Incorporating Micro Supply Chain in the Simulation of the Food-Energy-Water Nexus

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Abstract

In this paper, an agent-based model is employed to study urban farm interconnectivity, with the goal of increasing food availability for the population and efficiently managing food, energy and water resources. Urban farms are presented as a case study, that belong to community microgrids that generate electricity from renewables (solar, wind), in the province of Chiriqui in Panama, is utilized to investigate the food-energy-water (FEW) nexus. The idea of different farms serving different communities can be viable, however, sometimes there is a shortage of fresh food, or other times a surplus of fresh food, which leads to food wastage. Food waste has the capability of being transformed into fertilizers or into biomass energy, however when we consider the associated natural resources and costs used to produce food, avoiding waste would be a better alternative. Thus, it is crucial to investigate the food supply chain, and the interaction between different urban farms in a community shared agriculture fashion. An optimization model is employed to minimize food transportation cost between the farms within the agent-based framework. The results show that food availability is improved due to the exchange between farms while food wastage is reduced by 17,137kg. Furthermore, the simulations show that the sharing of energy through the microgrid employing renewable energy is economical and significantly reduced carbon emissions by avoiding 13,078 tonnes of CO_2 and generating 16,560 Mwh of electricity through solar, and 2,333 Mwh of electricity through wind.

Keywords

Agent-Based Model, Food-Energy-Water nexus, Urban Farms, Micro Supply Chain, Collaborating Farms

1. Introduction

In the industrialized global community, changes are occurring with regards to demographics, urban sprawls, technological advancements, globalization and changes in demand for water, food and energy resources. As demands for natural resources begin to increase, we must consider the fact that supply of these resources may decrease as well. This poses various challenges, that require policymakers to find more optimal methods of resource utilization in order to meet growing world demand. Energy and water resources are symbiotic and interconnected as shown through the generation, dissemination, and treatment of both energy and water resources, signifying the importance of efficiently managing these valuable natural resources. These resources are essential in the production and distribution of food and thus agricultural advancements are necessary in order to meet demands, and to ameliorate food and water security as well as resolving spatial challenges. A methodology has been established, known as the food-energy-water (FEW) nexus, which examines the interconnections and interdependence of resources, and is utilized to identify synergies, challenges and trade-offs that occur between resources. The FEW nexus approach is utilized to formulate policies and systems that would optimize the use of resources in order to meet strategic sustainability goals (Simpson and Jewitt 2019).

The key challenge will be to effectively integrate the interconnectedness of the progressing FEW nexus, as future projections indicate increased demand for food, energy and water resources. Water and Energy are key resources needed for food production, and energy and water are also related, as energy is required in treating and distributing water. This brief example signifies the importance of the connections that occur between resources and how it is crucial that we identify methods to manage them. There are a number of considerations that need to be undertaken with regards to food resources, and these include the optimization of food production, the diversification of food sources, and this will allow for the development of a robust food system, which looks to minimize carbon, water, and energy food prints, as well as reducing food waste. The current world population estimates will require that global food production be raised by 50% by the year 2050, and water demand is estimated to be increased by 55% by 2050. One solution that has been proposed to aid in the reduction of food waste and enhancing food accessibility for local communities where urban farms exist, is to encourage collaboration between urban farms (Kaufman and Bailkey 2000). An example in the United States, states that approximately 25% of greenhouse gas (GHS) emissions are in the food transportation sector, where carbon emissions released are due to the use of trucks for the transport of food (Weber and Matthews 2008). Introducing the concept of farm collaboration as well as establishing local agricultural producers in the form of local farms, can aid in solving spatial challenges, as well as reducing greenhouse gas emissions that would normally be emitted due to food transport.

1.1 Objectives

The main objective of this paper is to develop a comprehensive system that integrates community microgrids generating electricity from renewable sources with urban farms that collaborate with each other in the form of food exchange, thus synergizing strategies and measured aimed at achieving sustainability objectives of the FEW nexus. The development of such a system will lead to obtaining deeper insights into the FEW nexus, gaining an understanding of the interconnected relationships and dependencies between resources, and identifying the various trade-offs and synergies between resources, and the ability to address spatial aspects. In this paper, socio-economic tools, as well as spatial analysis are used to determine the connections between system components, and policies, management and technologies are integrated through a nexus framework to study urban farming activities. An agent-based model is introduced that simulates urban farms and community microgrids, and optimizes food exchange between farms, creating a farm-to-farm exchange (FFE). The establishment of food exchange between farms in this framework is noteworthy, as it can alleviate geographic challenges, resulting in the reduction of food waste, as well as increasing food availability for consumers in the surrounding area of a local urban farm.

The framework presented in this paper can benefit decision makers in achieving sustainability objectives, through the use of renewable energy, leading to reduced carbon emissions, as well as increasing access to fresh food for local communities and supporting local farmers, allowing them to expand their production, as well as collaborate with other farms. The work presented in this paper is an extension of our previous work (Elkamel et al. 2023a, Elkamel et al. 2023b), which looks to apply the methodology on a different case study. Panama is chosen as a case study in this paper due to its climate and because the agricultural sector has been declining in the 2010s, from contributing 7.4% to GDP in 2009 to a low of 2.19% in 2019, and this jumps to 2.77% in 2020 (IEA 2022). With efficient planning, Panama will be able to increase agriculture in the area, as well as aiding in employing locals and promoting subsistence agriculture.

2. Literature Review

Agent-based modeling (ABM) is a computational modeling technique that has been utilized to study complex systems, that contain autonomous agents, and the behavior of these agents is studied, focusing on the interactions of agents with one another and with their environment. Agents within an ABM are shaped by attributes and decision-making rules, which can be based om simple rules or heuristics. There are many applications of ABM, and these include: social sciences, agriculture, economics, epidemiology, supply chains, urban planning and marketplace behavior (Abar et al. 2017). In terms of agricultural ABMs, researchers have utilized models that focus on combating food deserts, as well as models that look to increase food availability for consumers. A developed ABM was employed to examine the impact of various policies on the accessibility of food for low-income consumers in Brooklyn, New York, and farmer's markets were found to be effective in increasing food availability, however, it was found that consumers that were not located near a farmer's market, were not able to increase their access to fresh food (Widener et al. 2013). Other models found that farmer's markets had a positive impact on consumer satisfaction but found that additional work needs to be completed on food distribution to further increase consumer satisfaction, due to the location of consumers (Ghandar et al. 2019). ABM was used for commodity markets, to gain a greater understanding of the effect of price and quantity on sales (Giulioni 2018). Small food shops are another area that is investigated through ABM, and locations of shops are studied to determine the effect on food purchases of consumers (Calisti et al. 2019).

Extensive research has been carried out on the FEW nexus, and this research has focused on investigating the interactions that occur between resources in the nexus, and determining which factors lead to shifts in one resource in relation to another. A variety of approaches were employed including life cycle assessment (Daignault et al. 2023), one way analysis (Gerbens-Leenes et al. 2009), and ecological network analysis (Spiegelberg et al. 2017). Social and environmental indicators were also examined to determine the effect on resources within the nexus, using an integrated index analysis (Florke et al. 2018). Other research involving the FEW nexus focused on formulating optimal systems and determining their impact on achieving strategic sustainable objectives and these included a number of methodologies. Optimization models were found to be effective in designing systems but did not consider the interconnectedness of resources in the FEW nexus (Zhang and Vesselinov 2017). System dynamics was utilized to investigate various scenarios that study social behaviors and dynamics of a modeled system (Newell et al. 2011). One conclusion about the FEW nexus is that collaboration is required between sectors which can result in economic growth in certain geographic regions (Markantonis et al. 2019).

In terms of food supply chain research, a majority of these works focused on large-scale supply chains. The purchase experience of consumers was investigated, and results found that additional shops are needed in order to increase food access (Christopher 2011). An exploration of the Mango supply chain found that farmers receive the lowest value out of all supply chain agents (Alam 2018). The rice supply chain was investigated using agent-based simulation to gain a greater understanding of contract farming, and the effect on rice production (Khanh et al. 2017). Other ABM food supply models focused on reducing food waste through the use of crowd-shipping for food insecure consumers (Mittal et al. 2019). The effect of farmer coordination was studied to determine impacts on food supply chains, and whether collaboration of producing a single crop would result in increased income, volume and profit sharing. An agent-based model was utilized, and results indicated that farmer consolidation led to a stronger supply chain structure (Krejca and Beamon 2015). A survey paper discussing the agri-food supply chain, and the use of ABM, concluded that the existing literature was lacking with regards to agent collaboration (Utomo et al. 2018). All of the research conducted on food supply chains which utilized agent-based simulation, did not consider the interconnectedness of resources within the FEW nexus, focusing solely on the food aspect of the nexus, and energy and water resources were excluded.

3. Methods

In this paper, an agent-based model (ABM) is developed to simulate and investigate the various interactions that occur between agents of an urban farm, with a primary objective of providing the local population with fresh vegetables. In addition, each urban farm has an attached renewable energy-based community microgrid that provides electricity for the urban farm, as well as the surrounding community, and this can aid in reducing carbon emissions, as well as contributing to Panama's goal of 15% renewable energy generation by 2030, and 50% by 2050 (IEA 2022). The developed model contains five agents that will interact with one another as well as with the environment, reproducing real-life scenarios that would occur in an urban farm context, allowing us to investigate the emergent phenomenon and these agents are: farmer agents, consumer agents, microgrid agents, electricity grid agents and water grid agents. Each agent in the ABM contains attributes, as well as a decision-making process. Differing attribute values shape agent behavior, leading to different results once a simulation is complete. In the proposed ABM, agent attributes are data-driven, and collected data is used as inputs, as well as shaping attribute data distributions. Once the execution of the ABM is complete, we are able to investigate the results, and measure their effect on social, economic and environmental sustainability.

The interactions that occur between agents as well as the main objective of each agent are illustrated in Figure 1. The first of the five agents is the farmer agent, whose main goal is to grow and sell vegetables every week to consumer agents, and these vegetables are packaged in harvest boxes and the size of the box depends on the consumer agent's family size. The box will contain a multiple of 1.4kg of vegetables, depending on the purchasing consumer's family size. In the developed model, farmer agents will grow vegetables until the summer, and in the summer, season spanning 16 weeks, will sell harvested vegetables packaged in harvest boxes to the consumer agents. Cultivated crops need to be irrigated, and when there is no sufficient rainfall, water needs to be purchased from the water grid agent. Satellite observations from the NASA database are used for climate variables, and the rainfall amount for each farm is scaled with the planted area of crops at each farm to determine rainfall values as well as irrigation requirements. There are seven urban farms of differing land sizes in the model, and the amount of harvested vegetables is calculated based on the land size of each farm.

The main goal of a consumer agent is to visit an urban farm during the summer weeks to purchase fresh vegetables for their family. The consumer agent's decision-making process is shaped by their income, location, family size, and preferred farm to visit attributes. The preferred farm to visit for a consumer agent is located within one kilometer of their home location. The farmer agents in the simulation are not able to satisfy demand for all consumer agents, and thus at certain points in the simulation, a consumer agent may be unable to satisfy their demand for fresh vegetables when they visit an urban farm and will look to supplement their food expenditure from other sources.

The microgrid agent in the model contains an hourly electricity demand that needs to be met through generated electricity from renewable sources, solar and wind energy, or through the purchase of electricity from the electricity grid agent. At some points, the microgrid agent may produce excess electricity, and this electricity can be stored in a battery, and can be used at a later point in time where produced renewable electricity is not sufficient to meet demand. Any additional produced electricity not stored in the battery is sold to the electricity grid agent. Before the microgrid agent purchases electricity from the electricity grid agent, it checks if sufficient electricity is available in the battery, and if demand is still not met, will proceed with the purchase from the electricity grid agent. The electricity grid agent that is modeled interacts with the microgrid agent, either by selling electricity or purchasing it. The water grid agent in the proposed model serves one purpose, and that is to sell water to the farmer agent, and this water is used for irrigation.

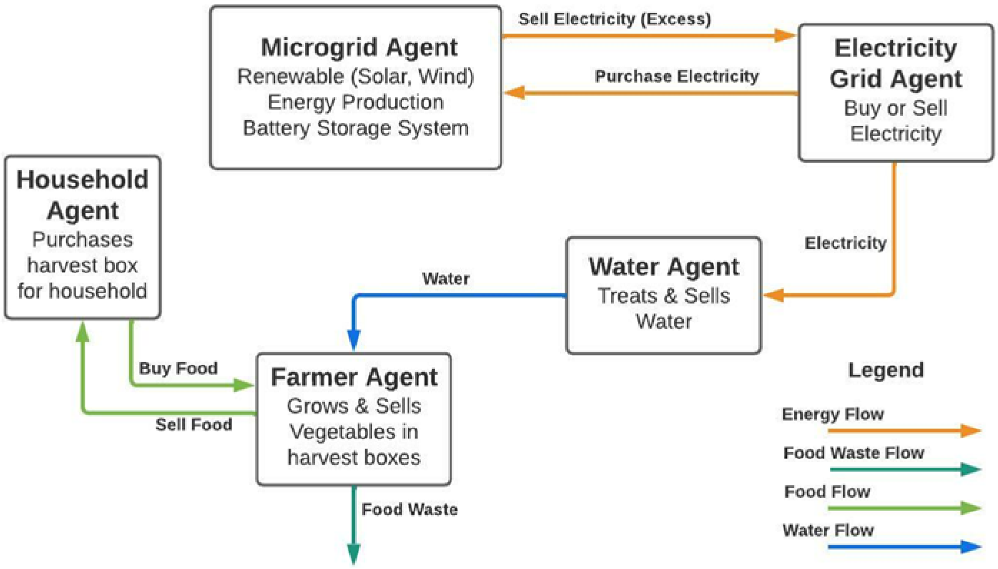

Figure 1. Agent Interactions in the ABM Simulation

This paper a transportation is modeled within the ABM and is used to optimize the food supply chain, with the objective of minimizing distance and waste between the seven urban farms while also satisfying the demand of each urban farm. Distance is chosen to be minimized due to its relation to costs as this directly correlates with fuel costs for the transportation vehicles as well as carbon emissions.

The transportation model occurs within the summer weeks in the simulation, and during these weeks, there are different demand and supply configurations of urban fans, and these depend on the purchasing behavior of consumer agents that visit each urban farm. Each week is unique, thus there are differing food quantity values present at each farm, in the form of surplus or deficit. The main objective of the transportation problem that is to be solved is to minimize transportation costs and to meet the produce requirements of each urban farm. For each week, we take the average of the last 5 weeks of food demand. For ($k < s$) the average of the simulation without food transportation is used. Depending on the week, a different case can occur with regards to the food supply chain, and thus the way the model is solved is altered. When the demand exceeds supply new demands are calculated for each farm taking into account the amount of the original demand so that the deficits at the demand farms are equally distributed. Similarly, when supply exceeds demand a new supply amount is calculated so that excess supply is uniformly distributed among the supply farms.

4. Data Collection

The urban farms used in the Panama case study each belong to a community scale microgrid, that generates electricity from solar and wind energy, and provides electricity to the urban farm as well as the surrounding area. Each urban farm has an irrigation requirement, which is needed for the cultivated crops in time periods where there is not sufficient rainfall. The objective of each urban farm is to employ a community shared agriculture (CSA) model for the distribution of vegetables packaged in harvest boxes to consumers. The harvest box will contain a mixture of harvested vegetables, and this box will be sold to visiting consumers every week during the summer season. The CSA model mirrors a farmer's market model but differs in the ideology that vegetables are packaged into harvest boxes ahead of time, and there is a mixture of vegetables. The visiting consumer purchases a harvest box depending on their family size, and this is during the summer season, starting in June and ending in September. The area of the different urban farms and their production of vegetables every week is listed in Table 1.

Production values of vegetables at each of the urban farms are calculated based on the farm's land size. The electricity demand values of the community microgrid include electricity demand of the urban farm, as well as the number of buildings in the local community for the province of Veraguas in Panama. The climate variables are also included in electricity demand calculations, taking into account the differing electricity demand values at different points of a day. Once electricity demand calculations are complete, the ABM will use electricity generated by solar and wind, and the battery storage system to meet electricity demands. If demand is not able to be met, the microgrid purchases electricity from the electricity grid to meet its demand. If there is a surplus of generated electricity from solar and wind, the excess is stored in the battery for later use, and if excess generated electricity still exists, then it is sold to the electricity grid. The capacities of solar, and wind energy, as well as the battery storage system size are displayed in Table 2, along with the electricity demand at each community microgrid at each urban farm. The distribution of generated solar and wind electricity depends on the capacity of each renewable energy source, as well as the geographic location, and data for these calculations are retrieved from the NASA database.

Table 1. Weekly Vegetable Production and Urban Farm Area at each Location

Farm	Size (m^2)	Production per Week (Kg)
1	4,047	1,341
2	2,023	671
3	86	29
4	201	67
5	6,495	2,153
6	4,162	1,379
7	6,556	2,173

Table 2. Electricity Consumption and Renewable Energy Capacities, and Battery Storage Capacity at each Microgrid

MG #	Avg Demand Per Hour (Kwh)	Solar Cap (Kwh)	Wind Cap (Kwh)	Battery Cap (Kwh)
1	518	1,600	350	320
2	483	1,500	300	300
3	151	600	100	90
4	896	2,700	600	550
5	361	1,100	250	220
6	712	2,200	650	440
7	855	2,600	550	530

5. Results and Discussion

The main objective of the conducted simulations presented in this paper is to study the effect of the establishment of community shared agriculture between urban farms. Two different scenarios are simulated, a scenario where there is no collaboration between urban farms, and a scenario where farm-to-farm exchange occurs, where farms collaborate to meet consumer demands, increasing food availability and also reducing food waste. The sustainability measures (social, economic, and environmental) are discussed in this section for both studied scenarios.

We investigate social sustainability first of the three sustainability measures that are studied. The way social sustainability is measured in this paper, is by calculating the food security levels of consumer agents in the simulation. There are many different approaches available to calculate food security, and the selected approach is the household consumption and expenditure survey (HCES) method. The results of the HCES calculation indicate that a consumer is food insecurity if the value is above 50% and that a consumer is food secure if the value is below 50%. The way the HCES value is calculated is by taking a consumer's expenditure on food and dividing this by the consumer's income. The scenario with no farm-to-farm exchange resulted in an average HCES (%) of 42.7%, indicating that consumers were found to be food secure. In the second scenario, where farms collaborated, participating in farm-to-farm exchange, the HCES (%) is 48%. The results of the farm collaboration scenario indicate that food availability was increased for consumers, leading them to increase their expenditure on food. The established food supply chain was found to increase food availability for consumers, and also lead to a reduction in food waste at the urban farms (Figure 2).

Economic Sustainability focuses on the difference between electricity purchases and sales in terms of economic sustainability. The electricity demand of the seven urban microgrids over the simulation is shown in Figure 3 grouped by week for a one-year time period. The total electricity demand of all the microgrids is 34,822 Mwh. Solar energy led to the production of 16,560 Mw of electricity and wind energy produced 2,333 Mwh of electricity. The difference in electricity demand and the electricity generated from renewable sources was found to be 15,929 Mwh, which was purchased from the electricity grid. One way to avoid potential costs from the purchase of electricity, is to invest in bigger renewable energy capacities, mainly solar, and to purchase more battery storage systems. Figure 4 illustrates the trend of generated electricity from solar energy, and Figure 5 illustrates the trend of generated electricity from wind energy. Figure 6 depicts electricity sales, while Figure 7 portrays electricity purchases. An observation of the electricity sales trend reveals that sales exhibited higher levels during the initial weeks of the year, and this is attributed to the increased generation of electricity from wind.

The carbon and water footprints are assessed here in terms of environmental sustainability. In terms of the carbon footprint, we investigate the carbon emissions avoided due to the utilization of renewable energy. For the one year time period of the simulation, we find the avoided CO_2 emissions to be 13,078 tonnes. The value of avoided carbon emissions is based on the electricity generation profile of Panama. Following the carbon footprint, we investigate the water footprint, which is comprised of two categories. The two categories of water footprint include the green water footprint, and the blue water footprint. The green water footprint is the rainwater that is used in food production, and this is found to be 54,338 m^3 for the simulation time period. Blue water footprint is the amount of irrigated water utilized in food production, and this is found to be 14,350 m^3. Our value for the total water footprint used for food production is 68,688 m^3. Figure 8 illustrates the rainfall trend at each urban farm location through the year, and the amount of water used in the form of irrigation is illustrated in Figure 9.

The initial hypothesis is validated by the results of the food supply chain, where it was hypothesized that the food availability would be increased for purchasing consumers, and the food waste at urban farms would be reduced. Due to the nature of supply and demand, when the problem is optimized for minimum cost, in this case, distance, the previous five weeks of supply and demand are taken into account. This leads to a lagging effect, and thus food waste (excess supply) still exists in the long term, however it is reduced as illustrated previously in Figure 2. The proposed farms in this paper are in close vicinity of one another, with the shortest distance being 2 kilometers, and the longest being 12.4 kilometers.

Over the course of the simulation, the same three farms are suppliers (Farms 1, 5, and 7) and the remaining farms (Farms 2, 3, 4, and 6) are the demand farms. The quantity of food that is exchanged between supply and demand farms is consistently fluctuating throughout the summer period. The changing levels of food supply at each urban farm, due to food exchange occurring, is illustrated in Figure 10. We observe a difference in food supply at each urban farm when comparing the values in Figure 10, to the initial values previously displayed in Table 1. The total volume (kg) of food exchanged between urban farms for each week of the summer period are illustrated in Figure 11 with the specific amount from which supply farm to which demand farm in Figure 12. The first week sees a large amount of food exchanged, and this is based on the previous demand history of the previous season. The following week, the amount of food exchanged changes due to there being less excess food supply in the first week of the food supply chain case. Due to the model taking the average demand of food of the previous five weeks, this changes the demand in the following week. However, it is important to note that the food supply exchange is successful, as it leads to increased food availability for consumers as well as leading to decreased food waste.

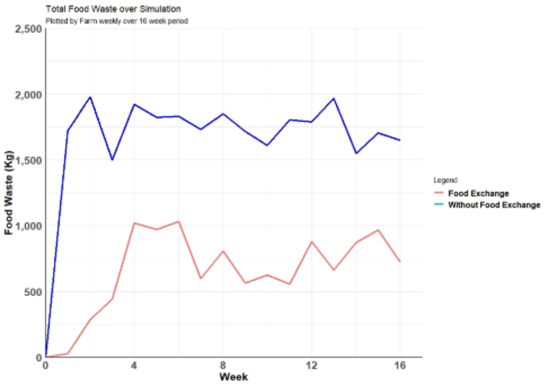

Figure 2. Food Waste (kg) of farms over summer period.

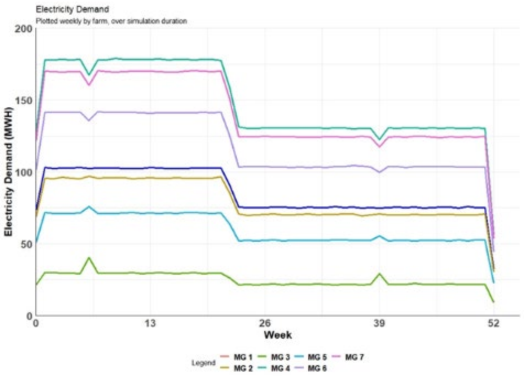

Figure 3. Weekly Electricity Demand (Mwh) of Microgrids over simulation period.

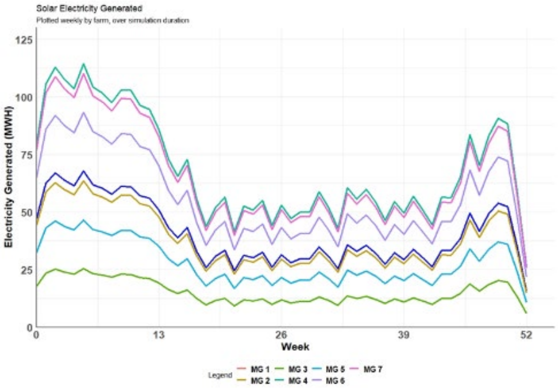

Figure 4. Weekly Solar Energy (Mwh) production at each Microgrid over simulation period.

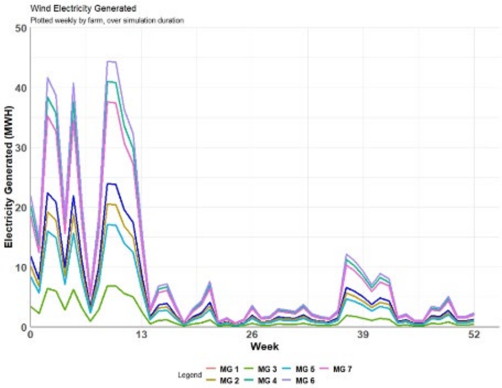

Figure 5. Weekly Wind Energy (Mwh) production at each Microgrid over simulation period.

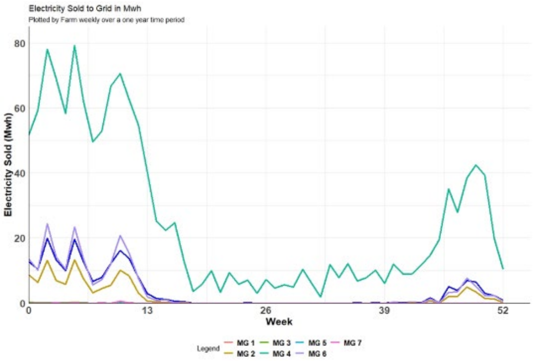

Figure 6. Weekly Electricity Sold (Mwh) at each Microgrid over simulation period.

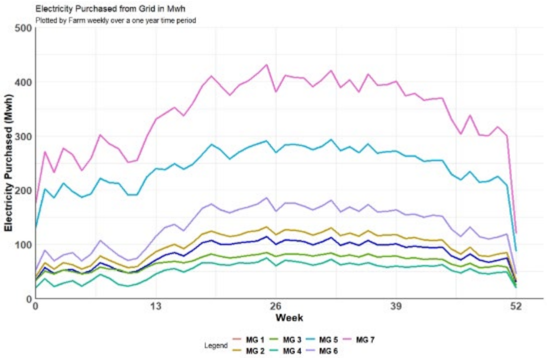

Figure 7. Weekly Electricity Purchased (Mwh) at each Microgrid over simulation period.

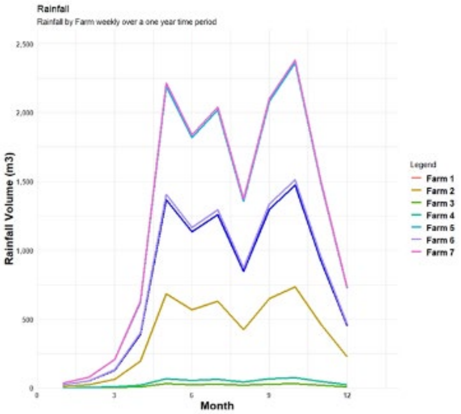

Figure 8. Monthly Rainfall (m^3) at each Farm location over simulation period.

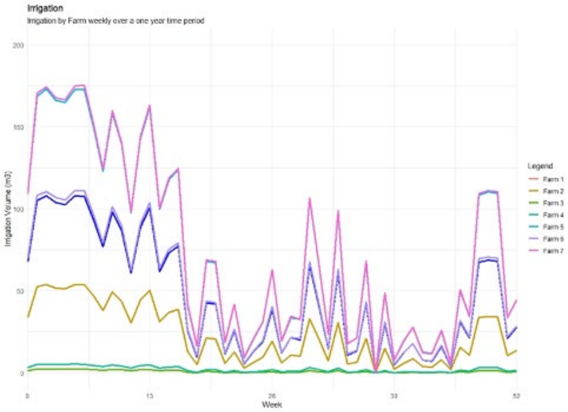

Figure 9. Weekly Irrigation (m^3) at each Farm location over simulation period.

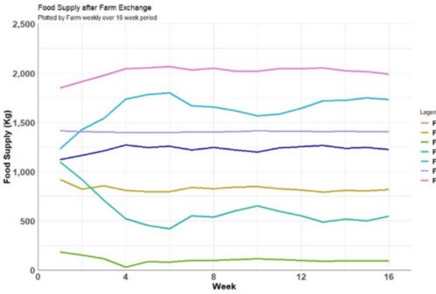

Figure 10. Food Supply (Kg) after Food Exchange between farms.

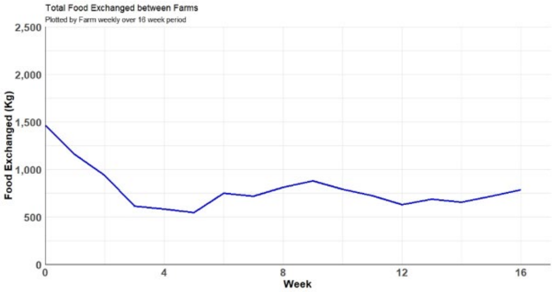

Figure 11. Food (Kg) Exchanged between Farms.

6. Conclusion

This study demonstrated the utilization of an agent-based model to simulate urban farms integrated with community microgrids for a case study in the province of Chiriqui in Panama. The developed model took into consideration, water, energy, and food resources, and once the simulation was complete, sustainability (social, economic, and environmental) was assessed.

The simulation centered on the assessment of food, energy, and water resources, along with the evaluation of social, economic, and environmental sustainability measures. In addition, a linear program was formulated to illustrate community shared agriculture, and urban farm collaboration in order to reduce food waste and increase food availability for households, and to minimize transportation costs. Consumers visited an urban farm during the summer harvest period spanning a duration of sixteen weeks, in order to buy fresh vegetables packaged in harvest boxes. The developed food supply chain was successful in increasing food availability and reducing food waste. The results are promising and can incentivize urban farms to collaborate with one another to better serve their local community, by increasing profits from food sales, and reducing food wastage, resulting in a higher return on investment. With regards to social sustainability, consumers were food secure in both scenarios due to their purchase of fresh vegetables from the urban farms.

In terms of economic sustainability, the community microgrids were beneficial as 16,560 Mwh of electricity was produced from solar energy and 2,333 Mwh from wind energy for a one-year time period. Finally, with regards to environmental sustainability, the proposed renewable energy systems led to 13,078 tonnes of CO_2 avoided, and this was based on Panama's electricity generation profile. The total water footprint was 68,688 m^3, with 14,350 m^3 from irrigation and 54,338 m^3 from rainwater. The implication of these results indicates that introducing renewable energy as a part of a microgrid system can aid countries in reaching renewable energy targets, and offsetting demand on country utility grids. In addition, the introduction of a food supply chain, and the incentivization for farms to collaborate, participating in farm-to-farm exchange was found to be beneficial as food availability was increased, and food waste was reduced.

The agricultural production of Panama has several items that include grains and fruits. Also, it has items such as coffee that are very sophisticated and of high quality worldwide. However, the agricultural sector has many problems that have affected it. For example, the appropriate techniques are often lacking, and sustainability and the use of renewable energy are at a basic level. Policymakers can introduce incentives for urban farms to produce renewable energy to help provide energy to the local area as well as contributing to reducing carbon emissions. In addition, the proposed framework in this paper can be utilized to educate the agricultural in employing more efficient methods at their farms. Furthermore, we know that most of the production is in the highlands of Chiriqui. Therefore, areas from the provinces of Veraguas, Herrera, or Los Santos could be the pilot plans for the ideas shown in this article. Another fundamental problem is logistics services despite having advanced ports such as Panama and Colon (on both sides of the Panama Canal). But the internal logistics is very underdeveloped, and that generates losses. Therefore, the models shown in this article can be used as a starting point for the high fragmentation of land not as a disadvantage but as an opportunity to create smarter and more sustainable farms in small urban communities.

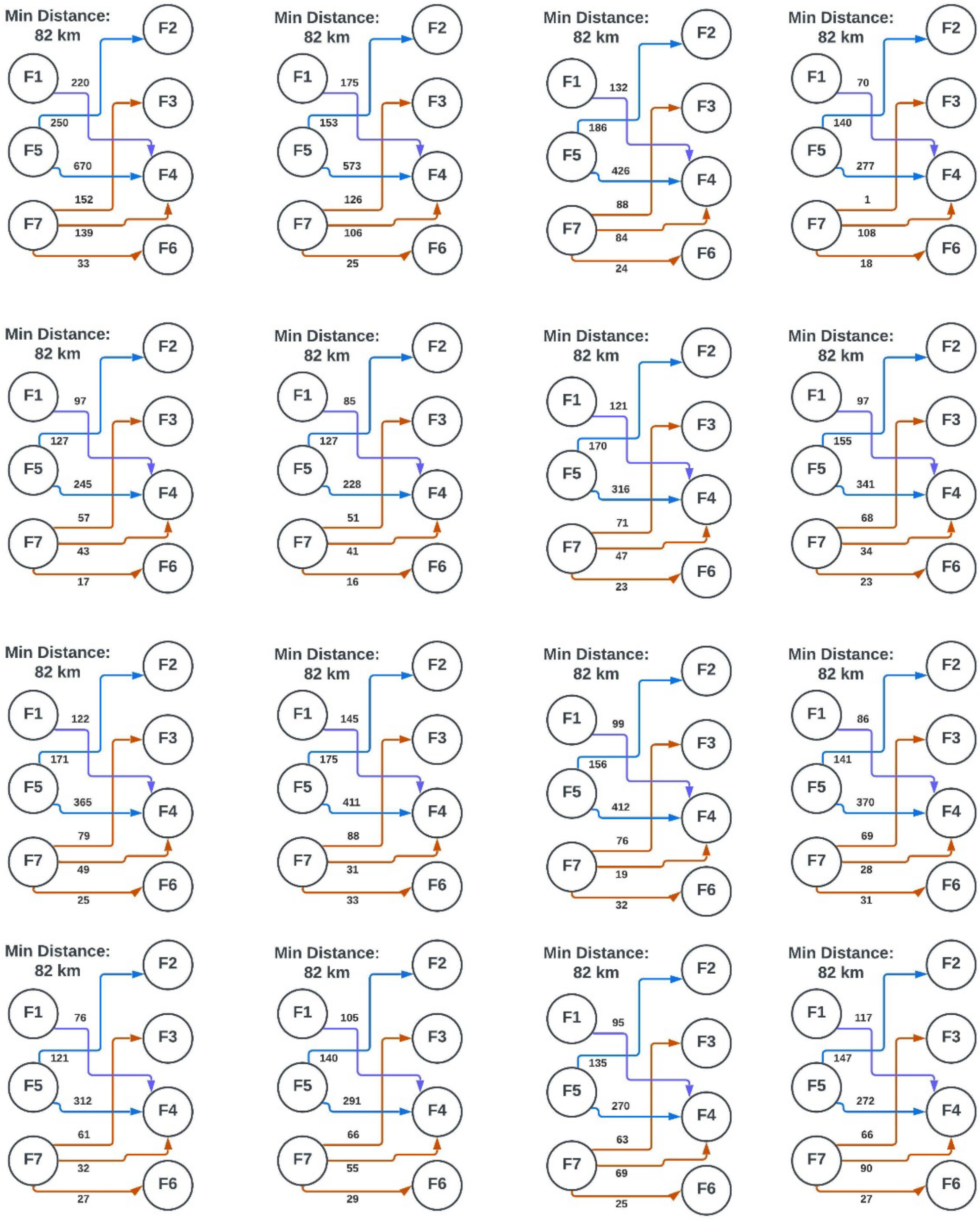

Figure 12. Food exchanged between farms visualizing the micro supply chain

References

Abar, S., Theodoropoulos, G. K., Lemarinier, P., and O'Hare, G. M. P. Agent Based Modelling and Simulation tools: A review of the state-of-art software. *Computer Science Review, 24*, 13-33, 2017.

Alam, M. M. Mango supply chain and value chain analysis from farm to market. *International Journal of Supply Chain Management, 7*, 7-12, 2018.

Calisti, R., Proietti, P., and Marchini, A. Promoting Sustainable Food Consumption: An Agent-Based Model About Outcomes of Small Shop Openings. *Journal of Artificial Societies and Social Simulation, 22*(1), 2, 2019.

Daignault, J., Wallace, C., Watkins, D., Handler, R., Yang, Y., Heaney, D., and Ahamed, S. A household-scale life cycle assessment model for understanding the food-energy-water nexus. *Frontiers in Environmental Science, 11*, 2023.

Elkamel, M., Rabelo, L., and Sarmiento, A. T. Agent-Based Simulation and Micro Supply Chain of the Food-Energy-Water Nexus for Collaborating Urban Farms and the Incorporation of a Community Microgrid Based on Renewable Energy. *Energies, 16*(6), 2614, 2023.

Elkamel, M., Valencia, A., Zhang, W., Zheng, Q. P., and Chang, N.-B. Multi-agent modeling for linking a green transportation system with an urban agriculture network in a food-energy-water nexus. *Sustainable Cities and Society, 89*, 104354, 2023.

Flörke, M., Schneider, C., and McDonald, R. I. Water competition between cities and agriculture driven by climate change and urban growth. *Nature Sustainability, 1*(1), 51-58, 2018.

Gerbens-Leenes, P. W., Hoekstra, A. Y., and van der Meer, T. The water footprint of energy from biomass: A quantitative assessment and consequences of an increasing share of bio-energy in energy supply. *Ecological Economics, 68*(4), 1052-1060, 2009.

Ghandar, A., Theodoropoulos, G., Zhong, M., Zhen, B., Chen, S., Gong, Y., and Ahmed, A. An Agent-Based Modelling Framework for Urban Agriculture. *In Proceedings of the 2019 Winter Simulation Conference (WSC),* pp. 1767-1778, National Harbor, MD, USA, December 8-11, 2019.

IEA. Panama - Countries & Regions, Available: https://www.iea.org/countries/panama, Accessed on March 21, 2022.

Kaufman, J., and Bailkey, M. Farming inside cities: entrepreneurial urban agriculture in the United States. *Lincoln Institute of Land Policy*, 2001.

Khanh, H. N., Chiong, R., Chica, M., and Middleton, R. H. Agent-based simulation of contract rice farming in the Mekong Delta, Vietnam. *In Proceedings of the 2017 21st Asia Pacific Symposium on Intelligent and Evolutionary Systems (IES),* pp. 127-132, Hanoi, Vietnam, November 15-17, 2017.

Krejci, C., and Beamon, B. Impacts of farmer coordination decisions on food supply chain structure. *Journal of Artificial Societies and Social Simulation*, 2015.

Markantonis, V., Reynaud, A., Karabulut, A., El Hajj, R., Altinbilek, D., Awad, I. M., and Bülent, S. Can the Implementation of the Water-Energy-Food Nexus Support Economic Growth in the Mediterranean Region? The Current Status and the Way Forward. *Frontiers in Environmental Science*, *7*, 2019.

Mittal, A., Gibson, N. O., and Krejci, C. C. An Agent-based Model of Surplus Food Rescue Using Crowd-shipping. *In Proceedings of the 2019 Winter Simulation Conference (WSC),* pp. 854-865, National Harbor, MD, USA, December 8-11, 2019.

Simpson, G. B., and Jewitt, G. P. W. The Development of the Water-Energy-Food Nexus as a Framework for Achieving Resource Security: A Review. *Frontiers in Environmental Science, 7*, 2019.

Spiegelberg, M., Baltazar, D. E., Sarigumba, M. P. E., Orencio, P. M., Hoshino, S., Hashimoto, S., and Endo, A. Unfolding livelihood aspects of the Water–Energy–Food Nexus in the Dampalit Watershed, Philippines. *Journal of Hydrology: Regional Studies, 11*, 53-68, 2017.

Utomo, D. S., Onggo, B. S., and Eldridge, S. Applications of agent-based modelling and simulation in the agri-food supply chains. *European Journal of Operational Research, 269*(3), 794-805, 2018.

Widener, M. J., Metcalf, S. S., and Bar-Yam, Y. Agent-based modeling of policies to improve urban food access for low-income populations. *Applied Geography, 40*, 1-10, 2013.

Zhang, X., and Vesselinov, V. V. Integrated modeling approach for optimal management of water, energy and food security nexus. *Advances in Water Resources, 101*, 1-10, 2017.

Biographies

Marwen Elkamel is a graduate student currently pursuing his PhD in the Department of Industrial Engineering & Management Systems at the University of Central Florida. He obtained a bachelor’s degree with distinction in Economics with a minor in Management Studies from the University of Waterloo, Ontario, Canada and a Master of Science degree in Management (Business Analytics track) from the University of Central Florida. Before starting his PhD, he worked as a data analyst for WeCare tlc. During his undergraduate studies, he served as a Research Assistant at the Waterloo Institute for Sustainable Energy (WISE). He was involved in two different projects that encompassed the acquisition and summary of data and preparation of computer programs to simulate processes and to make appropriate conclusions. During his PhD studies, he has been preparing machine learning models for electricity consumption with the consideration of socio-economic factors. He was also involved in a project that dealt with power resources scheduling and planning. He is currently focusing on modeling and optimizing the Urban Food-Energy-Water Nexus in order to find more efficient ways to supply water, energy and food and manage natural resources that can aid in sustainable energy development and improved water and food security. He is a member of IEOM, IFORMS, and the Institute of Industrial & Systems Engineering. He has published several journal and conference papers in the areas of modeling, simulation, optimization, and big data analytics.

Luis Rabelo is a Professor of Industrial Engineering & Management Systems at the University of Central Florida. He was the NASA EPSCoR Agency Project Manager (2009-2011). He received dual degrees in Electrical and Mechanical Engineering from the Technological University of Panama and Master’s degrees from the Florida Institute of Technology in Electrical Engineering (1987) and the University of Missouri-Rolla in Engineering Management (1988). He received a Ph.D. in Engineering Management from the University of Missouri-Rolla in 1990, where he also did Post-Doctoral work in Nuclear Engineering in 1990-1991. In addition, he holds a dual MS degree in Systems Engineering & Management from the Massachusetts Institute of Technology (MIT). He has over 300 publications, three international patents being utilized in the Aerospace Industry, and graduated 35 Master and 24 Doctoral students as advisor and co-advisor. He has consulted with NASA, NSF, ONR, NIST, Lockheed Martin Corporation, Boeing, Tyco, and others. His experience includes Ohio University, BF Goodrich Aerospace, Honeywell Laboratories, the National Institute of Standards and Technology, NASA, and MIT. He has received many awards among them ONE NASA in 2006, the Alumni of the Year of the Technological University of Panama in 2008, Fulbright Scholar in 2008, Two NASA Group Achievement Awards, the Emerald Literati Network Awards for Excellence 2007, the 2004 Arch T. Colwell Merit Award from the Society of Automotive Engineers (SAE), the 23rd Annual Hispanic Engineer National Achievement Awards Corporation (HENAAC) Education Award Winner in STEM in 2011, the Engineer Educator of the year 2011 by the US Engineer’s Council, and the 2013 International Joseph McFarland Award from SAE.