirela Rios et al., 2023).

Caquetá, Colombia, represents an ideal location to address these research gaps. This department, located in the Amazon region, exhibits social and economic characteristics that are particularly relevant for my doctoral research. Historically, Caquetá has been heavily affected by the armed conflict, which shaped its extensive livestock production patterns and caused severe environmental consequences. Following the signing of the peace agreement in 2016, deforestation rates have increased across Colombia, particularly in areas previously occupied by armed groups (Prem et al., 2020). Furthermore, data from FEDEGAN (2025) show that the livestock inventory in the department continues to grow, with low stocking densities—typically fewer than one head of cattle per hectare across most municipalities (see Figure 2). Despite this, recent years have seen a rise in the adoption of SPS in the region (Alvarado Sandino et al., 2023; Castro-Nunez et al., 2024; Buritica et al., 2026) as well as growing appreciation for cheese produced in Caquetá (see Figure 3).

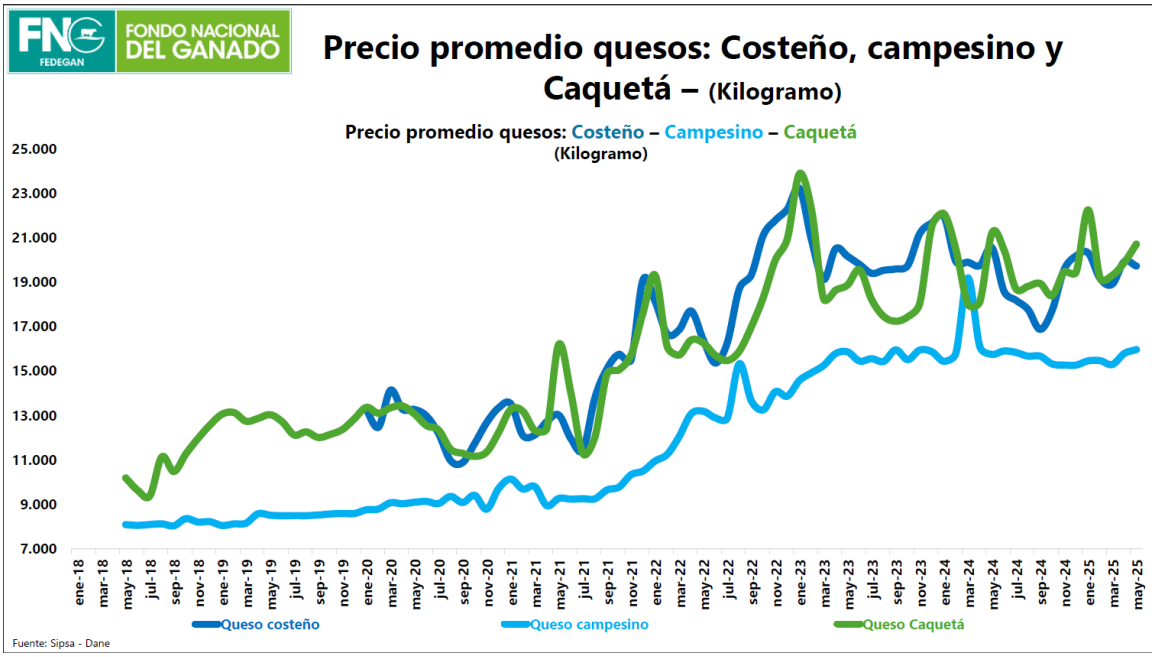
Figure 2. Cattle density in Caquetá by municipality



Source: Torrijos (2022)

Finally, I would like to express my sincere gratitude to the JST program for providing the funding that made my research stay possible. The impact of this program goes far beyond financial support. In my case, it allowed me to develop my doctoral proposal while connecting with a diverse network of academics and researchers in Germany. This experience not only strengthened my academic foundation but also deepened my motivation to pursue my PhD. No matter the path I choose moving forward, I am confident that the experience gained through the JST program will remain a defining milestone in my professional journey for years to come.

Figure 3. Tendency of different Colombian cheese prices



Source: FEDEGAN (2025)

Referencias

Alvarado Sandino, C. O., Barnes, A. P., Sepúlveda, I., Garratt, M. P., Thompson, J., & Escobar-Tello, M. P. (2023). Examining factors for the adoption of silvopastoral agroforestry in the Colombian Amazon. Scientific Reports, 13(1), 12252.

Buritica, A., Ngaiwi, M., Moreno, M., Gonzalez, C., & Castro-Nunez, A. (2026). Advancing sustainable Silvopastoral practices for achieving zero deforestation in the Colombian Amazon. Agricultural Systems, 231, 104525.

Castro-Nunez, A., Buritica, A., Holmann, F., Ngaiwi, M., Quintero, M., Solarte, A., & Gonzalez, C. (2024). Unlocking sustainable livestock production potential in the Colombian Amazon through paddock division and gender inclusivity. Scientific Reports, 14(1), 13644.

Dupraz, C., Marrou, H., Talbot, G., Dufour, L., Nogier, A., & Ferard, Y. (2011). Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes. Renewable energy, 36(10), 2725-2732.

FEDEGAN. (2025). Cifras de referencia del sector ganadero colombiano 2024. Federación Nacional de Ganaderos. https://estadisticas.fedegan.org.co/DOC/download.jsp?pRealName=Cifras_Referencia_2025_UV__.pdf&ildFiles=1157

Feuerbacher, A., Laub, M., Högy, P., Lippert, C., Pataczek, L., Schindele, S., ... & Zikeli, S. (2021). An analytical framework to estimate the economics and adoption potential of dual land-use systems: The case of agrivoltaics. Agricultural Systems, 192, 103193.

Groves, C., Henwood, K., Pidgeon, N., Cherry, C., Roberts, E., Shirani, F., & Thomas, G. (2023). Putting visions in their place: responsible research and innovation for energy system decarbonization. Journal of Responsible Innovation, 10(1), 2149954.

Marrou, H., Wéry, J., Dufour, L., & Dupraz, C. (2013). Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels. European Journal of Agronomy, 44, 54-66.
Melo, F. P., Parry, L., Brancalion, P. H., Pinto, S. R., Freitas, J., Manhães, A. P., ... & Chazdon, R. L. (2021). Adding forests to the water–energy–food nexus. Nature Sustainability, 4(2), 85-92.

Opdenbosch, H., & Hansson, H. (2023). Farmers' willingness to adopt silvopastoral systems: Investigating cattle producers' compensation claims and attitudes using a contingent valuation approach. Agroforestry Systems, 97(1), 133-149.

Pena-Calzada, K., Toledo, C., Garciga, J. P., Barrera-Cardoso, E. L., Iriondo-Pérez, M. E., Sotolongo-Hernández, E., & Scognamiglio, A. (2025). Advances and challenges of agrivoltaic in the Americas: a look at its current situation. Agroforestry Systems, 99(1), 8.

Pirela Rios, A. M., Díaz Baca, M. F., Enciso Valencia, K. J., Triana Ángel, N., & Burkart, S. (2023). Gender inequalities in the Colombian cattle sector: an econometric analysis. Development in Practice, 33(4), 400-415.

Prem, M., Saavedra, S., & Vargas, J. F. (2020). End-of-conflict deforestation: Evidence from Colombia's peace agreement. World Development, 129, 104852.

Stubblefield, K., Smith, M., Lovell, S., Wilson, K., Hendrickson, M., & Cai, Z. (2025). Factors affecting Missouri land managers' willingness-to-adopt agroforestry practices. Agroforestry Systems, 99(1), 1-21.

Torrijos, R. (2022). Cifras de Contexto Ganadero Caquetá 2022. Ed. Comité Departamental de Ganaderos del Caquetá. Florencia. Caquetá, Colombia. https://issuu.com/rafaeltorrijos/docs/contexto_2022_imp.

Trommsdorff, M., Kang, J., Reise, C., Schindele, S., Bopp, G., Ehmann, A., ... & Obergfell, T. (2021). Combining food and energy production: Design of an agrivoltaic system applied in arable and vegetable farming in Germany. Renewable and Sustainable Energy Reviews, 140, 110694.

Widmer, J., Christ, B., Grenz, J., & Norgrove, L. (2024). Agrivoltaics, a promising new tool for electricity and food production: A systematic review. Renewable and Sustainable Energy Reviews, 192, 114277.

Willockx, B., Herteleer, B., Ronsijn, B., Uytterhaegen, B., & Cappelle, J. (2020). A standardized classification and performance indicators of agrivoltaic systems. EU PVSEC Proceedings.