ANALYSIS OF SMART GARDENING TECHNOLOGY USAGE AND IMPLEMENTATION

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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AN EXAMINATION OF THE LACK OF INTERNATIONAL SMART GARDENING IMPLEMENTATION AND THE APPLICATION OF PRINCIPLES TO AN AUTONOMOUS PLANT NURSERY DEVICE

There has become a desire from people around to implement new agricultural methods in places such as the sub-Saharan country of Kenya, where climate change is expected to "continue to negatively affect crop production and food security to… already vulnerable communities," (Kogo et al., 2020, p. 23). The Organization for Economic Co-operation and Development (OECD) estimated for around 251 million people in least developed countries (LDCs) are severely food insecure due to factors such as the inability to meet domestic food demand due to a lack of mechanized farming equipment, reliance on international trade, changing circumstances of… agricultural exports, and other countries locally imposed export bans leading to shortages in growing materials (Vickers et al., 2022). A Least Developed Country (LDC) is a "low-income … [country] confronting severe structural impediments to sustainable development," and are "highly vulnerable to economic and environmental shocks," (United Nations, 2023). A method of cultivating plants and crops that has gained in both popularity and feasibility in recent years is the concept of "Smart Gardening", the purpose of which is to "minimize the scope of human involvement for irrigation, making it both labor-extensive and ecologically viable." (Muhtasim et al., 2019, p. 676). The concept of using Smart Gardening technology as a viable method of growing plants and food in developing nations of the world has so far has not seen widespread adoption for differing reasons. The vast majority of food production in these countries continue to be traditional manual home gardens that are "an integral part of local food systems and the agricultural landscape of developing countries all over the world," (Galhena et al., 2013, p. 1). In addition, the lack of a widespread extension system, which involves the knowledge and management of maintaining farms along with "integrated management of soil, nutrient, and water" may lead to "impacts are likely to be heterogeneous depending on agroclimates, soil quality, and farmers' abilities," (Takahashi et al., 2019, p.40). In developed nations, such as the United States of America, the number of commercially available plant watering sensors that actively measure the moisture content of the soil (functionality found in Smart Gardening devices) decreased due to loss in consumer demand, limited functionality of the device, the high number of devices needed to actively measure all desired climates, and high price point of the device given its functionality (Gebhart, 2018). Despite the overall perception that Smart Gardening is a sustainable and widely adopted alternative to traditional agricultural methods, it is clear from an implementation perspective that Smart Gardening has failed to capture an audience wider than niche groups that have already adopted the technology.

The technical topic pertains to the development of an autonomous plant nursery device that is able to define and save user-set settings for soil water content, soil nutrient content, and lighting times. The device determines if water and nutrients, such as soil nitrogen content, are less than the user-set preferences by analyzing complex impedances via capacitive soil moisture sensors placed in the soil. Electric motors pump the required materials until the user-specified threshold is met. LED plant grow lights illuminate the plots with the duration and time of day specified by the user. The front-facing LCD screen displays currently defined plot settings for two total plots, and pushbuttons for navigating the user interface. The two plots run independently, allowing for two different growth specifications to be specified at any time. The plant nursery will take care of plants automatically once the user sets their preferences, and the device will continue to operate until general maintenance is required by the user, such as refilling the containers that hold the water for the plots and replacing the lightbulbs that provide light to the plots.

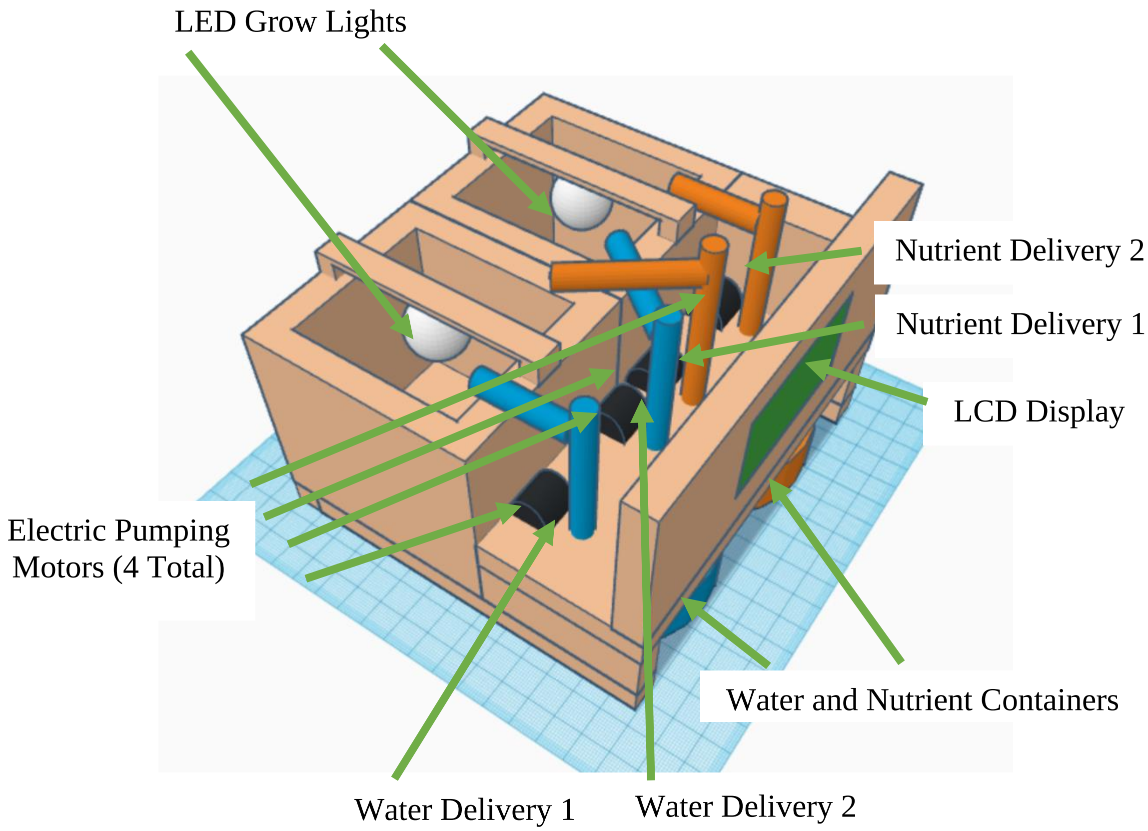

Figure 1: Virtual Proof-of-Concept Rendering of Autonomous Plant Nursery. This initial design presents the most critical components of the design as well as an initial chassis design which places the components near where the components will be in a finalized device (Buck 2022).

The STS research topic pertains to the analysis of Smart Gardening perceptions in both developed countries and developing countries. The differing expectations of Smart Gardening devices in developed and developing countries calls for an investigation into the various socioeconomic factors underlying the perceptions of the technology in both categories of countries. All Smart Gardening devices must provide the same basic functionality, in that the resultant device must be "a… garden that is controlled by [a] computer" (PCMAG, 2023). Developed and developing countries have not been analyzed in tandem such that the underlying desires for implementation, and the specific styles of implementation, are put into context with each other and compared for similarities and differences. By recognizing the desires and capabilities of prospective Smart Gardening implementation through the Social Construction of Technology frameworks by Bijker, Pinch, and Kline (1984), Smart Gardening will be able to evolve into a more robust field that can more readily supply different Smart Gardening implementations (Bijker & Pinch, 1984; Kline & Pinch, 1996).

The technical topic and tightly coupled STS research topic directly address the issues of plant growing in Smart Gardening and how similar solutions are perceived in different parts of the world. For the technical topic, my technical team and I constructed an “autonomous plant nursery” that allows for defining of various parameters relevant for growing plants, and takes care of the plants without actions needed from the user other than basic maintenance. The STS topic analyzes autonomous plant nursery implementations similar to those in the technical project around the world. In addition, the STS topic also analyzes the underlying socioeconomic factors that influence the implementation of Smart Gardening devices around the world. The question I hope to answer from my research of my STS topic is “How has the socioenvironmental factors in developed and developing countries affected the adoption and perception of Smart Gardening systems in those countries”?

IDENTIFICATION OF FACTORS INFLUENCING SMART GARDENING IMPLEMENTATION

BASIS OF SMART GARDENING TECHNOLOGY

Smart Gardening as a system works by feeding information, typically from a central hub, to small, low-power devices that actually perform desired tasks, with reports routinely given back to the central unit. This machine organization is further enhanced by the Internet of Things (IoT), which is described as “the network of physical objects—'things’—that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet,” (Oracle, 2023). Smart Gardening as an industry has benefitted from the proliferation of IoT technology, as evidenced by IoT’s applications in “multiple technologies, ranging from the Internet to wireless communication and from micro-electromechanical systems (MEMS) to embedded systems,” (Knight, 2021). IoT has benefitted Smart Gardening to become a more accessible and affordable paradigm, as evidenced by the Smart Gardening implementations reviewed by Dlnya Abdulahad Aziz and his colleagues that “allows the data collected by sensors to be saved in the cloud and may be accessed by the farmer via… smartphone or computer. The exact values… are noticed by the farmer, and irrigation runs automatically at the agricultural fields without human participation,” (Aziz et al., 2019, p. 102).

Factors That Affect Gardening and Smart Gardening

In order to understand the factors that affect Smart Gardening implementations, it is worthwhile to discuss the experiences involved with growing plants without the use of automated methods employed in Smart Gardening. The Encyclopedia Britannica considers the act of gardening as “derived from plant physiology, chemistry, and botany, modified by the experience of the planter,” (Encyclopedia Britannica, 2023). Given that the success of gardening as an activity depends on the experience of the planter, the maintenance of the plants in a garden should be a priority of the planter if the person wishes to see their garden succeed. When a plant or garden is successfully, there are several health-related benefits that can result from personally growing plants in a localized environment. In an analysis of the benefits of growing plants, the most significant were an “improvement in air quality, a reduction in stress, an improved sense of well-being, and support of cognitive health,” (“Health Benefits of Indoor Plants”, 2022). According to Hayes (2022), growing plants successfully can create increased exposure to Vitamin D, decreased risk of developing dementia, and mood-boosting benefits including a reduction in recorded stress levels (Hayes, 2022). Despite this responsibility assumed by obtaining plants, many individuals do not have good experiences involving the maintenance of plants. In one survey conducted by the researchers Narishkin and Tejapaibul, around 40% of houseplants that are grown for consumers die in the supply chain process, while another 30% of houseplants die inside the homes of customers (Narishkin & Tejapaibul, 2022). In another survey, researchers found that among 2,000 millennials aged between 25 and 39, the most anxiety-inducing features of growing houseplants include ensuring the plant received enough sunlight (60%), received enough water (56%), and ensuring the plant stays alive (48%) ("Survey: Decorating with houseplants", 2020). These studies into plant care and maintenance suggest the skills involved with traditional gardening methods are well known, but the caretaker of said plants falls short in terms of fulfilling duties associated with the successful growth of plants, whereas Smart Gardening automates this process such that successful plant growth is possible.

ANALYSIS OF SMART GARDENING IMPLEMENTATION IN DEVELOPING AND DEVLEOPED NATIONS THROUGH SOCIAL CONSTRUCTION OF TECHNOLOGY

The discussion of Smart Gardening implementation in the developed and developing world can be described as following the "Diffusion of Innovation" social paradigm. The paradigm was postulated, defined, and refined by sociologist Everett Rogers (1962) and defined the "main dependent variable was *innovativeness*, defined as the degree to which an individual or other unit is relatively earlier to adopt than are others," (Rogers, 1962). In the case of Smart Gardening technology, this would be defined as the ease of which current iterations of the technology are to adopt as compared to previous generations of devices. Individual factors that influence whether someone considers, and eventually adopts, a specific innovation or technology include training, managerial support, incentive, perceived usefulness, personal innovativeness, image, prior experience, enjoyment with innovation, peers and social network variables (Taluker, 2012). In the analysis of their Smart Gardening implementation, C.G. Raji and his colleagues (2022) noted that "with the improvement of sensor innovation, the framework will turn into more effective and helpful," (Raji et al., 2022, p. 116). In addition, in their overview analysis of Smart Gardening automation in general, Samuel Olawepo and his colleagues (2020) found that innovations outside the Smart Gardening paradigm such as the Internet of Things (IoT) has allowed for innovations such as "drones…for imaging for real-time monitoring of crop health and soil conditions over a long range," (Olawepo, 2022). As evidenced by these papers, the field of Smart Gardening has generated enough interest to spur innovations in fields such as IoT that directly affect Smart Gardening such that the cost of implementing the technology would be decreased by such improvements, thereby embodying the first main tenet of the "Diffusion of Innovation" paradigm.

The second main point of the "Diffusion of Innovation" paradigm expands upon the continuous variable of innovativeness and defines different stages of a technology's adoption process, specifically that "the continuous variable of innovativeness is often divided into adopter categories, such as innovators, early adopters, early majority, late majority, and laggards," (Rogers, 1983). Figure 2 shows the "Diffusion S-Curve" that shows the rate at which an innovation is adopted relative to the amount of people who have adopted the technology. The most crucial step towards a technology's successful adoption is the transition of just early adopters using the technology to an early majority of people who use the technology, as evidenced, for example, by a Pew Research Study that found "28% of Americans are 'strong' early adopters of technology" but "52% of adults say they "feel more comfortable using familiar brands and products," (Kennedy & Funk, 2020). In locations where Smart Gardening technology has not been widely adopted, research into the adoption process of Smart Gardening found that "opinion leaders' influence on the rate of adoption" should be the top priority of researchers of the technology, and that "the rate of adoption and subsequent diffusion is maximized by inclusion communications with opinion leaders and utilizing their trust within the community" to increase adoption of Smart Gardening with IoT technology (Strong et al., 2022). It seems there is a gap between innovators and early adopters and people who inclusion of Smart Gardening technology would make them the early majority users of the technology in that the features of Smart Gardening are not clearly presented to this hesitant group; the remainder of this paper will seek to resolve this shortcoming.

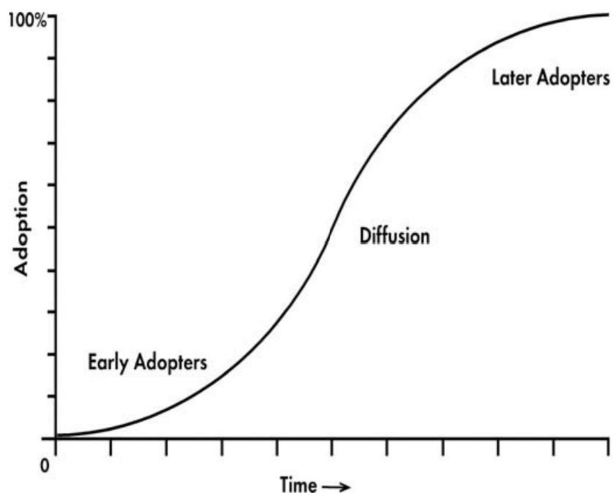

Figure 2: Diffusion of Innovation S-Curve. This graph shows the rate at which an innovation is adopted against the amount of people who have adopted the innovation. (Rogers, 1995).

The essential method by which omnipresent socioeconomic factors affecting the perception and adoption of implementations of Smart Gardening systems can be understood is through the analysis of the interactions between engineers who design and develop Smart Gardening implementations and groups of people who interact with the technology. The Social Construction of Technology, or SCOT, framework first proposed by Wiebe Bijker and Trevor Pinch in 1984 and later updated by Pinch and Ronald Kline allows for the visualization of the various expectations, desires, and goals of Smart Gardening technology by relevant social groups, and the engineer can offer an implementation to satisfy the group's needs. In this framework, relevant groups in relation to a particular technology, in this case Smart Gardening, provide unique perspectives that inform an engineer's activities and the particular characteristics of the technology. At the same time, the engineer develops and provides the technology that reflects the values, concerns, and interests of each group specified by the various group in exchange for their input (Bijker & Pinch, 1984; Kline & Pinch, 1996). The interactions between the engineer and various social groups within the SCOT model allows for flexibility of interpretation between groups (Johnson, 2005, p.1791). As shown in Figure 3, there are several social groups that are affected by Smart Gardening technology, but the social groups that affect implementation of Smart Gardening regardless of the location it is implemented are researchers, since these people perform research into which implementations work better than others, gardening experts since their credibility of horticultural expertise lends credence to the validity of the technology, and ordinary users since the adoption of Smart Gardening en masse by this social group would allow for the faster diffusion of the technology. These groups, in the context of the "Diffusion of Innovation" paradigm, can be designated as the innovators, early adopters, and early majority groups, respectively. The remainder of this paper will investigate the socioeconomic factors taken into account by each group in both developed and developing country contexts, and from this analysis determine how these factors affected the adoption and perception of Smart Gardening systems.

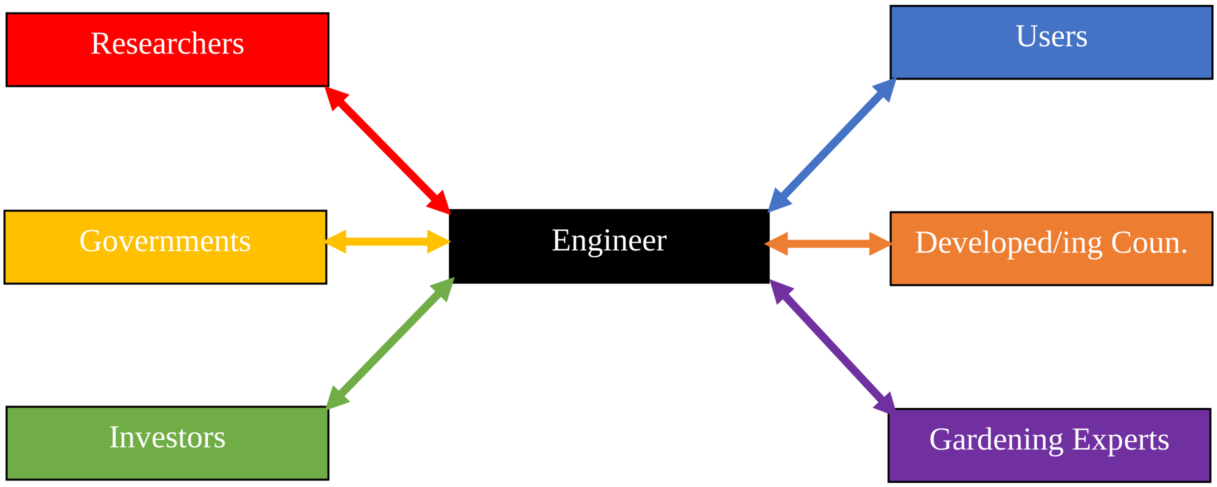

Figure 3: Smart Gardening Implementation SCOT Model. The engineer and relevant social groups negotiate in order for the finalized technology to represent each group's values, concerns, and interests. (Adapted by Buck (2022) from Carlson, 2009).

EXAMINING RELATIONSHIPS IN SMART GARDENING

Examining the Researcher Relationship in Smart Gardening

The first relationship between the engineers of Smart Gardening technology by which the socioeconomic factors affecting Smart Gardening implementation is investigated is the researcher group, who are considered the "innovators" of Smart Gardening with regards to the diffusion of innovation paradigm. The relationship between engineers and innovators with regards to Smart Gardening is such that either engineers design implementations that are tested by innovators or the researchers act as both engineer and innovator by both developing and testing different Smart Gardening implementations. Since these innovators are testing Smart Technology in different countries, these innovators use their position to take into account the socioeconomic situation where testing is performed in order to ensure the design is viable for usage by local populations in terms of understanding how to use the technology. In Malaysia, Izanoordina Ahmad and their colleagues designed their Smart Gardening implementation to utilize the Internet of Things (IoT) to "educate the farmer on the usage of integrated technology system to monitor and control the operations for smart farming" (Ahmad et al., 2021, p. 127). In addition to taking account the social factors present with potential implementation populations, innovators also take into account the economic factors of people who are or could be future users of the technology. In proposing a smart gardening implementation consisting of a "smart green house, IoT device, Block [chain] creation, cloud storage, and end user [interface]", T.S. RajaRajeswari and their colleagues found their tested device saved "time and cost" that in the future can be applied to "individual home[s] and… educational system[s]," (RajaRajeswari et al., 2022). While taking into account the local factors that influence Smart Gardening implementations, researchers in the innovator role also develop solutions that can be implemented without significant changes to implementation design, which would reduce the cost of implementation due to scalability. Conducting a survey to analyze the contributions IoT and Smart Gardening systems to agricultural, Setaji, Budiyato, and Yuana use reasons for using IoT in implementations, the scale of adoption, and the costs and benefits of IoT adoption to build a Smart Gardening system that if implemented would "beneficial for farmers…, [and] help advance crop harvests and global [agriculture] production," (Setaji et al., 2021, p. 5). It is apparent that researchers of Smart Gardening technologies actively pursue the role of innovators in the diffusion of innovation paradigm by building and testing implementations feasible in the areas where tested.

Examining Gardening Experts Involved in Smart Gardening

The second group between the engineers of Smart Gardening technology by which the socioeconomic factors affecting Smart Gardening implementation is investigated is the gardening expert group, who are considered the "early adopters" of Smart Gardening. With regards to the diffusion of innovation paradigm, people who are considered "early adopters" are those who “tend to buy and try out new software or hardware… sooner than many of their peers,” (Awati, 2023). In any particular market space, early adopters are influential in the adoption of a particular technology and tend to “have a degree of ‘thought leadership’ for other potential adopters,” (Interactive Design Foundation, 2023). Given the influence early adopters have on the adoption of a technology, there are methods by which early adopters can utilize their influence to change the diffusion rate of a technology. The first method by which early adopters utilize their influence is by testing and reviewing an implementation of a technology to determine their personal enthusiasm of the technology, thereby affecting how the technology is perceived. With regards to Smart Gardening technology, reviews have been performed that inspect various aspects of implementations such as price and comparison with traditional gardening. In his review of the Rise Gardens Smart Garden device, urban gardener and educator Timothy Hammond found the device “grows leafy greens well and simple to use” but also had limitations, such as “lack of customization, difficulty to clean and empty the water reservoir, and high price compared to the cost of growing plants naturally,” (Hammond & WSJ, 2021, 5:46). This review highlights how the advantages of Smart Gardening such as ease of implementation can be dampened by aspects such as price that can make a technology less feasible for people, thus reducing the overall diffusion of the technology. The second method by which early adopters can affect the diffusion of a technology is by determining the behaviors of people who could adopt the technology in order to appeal to those behaviors. In a study of effects of societal transition to urban gardening methods, which includes Smart Gardening, Bastian Winkler and his colleagues found that greater implementations of these systems would “create social communities and promote mutual learning by connecting people with diverse cultural identities, viewpoints, backgrounds and lifestyles,” (Winkler et al., 2019, p. 819). By demonstrating the positive social benefits from implementing Smart Gardening implementations, people who have yet to adopt the technology may feel compelled to do so given the scientifically verified benefits who are experts in the field. Early adopters have a significant and self-aware role in the diffusion of Smart Gardening technology, and use their influence to highlight their opinion of implementations and give people a more personal source by which to determine the personal feasibility of implementing Smart Gardening technology.

Examining Ordinary Users Involved in Smart Gardening

The third group between the engineers of Smart Gardening technology by which the socioeconomic factors affecting Smart Gardening implementation is investigated is the ordinary users group, who are considered the "early majority" of Smart Gardening. In relation to the diffusion of innovation paradigm, ordinary users are considered an early majority as their adoption of a particular technology allows that technology to pivot from a niche technology only analyzed by innovators and early adopters to a widely accepted and diffused technology (Rogers, 1983). With regards to Smart Gardening, the lack of diffusion of the technology suggests an early majority involving users who are not innovators or early adopters has not been achieved. In a study of the business models used to convince Smart Gardening and Climate-Smart Agriculture (CSA) adoption, Thomas Long and his colleagues found that business models for CSA technological innovations (BMfCSATI) are "not optimised for diffusing CSA technological innovations," (Long et al., 2016). Business models for promoting technology are important for the diffusion, and this study suggests there is a disconnect between how Smart Gardening and similar methods are being promoted and how these technologies are viewed by ordinary users. Perhaps more than critical than the way Smart Gardening is promoted, the factors underlying the lack of adoption, particularly with regards to the economic situations of ordinary users, in critical in understanding rate of ordinary users. In a study that analyzed the impact of "food deserts", or "geographic area[s] that lacks sufficient access to grocery stores, especially in low-income communities", Allison Karpyn and her colleagues found that these areas create a multitude of economic impacts, including "lost wages, reductions in the local tax base and lost potential for food retail to serve as an anchor institution for other retail development," (Shaw, 2006; Karpyn et al., 2019). From this study, it is clear that Smart Gardening technology has a clear opportunity to be adopted and used by ordinary users, but in order for this group of people to form the "early majority" of Smart Gardening diffusion, the socioeconomic factors of potential users must be taken into account in order for widespread adoption to occur.

SOCIOECONOMIC FACTORS INFLUENCE SMART GARDENING IMPLEMENTATION THROUGH DIFFUSION OF INNOVATION

By analyzing the relationships between engineers and researchers, gardening experts, and ordinary users of Smart Gardening technology reveals a common theme of socioeconomic factors being the primary motivating force towards the adoption of particular Smart Gardening implementations, regardless of whether the country where implementation is being considered is a developed or developing country. Researchers assess these factors when testing smart gardening implementations for affordability and feasibility, gardening experts assess these factors when comparing Smart Gardening implementations to traditional growing methods, and ordinary users assess these factors when determining if Smart Gardening applications are feasible given their circumstances both socially and economically. In discussing the diffusion of innovation paradigm, Rogers highlights the importance of identifying the steps at which a particular technology diffuses throughout society (2003). He identifies three key steps within the diffusion process: a) the "innovation-decision process", the mental process through which an individual passes from first knowledge of a new idea, to adoption and confirmation of the innovation, b) “innovativeness”, the degree to which an individual is relatively earlier in adopting new ideas than other members of a system, and c) an innovation’s “rate of adoption”, the relative speed with which an innovation is adopted by members of a system (Rogers, 2003). This paper examines all three steps of the diffusion process laid out by Rogers with regards to Smart Gardening technology. The diffusion innovation model asserts that aspects of plant growing such as market access, access to information communication, and social networks have about the same impact with regards to innovations in Smart Gardening and smart plant growing as aspects such as crop rotation and compost (Teklu et al., 2023, p.12). By analyzing the implementation of Smart Gardening through the diffusion of innovation paradigm, in order for Smart Gardening to become widely adopted, engineers must implement different versions of the technology depending on the location of implementation analyzed at a more local level, with the developed and developing country distinction one of many factors taken into account, and the socioeconomic factors that affect the location in question. Performing this more local approach to implementation will allow people to move through the innovation-decision process at a faster rate, thus improving increasing Smart Gardening’s rate of adoption towards a highly diffused and accepted technology.

FUTURE IMPLICATIONS OF STUDYING SMART GARDENING IMPLEMENTATIONS

Smart Gardening Technology can be considered to be a technological space, rather than a single technology that can have different implementations and capabilities depending on factors such as geography, cost, and willingness of the people who want to adopt the technology. In the Social Construction of Technology model, various individual people, groups of people, and bureaucratic structures have nearly identical contributions to the Smart Gardening paradigm by influencing what features are implemented in various designs and the scale of distribution of said implementations. Thus, from the SCOT perspective, the Smart Gardening technological paradigm fulfills the expectations of a viable plant growing alternative to standard agriculture by taking in various perspectives about the technology, and creating specialized designs that take said perspectives into account.

For future studies on Smart Gardening technology implementation, the detection of this characteristic will prove to be helpful for analysis. The United States of America is one potential country that could be analyzed for implementation factors in a future work, as it is a developed nation with many Smart Gardening implementations available, commercially or otherwise, but has yet to find widespread appeal from the general public. India, a developing country, is another potential country that could be analyzed in this future work, as many scientific papers outlining different implementations of Smart Gardening technology have been published in response to localized environmental factors, such as the annual monsoon season and struggles with current agricultural methods.

The second potential of research with regards to understanding the rate of Smart Gardening implementation is the comparison between the adoption of Smart Gardening and other smart technologies. Some fields of smart technology, such as smartphones and smart home devices, have achieved widespread social adaptation and commercial success, therefore these technologies, as examined from the Social Construction of Technology perspective, have “stabilized” as the majority of relevant social groups in the technologies’ development have agreed upon the expectations of the technologies, and the capabilities of these technologies are known given the stabilization process. In contrast, other examples of fields of smart devices, such as Smart Gardening, continue to have niche communities of adoption, and have so far been unable to achieve widespread expectation and acceptance from the public. This should be investigated, as the successful smart technologies had to undergo the same process of adoption under the "Diffusion of Innovation" paradigm as Smart Gardening and analyzing the "adoption" process could be helpful, in addition to the findings of this paper, in determining what factor or number of factors allow for a smart technology to gain widespread appeal and thus profile rate throughout society through the process of adoption.

REFERENCES

Article.com. (2022). *Survey: Decorating with houseplants*. Articulate. Retrieved from https://www.article.com/blog/survey-decorating-with-houseplants/

Ahmad, I., Shariffudin, S. E., Ramli, A. F., Maharum, S. M., Mansor, Z., & Kadir, K. A. (2021). Intelligent Plant Monitoring System via IOT and Fuzzy System. *2021 IEEE 7th International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA)*, 123–127. https://doi.org/10.1109/icsima50015.2021.9526312

Awati, R. (2023, March 10). *What is an early adopter? – TechTarget definition*. IT Operations. Retrieved from https://www.techtarget.com/searchitoperations/definition/early-adopter#:~:text=An%20early%20adopter%20is%20a,than%20many%20of%20their%20peers.

Aziz, D. A., Asgarnezhad, R., & Mahmood, S. N. (2021). The recent advances in IOT based Smart Plant Irrigation Systems: A brief review. *2021 5th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, 97–104. https://doi.org/10.1109/ismsit52890.2021.9604699

Buck, R. (2022). Virtual Proof-of-Concept Rendering of Autonomous Plant Nursery. [Figure 3]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Buck, R. (2022). Smart Gardening Implementation SCOT Model. [Figure 4]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Encyclopædia Britannica, inc. (2023). *Gardening*. Encyclopædia Britannica. Retrieved from https://www.britannica.com/science/gardening

Galhena, D. H., Freed, R., & Maredia, K. M. (2013). Home gardens: A promising approach to enhance household food security and Wellbeing. *Agriculture & Food Security*, *2*(1). https://doi.org/10.1186/2048-7010-2-8

Gebhart, A. (2018, March 23). *Is the smart garden growing or wilting?* CNET. Retrieved from https://www.cnet.com/home/smart-home/is-the-smart-garden-growing-or-wilting/

Hammond, T & WSJ. (2021, June 14). *Can an Indoor Smart Garden Beat Outdoor Gardening? We Tested It | WSJ* [Video]. Youtube. https://www.youtube.com/watch?v=ANLKNoZ_b4c&ab_channel=WallStreetJournal

Hayes, K. (2022, August 9). *5 health benefits of gardening and planting*. AARP. Retrieved from https://www.aarp.org/health/healthy-living/info-2017/health-benefits-of-gardening-fd.html

Interaction Design Foundation. (2023). *Understanding early adopters and customer adoption patterns*. The Interaction Design Foundation. Retrieved from https://www.interaction-design.org/literature/article/understanding-early-adopters-and-customer-adoption-patterns

Johnson, D. G. (2005). Social construction of technology. In C. Mitchem (Ed.), *Encyclopedia of Science, Technology, and Ethics* (pp. 1791-1794). Farmington Hills, MI.: Thomson Gale.

Karpyn, A., Young, C., & Weiss, S. (2019). Reestablishing Healthy Food Retail: Changing the landscape of food deserts. *Childhood Obesity*, *8*(1), 28–30. https://doi.org/10.1089/chi.2011.0113

Kennedy, B., & Funk, C. (2020, May 30). *28% of Americans are 'strong' early adopters of Technology*. Pew Research Center. https://www.pewresearch.org/fact-tank/2016/07/12/28-of-americans-are-strong-early-adopters-of-technology/

Kline, R., & Pinch, T. (1996). Users as agents of technological change: The Social Construction of the automobile in the rural United States. *Technology and Culture*, *37*(4), 763–795. https://doi.org/10.2307/3107097

Knight, M. (2021, March 12). *What is the internet of things (IOT)?* DATAVERSITY. Retrieved from https://www.dataversity.net/internet-things-iot/

Kogo, B. K., Kumar, L., & Koech, R. (2020). Climate change and variability in Kenya: A review of impacts on agriculture and food security. *Environment, Development and Sustainability*, *23*(1), 23–43. https://doi.org/10.1007/s10668-020-00589-1

Long, T. B., Blok, V., & Poldner, K. (2016). Business models for maximising the diffusion of technological innovations for climate-smart agriculture. *International Food and Agribusiness Management Review*, *20*(1), 5–23. https://doi.org/10.22434/ifamr2016.0081

Martin, M., & Schinzinger, R. (2009). Engineering as Social Experimentation. In Introduction to Engineering Ethics (2nd ed.) McGraw-Hill Higher Education

Muhtasim, M. A., Ramisa Fariha, S., & Ornab, A. M. (2018). Smart Garden Automated and real time plant watering and lighting system with security features. *2018 International Conference on Computing, Power and Communication Technologies (GUCON)*, 676–679. https://doi.org/10.1109/gucon.2018.8675077

Narishkin, A. (2022, March 8). *Americans kill nearly half their houseplants. so why do we still spend billions on them each year?* Business Insider. https://www.businessinsider.com/houseplant-industry-americans-billions-die-2022-3

Olawepo, S., Adebiyi, A., Adebiyi, M., & Okesola, O. (2020). An overview of Smart Garden Automation. *2020 International Conference in Mathematics, Computer Engineering and Computer Science (ICMCECS)*. https://doi.org/10.1109/icmcecs47690.2020.240892

Oracle. (2023). *What is the internet of things (IOT)?* What Is the Internet of Things (IoT)? Retrieved from https://www.oracle.com/internet-of-things/what-is-iot/

Piedmont Healthcare. (2022). *Health benefits of indoor plants*. Piedmont Healthcare. Retrieved from https://www.piedmont.org/living-better/health-benefits-of-indoor-plants

Pinch, T. J., & Bijker, W. E. (1984). The social construction of facts and artefacts: Or how the sociology of science and the Sociology of Technology might benefit each other. *Social Studies of Science*, *14*(3), 399–441. https://doi.org/10.1177/030631284014003004

RajaRajeswari, T. S., Chinnasamy, P., Pushparani, K., Thulasichitra, N., Rani, N. S., & Sivaprakasam, T. (2022). IOT based smart gardening for smart cities using Blockchain technology. *2022 International Conference on Computer Communication and Informatics (ICCCI)*. https://doi.org/10.1109/iccci54379.2022.9741024

Raji, C. G., Swalih, T., Nidha, F., Afrooz Shahana., T., & Muhammed Anas, k. (2022). Smart gardening and plant disease detection using internet of things. *2022 6th International Conference on Devices, Circuits and Systems (ICDCS)*, 112–116. https://doi.org/10.1109/icdcs54290.2022.9780838

Rogers, E. M. (1962). Diffusion of innovations (1st ed.). New York: Free Press.

Rogers, E. M. (1983). Diffusion of innovations (3rd ed.). New York: Free Press.

Rogers, E. M. (1995). Diffusion of innovations (4th ed.). New York: Free Press.

Rogers, E. M. (2003). Diffusion of innovations (5th ed.). New York: Free Press.

Setiaji, T., Budiyanto, C., & Yuana, R. A. (2021). The contribution of the internet of things and Smart Systems to agricultural practices: A survey. *IOP Conference Series: Materials Science and Engineering*, *1098*(5), 1–5. https://doi.org/10.1088/1757-899x/1098/5/052100

Shaw, H. J. (2006). Food deserts: Towards the development of a classification. *Geografiska Annaler: Series B, Human Geography*, *88*(2), 231–247. https://doi.org/10.1111/j.0435-3684.2006.00217.x

Strong, R., Wynn, J. T., Lindner, J. R., & Palmer, K. (2022). Evaluating Brazilian Agriculturalists' IOT smart agriculture adoption barriers: Understanding stakeholder salience prior to launching an innovation. *Sensors*, *22*(18). https://doi.org/10.3390/s22186833

Takahashi, K., Muraoka, R., & Otsuka, K. (2019). Technology adoption, impact, and extension in developing countries' agriculture: A review of the recent literature. *Agricultural Economics*, *51*(1), 31–45. https://doi.org/10.1111/agec.12539

Talukder, M. (2012). Factors affecting the adoption of technological innovation by individual employees: An Australian study. *Procedia - Social and Behavioral Sciences*, *40*, 52–57. https://doi.org/10.1016/j.sbspro.2012.03.160

Teklu, A., Simane, B., & Bezabih, M. (2023). Multiple adoption of climate-smart agriculture innovation for agricultural sustainability: Empirical evidence from the Upper Blue Nile Highlands of Ethiopia. *Climate Risk Management*, *39*, 1–15. https://doi.org/10.1016/j.crm.2023.100477

United Nations. (2023). *Least developed countries (ldcs) | Department of Economic and Social Affairs*. United Nations. Retrieved from https://www.un.org/development/desa/dpad/least-developed-country-category.html

Vickers, B., Ali, S., & Balchin, N. (2022, July 5). *The expanding threat to food security in least developed countries*. Development Matters. https://oecd-development-matters.org/2022/07/05/the-expanding-threat-to-food-security-in-least-developed-countries/

Winkler, B., Maier, A., & Lewandowski, I. (2019). Urban Gardening in Germany: Cultivating a sustainable lifestyle for the societal transition to a Bioeconomy. *Sustainability*, *11*(3), 801–822. https://doi.org/10.3390/su11030801

BIBLIOGRAPHY

Article.com. (2022). *Survey: Decorating with houseplants*. Articulate. Retrieved from https://www.article.com/blog/survey-decorating-with-houseplants/

Ahmad, I., Shariffudin, S. E., Ramli, A. F., Maharum, S. M., Mansor, Z., & Kadir, K. A. (2021). Intelligent Plant Monitoring System via IOT and Fuzzy System. *2021 IEEE 7th International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA)*, 123–127. https://doi.org/10.1109/icsima50015.2021.9526312

Awati, R. (2023, March 10). *What is an early adopter? – TechTarget definition*. IT Operations. Retrieved from https://www.techtarget.com/searchitoperations/definition/early-adopter#:~:text=An%20early%20adopter%20is%20a,than%20many%20of%20their%20peers.

Aziz, D. A., Asgarnezhad, R., & Mahmood, S. N. (2021). The recent advances in IOT based Smart Plant Irrigation Systems: A brief review. *2021 5th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, 97–104. https://doi.org/10.1109/ismsit52890.2021.9604699

Buck, R. (2022). Smart Gardening Implementation SCOT Model. [Figure 2]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Buck, R. (2022). Virtual Proof-of-Concept Rendering of Autonomous Plant Nursery. [Figure 1]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Dussarrat, T., Prigent, S., Latorre, C., Bernillon, S., Flandin, A., Díaz, F. P., Cassan, C., Van Delft, P., Jacob, D., Varala, K., Joubes, J., Gibon, Y., Rolin, D., Gutiérrez, R. A., & Pétriacq, P. (2022). Predictive metabolomics of multiple Atacama plant species unveils a core set of generic metabolites for extreme climate resilience. *New Phytologist*, *234*(5), 1614–1628. https://doi.org/10.1111/nph.18095

Encyclopædia Britannica, inc. (2023). *Gardening*. Encyclopædia Britannica. Retrieved from https://www.britannica.com/science/gardening

Findji, O. B., & Howland, F. (2019, January 21). *What are the socioeconomic factors that influence CSA adoption?* CCAFS. Retrieved from https://ccafs.cgiar.org/news/what-are-socioeconomic-factors-influence-csa-adoption

Galhena, D. H., Freed, R., & Maredia, K. M. (2013). Home gardens: A promising approach to enhance household food security and Wellbeing. *Agriculture & Food Security*, *2*(1). https://doi.org/10.1186/2048-7010-2-8

Gebhart, A. (2018, March 23). *Is the smart garden growing or wilting?* CNET. Retrieved from https://www.cnet.com/home/smart-home/is-the-smart-garden-growing-or-wilting/

Global smart indoor garden systems market (2020 to 2027) - by type, technology, end-user and region. Business Wire. (2021, March 25). Retrieved from https://www.businesswire.com/news/home/20210325005519/en/Global-Smart-Indoor-Garden-Systems-Market-2020-to-2027---by-Type-Technology-End-user-and-Region---ResearchAndMarkets.com

Grand View Research. (n.d.). *Smart home market share & size analysis report, 2022 - 2030*. Smart Home Market Share & Size Analysis Report, 2022 - 2030. Retrieved from https://www.grandviewresearch.com/industry-analysis/smart-homes-industry?utm_source=prnewswire&utm_medium=referral&utm_campaign=ict_14-june-22&utm_term=smart-homes-industry&utm_content=rd

Hammond, T & WSJ. (2021, June 14). *Can an Indoor Smart Garden Beat Outdoor Gardening? We Tested It | WSJ* [Video]. Youtube. https://www.youtube.com/watch?v=ANLKNoZ_b4c&ab_channel=WallStreetJournal

Hayes, K. (2022, August 9). *5 health benefits of gardening and planting*. AARP. Retrieved from https://www.aarp.org/health/healthy-living/info-2017/health-benefits-of-gardening-fd.html

Interaction Design Foundation. (2023). *Understanding early adopters and customer adoption patterns*. The Interaction Design Foundation. Retrieved from https://www.interaction-design.org/literature/article/understanding-early-adopters-and-customer-adoption-patterns

Johnson, D. G. (2005). Social construction of technology. In C. Mitchem (Ed.), *Encyclopedia of Science, Technology, and Ethics* (pp. 1791-1794). Farmington Hills, MI.: Thomson Gale.

Karpyn, A., Young, C., & Weiss, S. (2019). Reestablishing Healthy Food Retail: Changing the landscape of food deserts. *Childhood Obesity*, *8*(1), 28–30. https://doi.org/10.1089/chi.2011.0113

Kennedy, B., & Funk, C. (2020, May 30). *28% of Americans are 'strong' early adopters of Technology*. Pew Research Center. https://www.pewresearch.org/fact-tank/2016/07/12/28-of-americans-are-strong-early-adopters-of-technology/

Kline, R., & Pinch, T. (1996). Users as agents of technological change: The Social Construction of the automobile in the rural United States. *Technology and Culture*, *37*(4), 763–795. https://doi.org/10.2307/3107097

Knight, M. (2021, March 12). *What is the internet of things (IOT)?* DATAVERSITY. Retrieved from https://www.dataversity.net/internet-things-iot/

Kogo, B. K., Kumar, L., & Koech, R. (2020). Climate change and variability in Kenya: A review of impacts on agriculture and food security. *Environment, Development and Sustainability*, *23*(1), 23–43. https://doi.org/10.1007/s10668-020-00589-1

Long, T. B., Blok, V., & Poldner, K. (2016). Business models for maximising the diffusion of technological innovations for climate-smart agriculture. *International Food and Agribusiness Management Review*, *20*(1), 5–23. https://doi.org/10.22434/ifamr2016.0081

Martin, M., & Schinzinger, R. (2009). Engineering as Social Experimentation. In Introduction to Engineering Ethics (2nd ed.) McGraw-Hill Higher Education

Muhtasim, M. A., Ramisa Fariha, S., & Ornab, A. M. (2018). Smart Garden Automated and real time plant watering and lighting system with security features. *2018 International Conference on Computing, Power and Communication Technologies (GUCON)*, 676–679. https://doi.org/10.1109/gucon.2018.8675077

Narishkin, A. (2022, March 8). *Americans kill nearly half their houseplants. so why do we still spend billions on them each year?* Business Insider. https://www.businessinsider.com/houseplant-industry-americans-billions-die-2022-3

Olawepo, S., Adebiyi, A., Adebiyi, M., & Okesola, O. (2020). An overview of Smart Garden Automation. *2020 International Conference in Mathematics, Computer Engineering and Computer Science (ICMCECS)*. https://doi.org/10.1109/icmcecs47690.2020.240892

Oracle. (2023). *What is the internet of things (IOT)?* What Is the Internet of Things (IoT)? Retrieved from https://www.oracle.com/internet-of-things/what-is-iot/

PCMAG. (2023). *Definition of smart garden*. PCMAG. Retrieved from https://www.pcmag.com/encyclopedia/term/smart-garden

Pasman, H., Kottawar, K., & Jain, P. (2020). Resilience of process plant: What, why, and how resilience can improve safety and Sustainability. *Sustainability*, *12*(15), 6152. https://doi.org/10.3390/su12156152

PCMAG. (2023). *Definition of smart garden*. PCMAG. Retrieved from https://www.pcmag.com/encyclopedia/term/smart-garden

Piedmont Healthcare. (2022). *Health benefits of indoor plants*. Piedmont Healthcare. Retrieved from https://www.piedmont.org/living-better/health-benefits-of-indoor-plants

Pinch, T. J., & Bijker, W. E. (1984). The social construction of facts and artefacts: Or how the sociology of science and the Sociology of Technology might benefit each other. *Social Studies of Science*, *14*(3), 399–441. https://doi.org/10.1177/030631284014003004

RajaRajeswari, T. S., Chinnasamy, P., Pushparani, K., Thulasichitra, N., Rani, N. S., & Sivaprakasam, T. (2022). IOT based smart gardening for smart cities using Blockchain technology. *2022 International Conference on Computer Communication and Informatics (ICCCI)*. https://doi.org/10.1109/iccci54379.2022.9741024

Raji, C. G., Swalih, T., Nidha, F., Afrooz Shahana., T., & Muhammed Anas, k. (2022). Smart gardening and plant disease detection using internet of things. *2022 6th International Conference on Devices, Circuits and Systems (ICDCS)*, 112–116. https://doi.org/10.1109/icdcs54290.2022.9780838

Rogers, E. M. (1962). Diffusion of innovations (1st ed.). New York: Free Press.

Rogers, E. M. (1983). Diffusion of innovations (3rd ed.). New York: Free Press.

Rogers, E. M. (1995). Diffusion of innovations (4th ed.). New York: Free Press.

Rogers, E. M. (2003). Diffusion of innovations (5th ed.). New York: Free Press.

Setiaji, T., Budiyanto, C., & Yuana, R. A. (2021). The contribution of the internet of things and Smart Systems to agricultural practices: A survey. *IOP Conference Series: Materials Science and Engineering*, *1098*(5), 1–5. https://doi.org/10.1088/1757-899x/1098/5/052100

Shaw, H. J. (2006). Food deserts: Towards the development of a classification. *Geografiska Annaler: Series B, Human Geography*, *88*(2), 231–247. https://doi.org/10.1111/j.0435-3684.2006.00217.x

Strong, R., Wynn, J. T., Lindner, J. R., & Palmer, K. (2022). Evaluating Brazilian Agriculturalists' IOT smart agriculture adoption barriers: Understanding stakeholder salience prior to launching an innovation. *Sensors*, *22*(18). https://doi.org/10.3390/s22186833

Takahashi, K., Muraoka, R., & Otsuka, K. (2019). Technology adoption, impact, and extension in developing countries' agriculture: A review of the recent literature. *Agricultural Economics*, *51*(1), 31–45. https://doi.org/10.1111/agec.12539

Teklu, A., Simane, B., & Bezabih, M. (2023). Multiple adoption of climate-smart agriculture innovation for agricultural sustainability: Empirical evidence from the Upper Blue Nile Highlands of Ethiopia. *Climate Risk Management*, *39*, 1–15. https://doi.org/10.1016/j.crm.2023.100477

Talukder, M. (2012). Factors affecting the adoption of technological innovation by individual employees: An Australian study. *Procedia - Social and Behavioral Sciences*, *40*, 52–57. https://doi.org/10.1016/j.sbspro.2012.03.160

United Nations. (2023). *Least developed countries (ldcs) | Department of Economic and Social Affairs*. United Nations. Retrieved from https://www.un.org/development/desa/dpad/least-developed-country-category.html

U.S. Department of Agriculture. (2022, September 9). USDA opens people's garden initiative to gardens nationwide. Retrieved from https://www.fsa.usda.gov/news-room/news-releases/2022/usda-opens-peoples-garden-initiative-to-gardens-nationwide

Vickers, B., Ali, S., & Balchin, N. (2022, July 5). *The expanding threat to food security in least developed countries*. Development Matters. https://oecd-development-matters.org/2022/07/05/the-expanding-threat-to-food-security-in-least-developed-countries/

Winkler, B., Maier, A., & Lewandowski, I. (2019). Urban Gardening in Germany: Cultivating a sustainable lifestyle for the societal transition to a Bioeconomy. *Sustainability*, *11*(3), 801–822. https://doi.org/10.3390/su11030801