IJASD
ISSN 2618-1193

Green House Effect and Internet of Things: A Review

Qammar Shabbir Rana[1], Ali Iqtadar Mirza[2]
[1]* National Defence University, Islamabad
[2]Govt College University Lahore
*Email: qammar.edu@gmail.com

Citation | Qammar Shabbir Rana, Ali Iqtadar Mirza, "Green House Effect and Internet of Things: A Review," *Int. J. Agric. Sustain. Dev.*, vol. 5, no. 1, pp. 23- 31, 2023.
Received | Jan 30, 2023; **Revised |** Feb 16, 2023; **Accepted |** Feb 26, 2023; **Published |** March 04, 2023.

This article summarises the current state of knowledge concerning Internet of Things (IoT) systems for ideal greenhouse conditions. Descriptive and statistical methods were applied to the data in order to draw conclusions regarding the connections between the IoT, new technologies, precision farming, Agriculture 4.0, and productive commercial agriculture. This is discussed within the broader context of the Internet of Things (IoT) and its role in reducing the negative impacts of climate change and global warming on agriculture through the optimization of key parameters like temperature and humidity, intelligent data acquisition, rule-based control, and removing obstacles to the widespread use of IoT in this sector of the economy. Low agricultural yields and losses have been exacerbated by recent unexpected and severe weather events; this is a challenge that can be overcome with technology-mediated precision agriculture. Over time, technological advancements have led to the creation of sensors that can detect and warn of impending frost, monitor crops remotely, protect against fire hazards, precisely regulate nutrient levels in soilless greenhouse cultivation, eliminate the need for grid power by relying solely on solar power, and control feeding, shading, and lighting systems intelligently to maximize crop output while minimizing overhead expenses. The limited adoption of smart technologies in commercial agriculture, the price, and the accuracy of the sensors are just some of the specific challenges. Future R&D initiatives and commercial applications can be aided by considering the obstacles and challenges.

Keywords: Internet of Things, greenhouses, Information technology, farming systems.

Introduction

With an emphasis on IoT-mediated and optimized microclimates for crop production, this review article synthesizes current scholarly research on the application of IoT for optimized greenhouse environments. The Internet of Things (IoT) has received a lot of attention because of the tremendous contribution it has made to modern civilizations after computers and the internet [1]. Intelligent machines, actuators, sensors, unmanned aerial systems, radio frequency identification (RFID) devices, big data analytics, artificial intelligence, and satellites[2] all play a role in the enormous contribution of IoT in agriculture and commercial greenhouses, which has led to its widespread application in various agricultural and non-agricultural applications, such as intelligent farming and frost prevention in greenhouses [3]. Highly efficient communication protocols, such as MQTT Protocol (Message Queuing Telemetry Transport), have gradually replaced HTTP (HyperText Transfer Protocol) to facilitate the widespread adoption of IoT in smart greenhouses and precision agriculture[4]. MQTT can function on less bandwidth than other, more resource-intensive protocols.

There has been insufficient knowledge of how IoT systems in smart greenhouses can optimize greenhouse environments, especially in tropical regions that experience severe temperature fluctuations. Most of the development work has been done in developed countries because of the easy access to IoT infrastructure and resources there. There are knowledge gaps, and Internet of Things (IoT) systems' contributions to smart greenhouses in the tropics are underutilized[5].

Precision Farming

Implications for greenhouse water and energy conservation are briefly discussed, as are long-term cost-benefit analyses [6]. Methods to increase productivity can take many forms. Farmers, for instance, may use institution's archived predictive analytics data [7] to determine market supply and demand. Data transmission delays occur when users frequently upload and download large amounts of data. Implementing edge computing can help alleviate some of the difficulties[8]. [9][10].When technological barriers are removed, IoT can be used in many more contexts, including crop and machinery management, food safety, and pest identification. According to both sets of research, edge computing could be useful in the agriculture industry[11]. While cloud computing's use in farming has become commonplace, edge computing is just getting off the ground.[12]. In addition, widespread and trustworthy validation of edge-driven services in agricultural contexts has been lacking. Other issues, such as the standardisation of IoT systems, would emerge, however, if the necessary tools were available.

Agricultural Products and IoT

Climate change and global warming have already had devastating consequences on agricultural output and supply, so it's clear that technology will play a crucial part in farming's future.Extreme weather events, such as high temperatures and heavy rainfall, are known to significantly reduce agricultural output in the United States and other countries.

Extreme weather in 2012 cost Michigan cherry farmers an estimated $220 million[13] [14]. A rise in production costs would have a disproportionately negative impact on rural areas in poor countries [15]. Farmers would not be the only ones affected by climate change's effects on agriculture because the higher prices would be passed on to consumers. The United States and other developed economies in the Western Hemisphere weren't the only ones affected[16]. Researcher found that Greece was facing similar difficulties, as the country's available arable land had shrunk[17]. Disruptions in weather patterns and socio-demographic factors due to climate change have exacerbated food shortages and malnutrition. These include the regions of Messara, Ierapetra, and Crete[18][19]. Countries in the Gulf that have a shortage of farmland adopted similar systems. Greenhouse cultivation in Saudi Arabia increased to 3019 ha in 2016, with a harvest of 252,824 tonnes of fruiting vegetables[5][20]. We used commercially accessible sensors to show that technology answers to the challenges of growing costs and inefficient procedures are attainable.

Reducing the need for human intervention, raising crop yields, and making the most efficient use of materials and chemicals are all vitally important long-term objectives [21]. Early results suggest that IoT systems hold great potential for use in precision agriculture. When it was time to apply fungicides, for instance, farmers got notifications from decision support systems that were informed by weather data [22][23]. Unfortunately, developing countries do not show much evidence of adopting technology or practicing precision agriculture [24][25][26]. Differences in food security between developing and developing countries are partially explained by the slow adoption of new technologies[5]. The possibility of increased harvests bolstered the argument for individualized approaches to problem-solving and intervention. Although standard yield increases ranging from 10 to 12 percent [5], better performance is possible through the optimization of plant growth factors, improved sensor reliability technology, and cost management. Cost constraints may force farms with dispersed greenhouses, for instance, to opt for the less intensive deployment of sensors [27][28]. Most smallholder farmers, who are essential to the success of the world's food supply, could not afford to implement IoT in agriculture because of its high cost [27][29].

Smallholder farmers are unable to invest in Internet of Things technologies due to price fluctuations in the market and a lack of set rules governing energy and water allotment and energy use. It is challenging for smallholder farmers to make investments in innovative techniques like the Internet of Things due to their narrow profit margins (IoT). If we look at the two together, we can see that the high cost of IoT infrastructure has prevented its wider implementation. Similar issues were reported by Madushanki et al. The latter argument suggested that the advantages outweighed the risks, citing the potential of IoT infrastructure to stimulate smart farming and urban greening.

With a large number of sensor nodes dispersed across the greenhouse or farm, WSNs can monitor environmental conditions in real time.A dispersed configuration, on the other hand, is defined by a sparser deployment of sensors in the interest of keeping costs down[30]. Optimizing Systems for Intelligent Farming and High-Tech Greenhouses 3.1Scholars agree that selecting sensors, acquiring data, optimizing it, determining the desired settings, and using rule-based control are all crucial to achieving optimal performance in greenhouse IoT systems [26][28][31]. The sensors use advanced technologies including Bragg resonators, piezoelectric elements, electrochemical reactions, electromagnetic waves, and fibre optics to precisely measure parameters of interest.

Excessive heat or humidity is detrimental to plant growth, thus it's crucial to regulate and keep an eye on the greenhouse's climate.To maximize plant growth, the ideal environmental conditions included 35 degrees Celsius and 95 percent relative humidity[29][31]. Humidity and heat are detrimental to pollination, photosynthesis, leaf growth, and crop yield. In smart greenhouses, the optimization of such factors is hampered by the precision of currently available sensors.Certain sensors can only achieve an accuracy of 2-25% [32][33]. Regulating greenhouse microclimates, especially frost mitigation, at such a low level of accuracy could have disastrous consequences [34][35]. When used in other contexts, IoT sensors have a 99% success rate. Smart stick sensors, provide real-time monitoring data on soil moisture and temperature, allowing for extremely precise measurements to be taken. The information gathered by the sensors on the smart sticks is synchronised with smart devices so that changes in physical parameters may be monitored in real time. Rayhana et al. observed that greenhouse smart sensors had a high degree of accuracy, which is consistent with the findings of Castaeda-Miranda et al. The greenhouse's temperature was measured with the use of artificial neural networks, and the cropland's temperature was analysed with fuzzy control; the results of both were utilised to trigger the greenhouse's water pump. The use of spectrophotometers for regular system checks and calibrations, as well as localization adjustments, can help mitigate these drawbacks[34][36]. Researchers have found conflicting information regarding the sensors' reliability, casting doubt on their widespread commercialization for use in agricultural settings. The financial repercussions of the mistakes prove the importance of finding ways to improve the sensors' functionality. Incorrect readings from sensors, for instance, could increase the amount of energy needed to maintain a comfortable temperature and humidity level in a greenhouse [37]. Incorrect data from sensors may actually be advantageous to the crop because it may lead to more fertiliser and micronutrients being applied, which in turn increases crop yields. Yet, it is important to keep in mind that these benefits are not always shared.

Results.

Solar-powered sensor designs for intelligent greenhouses have been demonstrated. Researcher found that [38] found that these types of sensors worked well in off-grid settings. PV-powered sensors help make greenhouse smart devices more self-sufficient and compact, which equates to larger savings over time, in addition to fulfilling the power needs of the sensors themselves. Sahraei et al. acknowledge that the use of autonomous PV sensors has resolved the issue of how to provide the required electricity, but they also acknowledge that there remain substantial challenges.

All of these difficulties pose real-world obstacles for greenhouse sensors used to analyze soil and water. Barriers to the widespread deployment of internet-of-things technology in greenhouses are recognised, including issues with internet access, cost, and technological limits (3.3). Even still, substantial hurdles must be conquered before the technology can be used on a broad scale. Cisco and the ITU classified the barriers they encountered into two categories in their report: policy and technological. The convergence of these two areas introduces a third dimension in the form of challenges related to spectrum and bandwidth limitations, personal information protection and security, network interoperability, and technical standards.It is the UMTS and CDMA 2000 standards, for instance, that regulate 3G and 4G internet technology. But WiFi and LR-WPAN networks are governed by separate standards bodies, IEEE 802.11 and IEEE 802.15.4[25]. Different networks have varying frequencies, data speeds, and power needs, making it difficult to standardise IoT infrastructure in the agriculture industry.

Cisco and the International Telecommunication Union have both called attention to the importance of ensuring that IoT systems can be relied upon (ITU). The precision and dependability of sensors in greenhouse farming have projected the cost-effective manipulation of soil parameters and enhancement of production potential[39][40][41]. GPS positioning for unmanned aircraft system navigation, reflectance spectroscopy, and microwave sensing are all examples of technologies originally created for other industries that are now used in agriculture through IoT systems. This results in increased demands for spectrum, bandwidth, interoperability, and standardised protocols. These latter findings were backed up by statistics from the business world and the internet at large [64]. [42]. Yet, there has been little progress in LEO deployment, and there are several reasons to be sceptical of a wide-scale rollout[43].

Agriculture contributes significantly to CAR's economy, accounting for about half of GDP. According to Ruan et al., more has to be done to improve the current IoT infrastructure for use in agriculture because current loads and connections are insufficient. Unfortunately, it is still challenging to create IoT infrastructure for precision agriculture in open fields because of the low return on investment for private companies and the government. Whether or not investors would be willing to make a large financial commitment to deploy IoT infrastructures in the absence of adequate economic incentives is unclear. The need for precise sensors with sophisticated capabilities and the urgency to address the drawbacks of different IoT protocols like Zigbee, Bluetooth Low Energy (BLE), and Sigfox low-power wide-area network (LPWAN), among others, only add to the difficulties posed by burgeoning IoT adoption. Concerns regarding the high price tag and uneven global deployment of IoT infrastructure, as voiced by Ruan et al. and other experts, can be mitigated by emerging benefits.According to author, there are tangible advantages to implementing IoT infrastructures in agricultural settings[44].

Greenhouse buildings can be built with low-cost intelligent materials, as Lara et al. showed out, countering the claim that employing IoT and other systems in commercial agriculture wastes a lot of resources[45][46]. To accomplish this, they included state-of-the-art systems like 5G-enabled Wireless Sensor Networks (WSNs), WANs, or WiFi into their infrastructure for seamless data collecting and transfer.All told, the cost of developing an Internet of Things prototype was only 16 US dollars, which is commendable given the importance of cost in agricultural production.

The technology's rumored price drop, while welcome, was use-case dependent. In spite of recent progress in R&D, inexpensive sensors for tracking soil moisture remain elusive. According to Placidi et al. [45], the price of soil-water content sensors can range from $150 to $5,000, making them unaffordable for use in developing countries where the average greenhouse costs $27,000. The latter data shows that the anticipated savings were sensor-specific; this difficulty could be mitigated to some extent by further study and the widespread adoption of currently available innovations. Cost reductions from sensor technology can range widely depending on the application, as Cisco and the International Telecommunication Union (ITU) demonstrated in a research titled Leveraging IoT for Global Sustainable Development.

Leading industry player Mordor Intelligence (2021) forecast geographical and product-based growth in the smart greenhouse market. There is a strong argument for more research on greenhouse segmentation and the development of greenhouse-specific smart technology, although this topic has received less attention in the academic literature. End-users' worries may be attributable to the technologies' illusory rather than real advantages.

Hydroponics using solar water heaters and blockchain Another new technology emerging as a result of the Internet of Things is agrovoltaics, which has promising applications in energy-food sustainability. Two examples of exciting new advances in this area include the use of foldable PV modules and solar tiles to improve light transmission and lengthen service life, and the use of combined electrical and thermal energy producing systems.The relative infancy of agrovoltaic systems is a major limitation. In 2020, only a single agrovoltaic system in Belgium was operational. Given the challenges inherent in implementing novel technologies, agrovoltaics' relative novelty presents a significant barrier to its widespread use. The most recent findings uncovered by this review have real-world applications in industrial farming. Progress has also been made towards PV module and solar tile commercialization at the All-Russian Research Center of Solar Energy.

Institute for Research in Agriculture and Electricity. It is anticipated that the market for agrovoltaics would increase dramatically beyond Russia and Belgium as a result of the transition to renewable energy in agriculture. Further investment in R&D is necessary to fully realise the potential of blockchain technology in IoT-based farming systems.Decentralizing solar power generation and use, and improving safety in agricultural systems would be two areas where blockchain technology could make a significant impact.

Conclusions

The benefits and drawbacks of using various Internet of Things sensors to fine-tune greenhouse microclimate have been validated in the published literature. For one thing, there were extremely dependable greenhouse sensors with many potential industrial uses. According to the results of published studies, it was able to save up to $500 USD each cultivated acre. Depending on the crops cultivated, the sensors utilised, and the investment made in data-driven decision-making tools, the real savings may be higher or less than what was expected, as this was a one-time cost estimate.Another group of sensors, those with an accuracy of merely 2-25%, was wholly inadequate. If we invest in R&D, we can find solutions to the problems that arise from our propensity for innovation. However, the problems with emerging countries' ICT infrastructure have not been solved overnight.

Limitations

The primary focus of this research was on optimising sensing through the use of IoT, therefore not every form of sensor, including those used in microclimates and in greenhouses, was discussed in depth. Smallholder farmers were unable to commercialize the technology due to the high price of Internet of Things applications in optimizing the greenhouse microclimate.

References

[1] K. Wang *et al.*, "How does the Internet of Things (IoT) help in microalgae biorefinery?," *Biotechnol. Adv.*, vol. 54, p. 107819, Jan. 2022, doi: 10.1016/J.BIOTECHADV.2021.107819.

[2] Y. Zhang, P. Geng, C. B. Sivaparthipan, and B. A. Muthu, "Big data and artificial intelligence based early risk warning system of fire hazard for smart cities," *Sustain. Energy Technol. Assessments*, vol. 45, p. 100986, Jun. 2021, doi: 10.1016/J.SETA.2020.100986.

[3] Z. Allam and Z. A. Dhunny, "On big data, artificial intelligence and smart cities," *Cities*, vol. 89, pp. 80–91, Jun. 2019, doi: 10.1016/J.CITIES.2019.01.032.

[4] H. Agrawal, J. Prieto, C. Ramos, and J. M. Corchado, "Smart feeding in farming through IoT in silos," *Adv. Intell. Syst. Comput.*, vol. 530, pp. 355–366, 2016, doi: 10.1007/978-3-319-47952-1_28/COVER.

[5] B. Dawson and M. Spannagle, "AGRICULTURE AND FOOD SUPPLY IMPACTS," *Complet. Guid. to Clim. Chang.*, pp. 21–25, Nov. 2008, doi: 10.4324/9780203888469-6.

[6] A. A. R. Madushanki, M. N. Halgamuge, W. A. H. S. Wirasagoda, and A. Syed, "Adoption of the Internet of Things (IoT) in agriculture and smart farming towards urban greening: A review," *Int. J. Adv. Comput. Sci. Appl.*, vol. 10, no. 4, pp. 11–28, 2019, doi: 10.14569/ijacsa.2019.0100402.

[7] A. Villa-Henriksen, G. T. C. Edwards, L. A. Pesonen, O. Green, and C. A. G. Sørensen, "Internet of Things in arable farming: Implementation, applications, challenges and potential," *Biosyst. Eng.*, vol. 191, pp. 60–84, Mar. 2020, doi: 10.1016/J.BIOSYSTEMSENG.2019.12.013.

[8] M. N. Akhtar, A. J. Shaikh, A. Khan, H. Awais, E. A. Bakar, and A. R. Othman, "Smart Sensing with Edge Computing in Precision Agriculture for Soil Assessment and Heavy Metal Monitoring: A Review," *Agric. 2021, Vol. 11, Page 475*, vol. 11, no. 6, p. 475, May 2021, doi: 10.3390/AGRICULTURE11060475.

[9] Y. Bo and H. Wang, "The application of cloud computing and the internet of things in agriculture and forestry," *Proc. - 2011 Int. Jt. Conf. Serv. Sci. IJCSS 2011*, pp. 168–172, 2011, doi: 10.1109/IJCSS.2011.40.

[10] Y. Syafarinda, F. Akhadin, Z. E. Fitri, Yogiswara, B. Widiawanl, and E. Rosdiana, "The Precision Agriculture Based on Wireless Sensor Network with MQTT

Protocol," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 207, no. 1, p. 012059, Nov. 2018, doi: 10.1088/1755-1315/207/1/012059.

[11] G. Chiesa, D. Di Vita, A. Ghadirzadeh, A. H. Muñoz Herrera, and J. C. Leon Rodriguez, "A fuzzy-logic IoT lighting and shading control system for smart buildings," *Autom. Constr.*, vol. 120, p. 103397, Dec. 2020, doi: 10.1016/J.AUTCON.2020.103397.

[12] R. K. Singh, R. Berkvens, and M. Weyn, "Energy Efficient Wireless Communication for IoT Enabled Greenhouses," *2020 Int. Conf. Commun. Syst. NETworkS, COMSNETS 2020*, pp. 885–887, Jan. 2020, doi: 10.1109/COMSNETS48256.2020.9027392.

[13] N. Sahraei, S. Watson, S. Sofia, A. Pennes, T. Buonassisi, and I. M. Peters, "Persistent and adaptive power system for solar powered sensors of Internet of Things (IoT)," *Energy Procedia*, vol. 143, pp. 739–741, Dec. 2017, doi: 10.1016/J.EGYPRO.2017.12.755.

[14] H. Gai, J. Beath, J. Fang, and H. H. Lou, "Alternative emission monitoring technologies and industrial internet of things–based process monitoring technologies for achieving operational excellence," *Curr. Opin. Green Sustain. Chem.*, vol. 23, pp. 31–37, Jun. 2020, doi: 10.1016/J.COGSC.2020.04.009.

[15] Z. Ullah, F. Al-Turjman, L. Mostarda, and R. Gagliardi, "Applications of Artificial Intelligence and Machine learning in smart cities," *Comput. Commun.*, vol. 154, pp. 313–323, Mar. 2020, doi: 10.1016/J.COMCOM.2020.02.069.

[16] A. Sagheer, M. Mohammed, K. Riad, and M. Alhajhoj, "A Cloud-Based IoT Platform for Precision Control of Soilless Greenhouse Cultivation," *Sensors 2021, Vol. 21, Page 223*, vol. 21, no. 1, p. 223, Dec. 2020, doi: 10.3390/S21010223.

[17] M. Raj *et al.*, "A survey on the role of Internet of Things for adopting and promoting Agriculture 4.0," *J. Netw. Comput. Appl.*, vol. 187, p. 103107, Aug. 2021, doi: 10.1016/J.JNCA.2021.103107.

[18] A. Castañeda-Miranda and V. M. Castaño-Meneses, "Internet of things for smart farming and frost intelligent control in greenhouses," *Comput. Electron. Agric.*, vol. 176, p. 105614, Sep. 2020, doi: 10.1016/J.COMPAG.2020.105614.

[19] K. Lova Raju and V. Vijayaraghavan, "IoT Technologies in Agricultural Environment: A Survey," *Wirel. Pers. Commun.*, vol. 113, no. 4, pp. 2415–2446, Aug. 2020, doi: 10.1007/S11277-020-07334-X/METRICS.

[20] M. P. Caro, M. S. Ali, M. Vecchio, and R. Giaffreda, "Blockchain-based traceability in Agri-Food supply chain management: A practical implementation," *2018 IoT Vert. Top. Summit Agric. - Tuscany, IOT Tuscany 2018*, pp. 1–4, Jun. 2018, doi: 10.1109/IOT-TUSCANY.2018.8373021.

[21] V. Kharchenko, V. Panchenko, P. V. Tikhonov, and P. Vasant, "Cogenerative PV thermal modules of different design for autonomous heat and electricity supply," *Handb. Res. Renew. Energy Electr. Resour. Sustain. Rural Dev.*, pp. 86–119, Jan. 2018, doi: 10.4018/978-1-5225-3867-7.CH004.

[22] V. Panchenko, A. Izmailov, V. Kharchenko, and Y. Lobachevskiy, "Photovoltaic Solar Modules of Different Types and Designs for Energy Supply," *https://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/IJEOE.2020040106*, vol. 9, no. 2, pp. 74–94, Jan. 1AD, doi: 10.4018/IJEOE.2020040106.

[23] A. and Kate, "Global refining catalysts market (2021 to 2026) – Growth, trends, COVID-19 impact and forecasts," *Focus Catal.*, vol. 2021, no. 9, p. 2, Sep. 2021, doi: 10.1016/J.FOCAT.2021.08.004.

[24] A. Sinha, G. Shrivastava, and P. Kumar, "Architecting user-centric internet of things for smart agriculture," *Sustain. Comput. Informatics Syst.*, vol. 23, pp. 88–102, Sep. 2019,

doi: 10.1016/J.SUSCOM.2019.07.001.

[25] J. Ruan *et al.*, "Agriculture IoT: Emerging Trends, Cooperation Networks, and Outlook," *IEEE Wirel. Commun.*, vol. 26, no. 6, pp. 56–63, Dec. 2019, doi: 10.1109/MWC.001.1900096.

[26] Y. L. Zhong, Z. Tian, G. P. Simon, and D. Li, "Scalable production of graphene via wet chemistry: progress and challenges," *Mater. Today*, vol. 18, no. 2, pp. 73–78, Mar. 2015, doi: 10.1016/J.MATTOD.2014.08.019.

[27] R. R. Shamshiri *et al.*, "Greenhouse Automation Using Wireless Sensors and IoT Instruments Integrated with Artificial Intelligence," *Next-Generation Greenhouses Food Secur.*, May 2021, doi: 10.5772/INTECHOPEN.97714.

[28] X. Wan, F. Zhang, Y. Liu, and J. Leng, "CNT-based electro-responsive shape memory functionalized 3D printed nanocomposites for liquid sensors," *Carbon N. Y.*, vol. 155, pp. 77–87, Dec. 2019, doi: 10.1016/J.CARBON.2019.08.047.

[29] A. I. Mtz-Enriquez *et al.*, "Tailoring the detection sensitivity of graphene based flexible smoke sensors by decorating with ceramic microparticles," *Sensors Actuators B Chem.*, vol. 305, p. 127466, Feb. 2020, doi: 10.1016/J.SNB.2019.127466.

[30] J. Ruan *et al.*, "An IoT-based E-business model of intelligent vegetable greenhouses and its key operations management issues," *Neural Comput. Appl.*, vol. 32, no. 19, pp. 15341–15356, Oct. 2020, doi: 10.1007/S00521-019-04123-X/METRICS.

[31] J. Bontsema, E. J. Van Henten, T. H. Gieling, and G. L. A. M. Swinkels, "The effect of sensor errors on production and energy consumption in greenhouse horticulture," *Comput. Electron. Agric.*, vol. 79, no. 1, pp. 63–66, Oct. 2011, doi: 10.1016/J.COMPAG.2011.08.008.

[32] M. Molinara, A. Bria, S. De Vito, and C. Marrocco, "Artificial intelligence for distributed smart systems," *Pattern Recognit. Lett.*, vol. 142, pp. 48–50, Feb. 2021, doi: 10.1016/J.PATREC.2020.12.006.

[33] L. Bosmans *et al.*, "Habitat-specific variation in gut microbial communities and pathogen prevalence in bumblebee queens (Bombus terrestris)," *PLoS One*, vol. 13, no. 10, p. e0204612, Oct. 2018, doi: 10.1371/JOURNAL.PONE.0204612.

[34] G. L. Baron, V. A. A. Jansen, M. J. F. Brown, and N. E. Raine, "Pesticide reduces bumblebee colony initiation and increases probability of population extinction," *Nat. Ecol. Evol. 2017 19*, vol. 1, no. 9, pp. 1308–1316, Aug. 2017, doi: 10.1038/s41559-017-0260-1.

[35] H. Connelly, K. Poveda, and G. Loeb, "Landscape simplification decreases wild bee pollination services to strawberry," *Agric. Ecosyst. Environ.*, vol. 211, pp. 51–56, Dec. 2015, doi: 10.1016/J.AGEE.2015.05.004.

[36] J. Bryden, R. J. Gill, R. A. A. Mitton, N. E. Raine, and V. A. A. Jansen, "Chronic sublethal stress causes bee colony failure," *Ecol. Lett.*, vol. 16, no. 12, pp. 1463–1469, Dec. 2013, doi: 10.1111/ELE.12188.

[37] P. Dai *et al.*, "The Herbicide Glyphosate Negatively Affects Midgut Bacterial Communities and Survival of Honey Bee during Larvae Reared in Vitro," *J. Agric. Food Chem.*, vol. 66, no. 29, pp. 7786–7793, Jul. 2018, doi: 10.1021/ACS.JAFC.8B02212/SUPPL_FILE/JF8B02212_SI_001.PDF.

[38] F. Li *et al.*, "Effects of phoxim exposure on gut microbial composition in the silkworm, Bombyx mori," *Ecotoxicol. Environ. Saf.*, vol. 189, p. 110011, Feb. 2020, doi: 10.1016/J.ECOENV.2019.110011.

[39] V. J. McCracken, J. M. Simpson, R. I. Mackie, and H. R. Gaskins, "Molecular Ecological Analysis of Dietary and Antibiotic-Induced Alterations of the Mouse Intestinal Microbiota," *J. Nutr.*, vol. 131, no. 6, pp. 1862–1870, Jun. 2001, doi: 10.1093/JN/131.6.1862.

[40] G. Kairo *et al.*, "Drone exposure to the systemic insecticide Fipronil indirectly impairs queen reproductive potential," *Sci. Reports 2016 61*, vol. 6, no. 1, pp. 1–12, Aug. 2016, doi: 10.1038/srep31904.

[41] Y. S. Wang, Y. J. Huang, W. C. Chen, and J. H. Yen, "Effect of carbendazim and pencycuron on soil bacterial community," *J. Hazard. Mater.*, vol. 172, no. 1, pp. 84–91, Dec. 2009, doi: 10.1016/J.JHAZMAT.2009.06.142.

[42] T. Lu *et al.*, "Understanding the influence of glyphosate on the structure and function of freshwater microbial community in a microcosm," *Environ. Pollut.*, vol. 260, p. 114012, May 2020, doi: 10.1016/J.ENVPOL.2020.114012.

[43] W. Skeff, C. Neumann, and D. E. Schulz-Bull, "Glyphosate and AMPA in the estuaries of the Baltic Sea method optimization and field study," *Mar. Pollut. Bull.*, vol. 100, no. 1, pp. 577–585, Nov. 2015, doi: 10.1016/J.MARPOLBUL.2015.08.015.

[44] J. Praet, A. Parmentier, R. Schmid-Hempel, I. Meeus, G. Smagghe, and P. Vandamme, "Large-scale cultivation of the bumblebee gut microbiota reveals an underestimated bacterial species diversity capable of pathogen inhibition," *Environ. Microbiol.*, vol. 20, no. 1, pp. 214–227, Jan. 2018, doi: 10.1111/1462-2920.13973.

[45] M. T. Bartling, A. Vilcinskas, and K. Z. Lee, "Sub-Lethal Doses of Clothianidin Inhibit the Conditioning and Biosensory Abilities of the Western Honeybee Apis mellifera," *Insects 2019, Vol. 10, Page 340*, vol. 10, no. 10, p. 340, Oct. 2019, doi: 10.3390/INSECTS10100340.

[46] D. Shin and C. T. Smartt, "Assessment of esterase gene expression as a risk marker for insecticide resistance in Florida Culex nigripalpus (Diptera: Culicidae)," *J. Vector Ecol.*, vol. 41, no. 1, pp. 63–71, Jun. 2016, doi: 10.1111/JVEC.12195.