GREEN REVOLUTIONARY TECHNOLOGIES

EDITORS
Assoc. Prof. Dr. Yunus EGI
Assoc. Prof. Dr. Mortaza HAJYZADEH
Asst. Prof. Dr. İlhan EHSANİ

İKSAD
Publishing House

GREEN REVOLUTIONARY TECHNOLOGIES

EDITORS
Assoc. Prof. Dr. Yunus EGI
Assoc. Prof. Dr. Mortaza HAJYZADEH
Asst. Prof. Dr. İlhan EHSANİ

AUTHORS
Prof. Dr. Khalid Mahmood KHAWAR
Assoc. Prof. Dr. Ahmet TURŞUCU
Assoc. Prof. Dr. Mortaza HAJYZADEH
Assoc. Prof. Dr. Yunus EGI
Asst. Prof. Dr. Engin EYCEYURT
Asst. Prof. Dr. İbrahim Behram UĞUR
Asst. Prof. Dr. İlhan EHSANI
Asst. Prof. Dr. Sadiye KANTARCI
Asst. Prof. Dr. Sahin GULLU
Muhammed Said ULAŞ

İKSAD
Publishing House

Institution of Economic Development and Social Researches Publications®
(The Licence Number of Publicator: 2014/31220)
TÜRKİYE TR: +90 342 606 06 75
USA: +1 631 685 0 853
E mail: iksadyayinevi@gmail.com
www.iksadyayinevi.com

ISBN: 978-625-378-024-1
Cover Design: İbrahim KAYA
December / 2024
Ankara / Türkiye
Size: 16x24cm

CONTENTS

PREFACE

Humanity stands at a critical crossroads due to growing global issues including resource depletion, climate change, and population expansion. The need for sustainable solutions has never been more urgent. The title “Green Revolutionary Technologies” reflects not only a call to action but also a celebration of the innovative strides being made to secure a more sustainable future.

This book examines the eco-friendly applications and innovative technologies that could be helpful for sustainable industries, economies and the environment. To achieve this goal, advancing in agriculture, waste management, recycling, energy consumption, eco-friendly materials, renewable energy construction and other areas must be made.

The aim of this book is to inspire, inform, and ignite action. This book is for everyone who appreciates their surroundings and wishes for a greener and more sustainable future. We hope that it will be helpful and educational in this regard, even if only little.

Assoc. Prof. Dr. Yunus EGI[1]
Assoc. Prof. Dr. Mortaza HAJYZADEH[2]
Asst. Prof. Dr. İlhan EHSANİ[3]

---

[1] Department of Electrical and Electronics Engineering, Faculty of Engineering, Şırnak University, Şırnak 73000, Türkiye. yunusegi@sirnak.edu.tr, Orcid ID: 0000-0001-5185-8443

[2] Department of Field Crop, Faculty of Agriculture, Şırnak University, Şırnak 73000, Türkiye. m.hajyzadeh@gmail.com, Orcid ID: 0000-0002-8808-6974

[3] Şırnak University, Faculty of Engineering, Mining Engineering Department, Şırnak, Türkiye. ilhan.ehsani@sirnak.edu.tr, Orcid ID: 0000-0001-9741-8777

CHAPTER 1

REVOLUTIONIZING AGRICULTURE: AI, BLOCKCHAIN, AND AUTONOMOUS FARMING TECHNOLOGIES

Assoc. Prof. Dr. Yunus EGI[1], Assoc. Prof. Dr. Mortaza HAJYZADEH[2]

DOI: https://dx.doi.org/10.5281/zenodo.14540634

---

[1] Department of Electrical and Electronics Engineering, Faculty of Engineering, Şırnak University, Şırnak 73000, Türkiye. yunusegi@sirnak.edu.tr, Orcid ID: 0000-0001-5185-8443

[2] Department of Field Crop, Faculty of Agriculture, Şırnak University, Şırnak 73000, Türkiye. m.hajyzadeh@gmail.com, Orcid ID: 0000-0002-8808-6974

INTRODUCTION

Agriculture, long regarded as the cornerstone of human civilization, is now experiencing a profound and unprecedented transformation driven by rapid technological advancements. These innovations are reshaping traditional practices, improving efficiency, and addressing global challenges such as food security, climate change, and resource management (Cao et al., 2022). The increase in human population has caused various environmental challenges that inspire people to rethink and innovate in agriculture. The varied and complex challenges of modern farming-from resource inefficiency to labor shortages and sustainability-are not amenable to traditional farming practices (Djordjevic et al., 2020).

Artificial Intelligence (AI), blockchain and autonomous farming technologies have revolutionized traditional agricultural methods offered solutions to the aforementioned challenges (Sharma et al., 2022). These newer innovations have been helpful by creating new standards for efficiency, transparency, and sustainability in eco-friendly practices and ushering in a new "Green Revolution" in agriculture. The new technologies at hand hence pose for an industry upon whose operations, the environment and in turn the economic pressures may be somewhat at the disposal.

In this sense, artificial intelligence will not only support sustainable practices but will lead to a new way of innovation in greenhouse and open-field farming (Khan et al., 2021). It analyzes vast amounts of information to enable correct decision-making. For example, in greenhouse environments, it improves climate control and irrigation to enhance plant growth while saving resources. Certain tasks in open fields for harvesting, product tracking, and efficiency improvements that lower labor costs have also adopted AI processes.

As the technology that goes hand in hand with AI, Blockchain plays a substantial role in security and transparency for modern agriculture since it adds the traceability feature to the supply chain (Alzoubi et al., 2024). At its center, blockchain offers a decentralized and fixed ledger that logs every transaction and movement of the product to be shared to all participants and other stakeholders. (Prashar et al., 2020; Galves et al., 2018).

Autonomous systems in greenhouses are mainly about precise planting, pruning, and harvesting. These applications reduce time and labor work with precision and efficiency (Zhang et al., 2022). Similarly, in agriculture, soil management and crop harvesting can be handled through autonomous systems for more sustainable agriculture practices.

This chapter covers AI, blockchain and autonomous systems in agriculture. The aim is to find the recent technological advancement in greenhouses and field agriculture that provide sustainable, transparent and efficient results. The chapter topics are as following: AI-Powered Innovations for Greenhouse Sustainability: Enhancing Energy and Resource Efficiency, AI-Powered Autonomous Greenhouses: Shaping the Future of Precision Farming; Automating Traditional Farming, AI in Harvesting, Pruning, and Ploughing; Blockchain in Agriculture: Strengthening Supply Chains and Ensuring Transparency, and Autonomous Systems in Agriculture: Transforming Greenhouse and Field Operations.

AI-POWERED INNOVATIONS FOR GREENHOUSE SUSTAINABILITY: ENHANCING ENERGY AND RESOURCE EFFICIENCY

Energy consumption and resource management in greenhouses are essential for sustainable agriculture. Therefore, AI-powered innovations are being utilized to reduce the potential management related inefficiencies (Titirmare et al., 2024). These inefficiencies not only reduce greenhouse crops production but also create serious environmental concerns. AI-powered innovations resolve these types of concerns by reducing the levels of resource utilization in an environmentally sustainable manner (Gupta et al., 2024). AI offers intelligent climate control systems and optimized irrigation systems. Each one of these innovations supports the Green Revolution's promises such as increasing productivity while reduction of environmental damage.

AI-Powered Climate Control Systems

The integration of AI in climate control system is another revolutionary step for sustainable agriculture and green environment since it addresses environmental challenges by means of analyzing in real time a number of variables, from temperature to humidity and light levels (Selvam et al., 2023).

In their research, for example, Belhaj Salah and Fourati used a type of AI model called the Deep Elman neural network in greenhouse management. Their complex dynamics of greenhouses and a multilayer feed-forward neural network help to control the internal climate of the greenhouse. Through the combination of these approaches, the system successfully controlled and maintained temperature and humidity levels, thereby improving accuracy compared to conventional approaches. Compared to the previous model, their AI model reduced the error margins, wherein the error criterion (E_t)was reduced from 344.12 to 129.89, showing an improvement of more than 60%. This clearly indicates that the proposed system might become a good tool in terms of improving the precision of climate control for better crop productivity and resource efficiency (Belhaj Salah & Fourati, 2021).

Optimized Irrigation Systems

Artificial intelligence significantly changes irrigation methodologies at a revolutionary pace for agricultural practices. Most traditional irrigation systems result in the wastage of water due to improper distribution. Optimized irrigation systems reduce these effects by utilizing sensors and predictive algorithms that can deliver the correct amount of water based on real-time data.

For instance, Singh et al. develop an optimized irrigation system with improved sustainability by refining the usage of water and energy in sprinkler irrigation. This is done with the help of a CNN model that assesses soil moisture classification from in-field images to determine optimal irrigation timing. The mobile app, integrated with CNN, improved water productivity by 32.75% and saved 27.59% of water and 27.42% of energy compared to traditional methods. Such AI-based systems can reduce human error, efficiently use available resources, and improve agricultural productivity (Singh et al., 2023)

AI-POWERED AUTONOMOUS GREENHOUSES: SHAPING THE FUTURE OF PRECISION FARMING

Contemporary greenhouses use AI-powered autonomous tools to achieve maximum efficiency in precision agriculture. These systems are essentially used for plant management and monitoring processes. The section intends to explore a few dimensions of greenhouses and their impact on modern agricultural practices.

Robotic Systems for Plant Management

Artificial intelligence-driven robotic systems are engaged in every key operation concerning planting, pruning, and harvesting in a greenhouse environment. These robots are trained using machine learning algorithms to handle sensitive tasks with great precision. In respect to AI-based plant management, MRP has vital roles in enhancing the accuracy of agriculture.

For instance, Ren et al. designed an AMR and an MPR that could acquire temporal–spatial phenotypic data over whole agricultural facilities, including a strawberry production site. This system utilizes an ATI navigation algorithm for navigation in tight and repetitive environments while maintaining a high positional accuracy of 13.0 mm. The yield monitoring capabilities, along with the use of video-based artificial intelligence systems for fruit detection and feature extraction, show outstanding results in terms of performance, reaching a minimum error rate of 6.26% at a constant speed of 0.2 m/s. Their study concludes that plant growth dynamic models are key to successful production management.

AI-Based Monitoring Systems

The development of the visual system in artificial intelligence, with very sensitive sensors, enables the detection of symptoms for diseases, nutritional deficiencies, and a range of other issues. Fernando et al., for instance, present an advanced AI-based monitoring system for the management of greenhouses by using LiDAR technology in combination with navigation and advanced image processing techniques for disease detection. The methodology they used combines conventional machine learning methods with CNNs, where they achieved an accuracy of 99.4% validation in detecting ailments like leaf mold and yellow leaf curl virus. This merged approach is indicative of remarkable achievement in plant surveillance and especially in AI-Based Monitoring Systems applicable to agricultural practices.

AUTOMATING TRADITIONAL FARMING: AI IN HARVESTING, PRUNING, AND PLOUGHING

Traditional Farming tasks such as harvesting, pruning, and ploughing leave their place to AI-powered applications that increases the efficiency and productivity, significantly. In this section, we will be exploring the trend AI-powered research in agriculture.

AI-Powered Harvesting Systems

Generally, manual harvesting in agriculture concerns processes such as cropping, collecting, and bundling, which often lead to considerable losses due to grain shattering, shedding, and improper handling methods (Mishra & Satapathy, 2021). This kind of inefficiency drives the need for better solutions, most especially in large-scale farming. Harvesters that utilize artificial intelligence harness computer vision and deep learning algorithms in distinguishing and selecting crops based on their ripeness, among other quality parameters. The systems reduce waste and increase the quality and consistency of crops by using automated selection mechanisms that allow for efficient harvesting with a minimized use of labor-intensive practices.

For example, the AI-powered harvesting method is used by the palm date sector, which is culturally and economically important for the Arab world. Khan et al., in their study, employed a machine learning model along with explainable AI to make a correct estimation of the maturity, type, and disease of the fruit that directly affects the productivity and health of palms. Their proposed method introduces the machine learning framework for classification of date fruit characteristics and monitoring of palm health, where both individual and merged datasets can be focused for optimal performance. By employing XAI techniques on the improved and optimized version of the VGG16 deep learning model, the model adds clarity when it comes to decision-making processes. The model was quite accurate in date type identification (98%), date ripeness identification (93%), and WSD stages identification (99.7%). These findings illustrate the capability of machine learning-based analysis to assist harvesting systems and precision agricultural methodologies that promote sustainability and resource efficiency. Further, it was proved that the integration of AI-empowered harvesting systems into crop management enables optimum productivity with minimal losses and ensures long-term sustainability of this industry.

AI in Pruning and Ploughing

AI-powered pruning and ploughing operations have made a significant change on agricultural due to precise analysis of plant growth patterns and health. Once these technologies are combined with GPS and 3D Lidar mapping, the field operations can be more efficient and accurate.

Siciliano et al. built an AI-powered system for an automated pruning process in vineyards. This AI-powered system contained trinocular stereo cameras to capture images of the grapevines and created 3D models using computer vision. These 3D models were implemented on a robot to identify and target specific canes for pruning. Then, a six-degree-of-freedom robotic arm made a precise cut using AI-powered prediction model. This system was experimented on a 96-meter-long vine row. The process lasted two minutes per row which could match human performance. According to their research, the 3D model is a key component in ensuring robot accuracy in identifying the vines for pruning (Siciliano et al., 2020).

In addition, Priyadharsini et al. also used an AI-powered system, specifically Artificial Neural Networks (ANNs), to increase agricultural yield. The created automated system was used to detect soil nutrients and suggest the best practices in crop management. Their ANN supported system used optical transducers to measure the concentration of soil nutrients (NPK) and soil pH. The outcomes are stored in cloud systems for cross-referencing with previous records. The model, therefore, would be used to make predictions of the best soil nutrient composition and recommend the kind of fertilizer to be applied in case of a deficiency in nutrients. The system also provided farmers with real-time information on prevailing market prices for agricultural products and weather forecasts. In addition, the mobile app developed allows farmers to view AI-generated analyses and make better decisions. The innovative approach provided an alternative way, so instead of using conventional methods that required much time and increased cost in their offer—using automation and AI to supply real-time data into farmers' hands (Priyadharsini K. et al., 2021).

BLOCKCHAIN IN AGRICULTURE: STRENGTHENING SUPPLY CHAINS AND ENSURING TRANSPARENCY

Blockchain is a game changer technology in agriculture that resolves Agri-product fraud, traceability problem, price manipulation, and doubt about the origin of the product (Bhusal et al.,2021). This section will take a look at how this technology boosts transparency in the supply chain and enhances the coordination of stakeholders.

Enhancing Supply Chain Transparency

Many businesses are dealing with a huge demand for global transparency along with supply chain which is mainly related to public sharing of essential information of suppliers and their sustainability standards and purchasing procedures (Egels-Zandén et al., 2015). Implementing blockchain technology helps achieve this purpose since all transactions are registered and therefore follow the course of agriculture products, hence guaranteeing trust and lowering levels of fraud.

In their research, Sakthivel et al. proposed a blockchain model to improve transparency and traceability in agriculture by integrating IoT devices. They used smart devices for monitoring and collecting information about the condition of crops, weather, and quality of products, which is then safely stored in the blockchain. This provides immutable and transparent records that can be accessed by consumers through mobile apps or QR codes to check the origin, farming, and storage practices of products. Their system's utilization of blockchain guarantees the security of data and prevents tampering, thus building trust in the food supply chain (Sakthivel et al., 2024). It does this through automated management in their system, where a transaction is made between the clients, such as farmers and retailers, and the service providers in logistics, storage facilities, etc. Through smart contracts, client registration in the system automatically goes through the identity proof process, following which encrypted secure communication happens between him and the different service providers. All the interactions will be recorded in the blockchain, ensuring lesser intermediaries, transparency, and improvement in efficiency with lower costs.

Improving Coordination Among Stakeholders

Blockchain is also useful when it comes to the coordination of stakeholders in agricultural supply chain. Real-time data sharing and validation creates efficient communication between farmers, distributors and retailers. A study conducted by Cao et al. (2022) shows that blockchain technology not only reduces transaction time in agricultural supply chains but also significantly improves coordination among stakeholders. In their study, they highlighted that blockchain can facilitate a smart contract, an automatic payment and product delivery form, to solve the compliance problem between contractual terms and intermediaries. By doing so, this system builds trust among stakeholders (Cao et al., 2022).

AUTONOMOUS SYSTEMS IN AGRICULTURE: TRANSFORMING GREENHOUSE AND FIELD OPERATIONS

Autonomous systems are revolutionizing greenhouse and field activities, thanks to the enhancement brought by precision and operational efficiency. This session will look at how these systems are impacting agricultural practices and how they contribute to making conventional methodologies sustainable and environmentally friendly.

Autonomous Greenhouse Technologies

Most of the autonomous systems developed for greenhouses are targeted to improve efficiency in planting, harvesting, and monitoring, while reducing labor requirements and time. Generally, autonomous systems make use of AI, more specifically reinforcement learning, by which observations are analyzed to decide on actions taken to iteratively improve their policy models. For instance, Zhang et al. (2021) showed the tremendous potential of autonomous systems applied to greenhouse environments using advanced model-based reinforcement learning. Their work's findings show that RL-powered greenhouses can be used to control environmental factors like temperature and CO_2 levels for better resource efficiency and maximum production of crops. Their findings indicate that RL-based autonomous greenhouses can effectively control environmental factors such as temperature and CO_2 concentrations, resulting in increased resource efficiency and higher crop yields.

Their findings of the research show that well-adjusted parameters, like dropout rate ($p = 0.8$), increase the effectiveness and robustness of the algorithm. This proves the viability of the applications of autonomous greenhouse to reach high levels of profitability with sustainability. The research also found that such systems are capable of reducing environmental problems while improving the efficiency of operations, hence offering long-term huge benefits in agricultural automation.

Field Agriculture Automation

There are various types of field agriculture automation examples such as autonomous tractors and harvesters using AI and GPS technology. These systems improve precision and efficiency while addressing labor shortages.

The semi-autonomous technologies in agricultural machinery, as demonstrated by the work of Stentz et al., have shown the huge potential for transformative changes that robotics can bring to farming methodologies. This paper presents a system for semi-autonomous operation of tractors, which combines GPS-guided navigation with stereoscopic imaging and obstacle identification to improve operational efficiency, reduce costs, and increase safety in agricultural tasks such as spraying, tilling, and seeding. One of the salient features of the system is that it has both the ability to instruct and play back, allowing a human operator to program routes manually but also control many tractors remotely using wireless communication. Experimental tests in a Florida orange grove showed that the system was able to follow predetermined paths with precision while autonomously handling obstacles and environmental challenges. This research shows the importance of introducing redundancy in sensor systems, together with human supervision, in order to achieve resilient and reliable automation in complex agricultural settings.

CONCLUSION

Agriculture is undergoing a major transformation, what's being termed as a green revolution, because artificial intelligence, blockchain technology, and autonomous systems are now in place to finally address the most pressing issues of efficiency, transparency, and sustainability. The leading technologies are helping sectors meet the yearning of a growing population while at the same time being able to reduce their ecological footprint.

AI empowers the producers with tools to optimize energy use, resource management and crop monitoring. Blockchain completes these advancements by guaranteeing secure and transparent supply chains, fostering trust among stakeholders and consumers. On the other hand, autonomous systems are renovating traditional labor-intensive tasks into efficient, automated processes, reshaping both greenhouse and field farming.

Despite the potential of these technologies, there are challenges such as high implementation costs, technological literacy, and infrastructure constraints that need to be addressed. Furthermore, ethical considerations, data privacy, and equitable access to these advancements are vital to guaranteeing their broad and fair adoption.

The various disciplines coming together and the continuous development are vital in facing the challenges in agriculture with a view to increasing sustainability, resilience, and productivity. Through these emerging technologies, humanity can better ensure a sustainable and prosperous future for generations to come.

REFERENCES

Cao, X., Yao, Y., Li, L., Zhang, W., An, Z., Zhang, Z., ... & Luo, D. (2022, June). igrow: A smart agriculture solution to autonomous greenhouse control. In Proceedings of the AAAI Conference on Artificial Intelligence (Vol. 36, No. 11, pp. 11837-11845).

Djordjevic, M., Punovic, V., Dankovic, D., & Jovicic, B. (2020). Smart autonomous agricultural system for improving yields in greenhouse based on sensor and IoT technology. Journal of Applied Engineering Science, 18(4), 606-613.

Sharma, V., Tripathi, A. K., & Mittal, H. (2022). Technological revolutions in smart farming: Current trends, challenges & future directions. Computers and Electronics in Agriculture, 201, 107217.

Khan, N., Ray, R. L., Kassem, H. S., Hussain, S., Zhang, S., Khayyam, M., ... & Asongu, S. A. (2021). Potential role of technology innovation in transformation of sustainable food systems: A review. Agriculture, 11(10), 984.

Alzoubi, M. M. (2024). Investigating the synergy of Blockchain and AI: enhancing security, efficiency, and transparency. Journal of Cyber Security Technology, 1-29.

Prashar, D., Jha, N., Jha, S., Lee, Y., & Joshi, G. P. (2020). Blockchain-based traceability and visibility for agricultural products: A decentralized way of ensuring food safety in india. Sustainability, 12(8), 3497.

Galvez, J. F., Mejuto, J. C., & Simal-Gandara, J. (2018). Future challenges on the use of blockchain for food traceability analysis. TrAC Trends in Analytical Chemistry, 107, 222-232.

Zhang, M., Yan, T., Wang, W., Jia, X., Wang, J., & Klemeš, J. J. (2022). Energy-saving design and control strategy towards modern sustainable greenhouse: A review. Renewable and Sustainable Energy Reviews, 164, 112602.

Titirmare, S., Margal, P. B., Gupta, S., & Kumar, D. AI-Powered Predictive Analytics for Crop Yield Optimization. In Agriculture 4.0 (pp. 89-110). CRC Press.

Gupta, D. K., Pagani, A., Zamboni, P., & Singh, A. K. (2024). AI-powered revolution in plant sciences: advancements, applications, and challenges for sustainable agriculture and food security. Exploration of Foods and Foodomics, 2(5), 443-459.

Selvam, A. P., & Al-Humairi, S. N. S. (2023). The Impact of IoT and Sensor Integration on Real-Time Weather Monitoring Systems: A Systematic Review.

Belhaj Salah, L., & Fourati, F. (2021). A greenhouse modeling and control using deep neural networks. Applied Artificial Intelligence, 35(15), 1905–1929. https://doi.org/10.1080/08839514.2021.1995232

Singh, N., Ajaykumar, K., Dhruw, L. K., & Choudhury, B. U. (2023). Optimization of irrigation timing for sprinkler irrigation system using convolutional neural network-based mobile application for sustainable agriculture. Smart Agricultural Technology, 5, 100305. https://doi.org/10.1016/j.atech.2023.100305.

Ren, G., Wu, H., Bao, A., Lin, T., Ting, K. C., & Ying, Y. (2023). Mobile robotics platform for strawberry temporal–spatial yield monitoring within precision indoor farming systems. Frontiers in Plant Science, 14, 1162435.

Omer Faruk Akman, Halil Ibrahim Duru, and Aydin M. Turgut, "Automated Greenhouse Monitoring System Using Mobile Robot and Image Processing," IEEE, 2021. DOI: 10.1109/IEEECON49548.2021.9293745.

Mishra, D., & Satapathy, S. (2021). Technology adoption to reduce the harvesting losses and wastes in agriculture. Clean Technologies and Environmental Policy, 23, 1947-1963.

Botterill, T., Paulin, S., Green, R., Williams, S., Lin, J., Saxton, V., Mills, S., Chen, X. and Corbett-Davies, S. (2017), A Robot System for Pruning Grape Vines. J. Field Robotics, 34: 1100-1122. https://doi.org/10.1002/rob.21680

Khan, S. Z., Dhou, S., & Al-Ali, A. R. (2024). Machine Learning Based Palm Farming: Harvesting and Disease Identification. IEEE Access.

Sakthivel, V., Prakash, P., Lee, J.-W., & Prabu, P. (2024). Enhancing transparency and trust in agrifood supply chains through novel blockchain-based architecture. KSII Transactions on Internet and Information Systems, 18(7), https://doi.org/10.3837/tiis.2024.07.013

Cao, Y., Yi, C., Wan, G., Hu, H., Li, Q., & Wang, S. (2022). An analysis on the role of blockchain-based platforms in agricultural supply chains. Transportation Research Part E: Logistics and Transportation Review, 163, 102731.

Zhang, L., Chen, X., & Wang, X. (2021). A modular framework for greenhouse automation. Proceedings of Machine Learning Research, 157, 1-15. https://proceedings.mlr.press/v157/zhang21e

Bhusal, Chandra Sekhar, Blockchain Technology in Agriculture: A Case Study of Blockchain Start-Up Companies (October 1, 2021). International Journal of Computer Science & Information Technology (IJCSIT) Vol 13, No 5, October 2021, Available at SSRN: https://ssrn.com/abstract=3960631

Egels-Zandén, N., Hulthén, K., & Wulff, G. (2015). Trade-offs in supply chain transparency: the case of Nudie Jeans Co. Journal of Cleaner Production, 107, 95-104.

Stentz, A., Dima, C., Wellington, C. et al. A System for Semi-Autonomous Tractor Operations. Autonomous Robots 13, 87–104 (2002). https://doi.org/10.1023/A:1015634322857

CHAPTER 2

METAL RECYCLING FROM INDUSTRIAL WASTES

Asst. Prof. Dr. İlhan EHSANI [1], Asst. Prof. Dr. Sadiye KANTARCI[2]

DOI: https://dx.doi.org/10.5281/zenodo.14540649

---

[1] Şırnak University, Faculty of Engineering, Mining Engineering Department, Şırnak, Türkiye. ilhan.ehsani@sirnak.edu.tr, Orcid ID: 0000-0001-9741-8777
[2] Şırnak University, Faculty of Engineering, Mining Engineering Department, Şırnak, Türkiye. sadiyekantarci@sirnak.edu.tr, Orcid ID: 0000-0002-1024-0812

INTRODUCTION

Extracting metals from ores as their primary sources requires investment of money and time in mineral exploration and development of ore preparation methods. Also, not only during the production process of these metals, but also after they have completed their useful life, large amounts of waste is generated. These wastes pose significant environmental problems but have significant economic value, as well. With the increasing demand for metals and the increase in production accordingly, limited ore resources, which are the main source of metals, are being depleted day by day.

Metal recovery from waste helps conserve natural resources by reducing the demand for virgin materials. This conservation is critical because many metals are finite resources. Metal recovery from waste also helps reduce the volume of waste that ends up in tailing dams, waste dumps or landfills. Where metal content of landfills can leak into the ground and groundwater, could cause serious long-term environmental problems. This is essential not only for reducing landfill space but also for mitigating the environmental hazards associated with waste disposal.

Among these industrial wastes, there are examples of the recycle/recovery of different metals from industrial wastes such as slag, sludge, chimney ashes, red mud, metal and mining waste, coal ashes, batteries and electronic waste which occupy a significant place in terms of size and economy. By recycling and reusing metals from wastes, it is possible to extend the lifespan of the available resources and decrease the cost and the environmental degradation like habitat destruction and water pollution caused by many industries including mining, metal, energy, construction, electronic, automotive.

METAL RECOVERY FROM ELECTRIC ARC FURNACE (EAF) DUST

EAF dust, which is classified as hazardous waste, is produced during scrap melting in an electric arc furnace and collected using bag filters or electrostatic precipitators then stored as a pellet. In 2010, EAF facilities created around 400,000 tons of dust. This amount of dust and slag produced as waste has risen even more due to the current growth in steel production values. The micron size EAF dust ($d_{80} \approx 2$ μm) contain iron oxides (Fe_xO_y), zinc ferrirte

($ZnFe_2O_4$), zinc oxide (ZnO) lead oxide (PbO), titanium oxide (TiO_2), cadmium oxide (CdO), chromium oxide (CrO), alkaline chlorides ($NaCl$, KCl) and Zn-Mn silicates. (de Araújo, 2014; Marzinc, 2010; Çifçi, 2014; Lin et al., 2017)

Instead of treatment with methods such as stabilization and solidification studies in the fields of pyrometallurgy, hydrometallurgy and bio-hydrometallurgy have increased considerably in recent years, thus several efficient results are obtained in waste recycling. Choosing hydrometallurgical and bio-hydrometallurgical methods for recycling EAF wastes is advisable, as these methods are more cost-effective, eco- friendly, and efficient compared to pyrometallurgical processes.

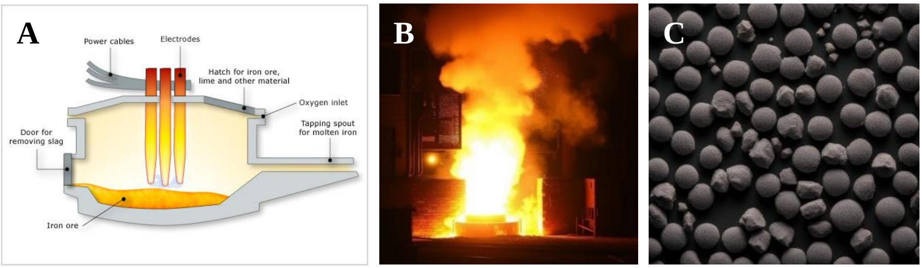

Figure 1. A) Diagram of an electric-arc-furnace, **B)** An image of EAF, **C)** Pelletized EAF Dust
Source: “https://teara.govt.nz/en/diagram/5885/electric-arc-furnace”

In the last decades numerous studies have been conducted on metal recovery from EAF wastes using hydrometallurgical methods, including chemical leaching processes with various acids and bases as reactants. During treating EAF dust and recovering Zn from it using both acidic and alkaline leaching procedures, the loss of zinc resulting from the low leaching efficiencies of zinc ferrites’ complex structures is thought to be of significant concern. Traditional acidic and alkaline leaching methods are unable to efficiently leach the zinc ferrites in the EAF dust due to issues with zinc calcine leaching processes. Zinc ferrites will readily generate when metallic zinc and iron combinations are roasted to temperatures over 650°C, where melting and roasting are carried out in EAFs. Between one-fifth and one-half of the Zn content of the dust could be found in the form of zinc ferrites (Youcai & Chenglong, 2017).

Sulfuric acid (H_2SO_4) is the most popular leaching agent used for extracting zinc ferrites from the dust. But still Sulfuric acid solution is useless towards zinc ferrites. Some modifications could be helpful, like pretreatment with acetic acid solution, sulphide precipitation and dissolution with H_2SO_4 solution. Another approach is extraction zinc ferrites with hot sulfuric acid solution, in a same way of leaching residues of hydrometallurgical process of zinc remainders. The major contents of dust iron oxides, that will be dissolved in acidic solution, hence the removing (neutralization and/or precipitation) of Fe from this solution is an important impediment to the use of this leaching technique in industry (Youcai & Chenglong, 2017).

Likewise, even though zinc oxide is known to dissolve easily in alkaline solution, zinc ferrites cannot be broken down by using alkaline solution, regardless of the solution temperature and sodium hydroxide (NaOH) concentration utilized. Jarupisitthorn et al. (2002) investigated parameters affecting Zn recovery from EAF flue dust using sodium hydroxide (NaOH) in their study. Shawabkeh (2009) studied Zn recovery from Jordanian EAF flue dust using sulfuric(H_2SO_4), nitric (HNO_3), and hydrochloric (HCl) acids, achieving the highest removal efficiency of 72% with sulfuric acid. Ruiz et al. (2005) used ammonia (NH_3) to obtain pure zinc oxide (ZnO) from EAF flue dust, dissolving Zn and other impurities (Cd, Cu, etc.). In Turkey, a study determined optimum conditions using NaOH for Zn and Pb recovery from EAF dusts, achieving 85% Zn and 90% Pb recovery, followed by Zn cementation and purification (Orhan, 2004; Çifçi, 2014).

Xia and Pickles (1999) investigated the transformation of zinc ferrite ($ZnFe_2O_4$) present in dust into sodium zincate (Na_2ZnO_2) and hematite (Fe_2O_3) during a subsequent dilute caustic leaching process. Both zincite (ZnO) and sodium zincate were found to be soluble, whereas hematite exhibited relative insolubility. Their study demonstrated that the combined roasting and leaching process achieved a zinc recovery rate of approximately 95%, with most of the iron oxide remaining in the leach residue. Additionally, recoveries of lead, cadmium, and chromium were observed at around 85%, 89%, and 37%, respectively, under roasting conditions that included added moisture. Based on these findings, the authors proposed a hybrid approach integrating low-temperature roasting, dilute caustic leaching, zinc cementation, and electrowinning, which is further elaborated upon in their discussion (Xia and Pickles, 1999).

The process produced two by-products: zinc dust, which contained more than 50% zinc due to the metal's volatilization during the sintering process, and pre-cast agglomerated, which had a total Fe content of over 70% and was collected by filter bags. Furthermore, around 90% of the Pb and Cd present in the original EAF dust was removed (de Araújo and Schalch, 2014).

METAL RECOVERY FROM BAYER PROCESS RESIDUE (RED MUD)

The process patented by Bayer in 1892 revolutionized mineral processing by making it economically and operationally feasible to extract alumina from bauxite ore on a large scale. Bayer himself observed that this process inevitably produced substantial amounts of residue (red mud), which he identified as a possible source of iron due to its high Fe and low Al content. Typical bauxite residue of the Bayer process appears red or reddish-brown, thus it is commonly known as red mud. Red mud has caused serious environmental problems, owing to its high alkalinity, heavy metal content and large output. The worldwide stocks of bauxite residue stored on land currently is expected to be over 2.7 billion tons, with an annual increase of 120 million tons. Typically, 1.75 tons of bauxite residue for every ton of alumina produced by refineries. Despite its huge amount, regulated storage in certain areas reduces the negative environmental effect (Klauber C, et al., 2009).

One of the biggest environmental disasters in recent years occurred in 2010, when residue reservoir containing some 30 million cubic meters of waste from an aluminium factory in the village of Ajka, in western Hungary, collapsed and one million cubic meters of red mud flow and cause an environmental catastrophe shows the vital importance of this issue.

The disposal and reuse of red mud have become critical challenges for alumina industries, necessitating the development of more innovative and efficient techniques. To date, red mud has been explored for various applications, including its use as adsorbents, construction materials, catalysts, refractories, ceramics, cements, bricks, geopolymers, fillers, adsorption materials, nanomaterials, and pigments. Bauxite residue consists mainly of iron (Fe), aluminium (Al), silica (Si), sodium (Na), and titanium (Ti) with trace amounts of potassium (K), chromium (Cr), nickel (Ni), vanadium (V), zinc (Zn), cobalt (Co), rare earth elements including neodymium (Nd), scandium (Sc), cerium (Ce), Gadolinium (Gd), Samarium (Sm), lanthanum (La), yttrium (Y), Praseodymium (Pr), europium (Eu), dysprosium (Dy), holmium (Ho), Niobium (Nb), Zirconium (Zr). Given the presence of several valuable components in red mud, the recovery of metals such as sodium (Na), calcium (Ca), iron (Fe), aluminium (Al), titanium (Ti), scandium (Sc), and rare earth elements (REEs) has been extensively investigated (Zhou et al., 2008; Li et al., 2024; Klauber C, et al., 2009).

Figure 2. An image of bauxite residue (red mud) tailing dam

More than simply the creation of technological solutions is needed to effectively convert bauxite residue from a tail or by-product that must be disposed of at a cost into a lucrative product. To completely utilize red mud (bauxite residue), several methods are now accessible. However, there are main challenges that need to be solved such as large volume of residues, efficient soda removal or treatment, heavy and radioactive metals, and the economics of further downstream processing (Klauber C, et al., 2009).

The production of alumina from bauxite waste due to the embargo and import restrictions in the United States during the World War II show the possibility of utilizing these wastes as alumina source.

Any process designed to extract only iron from bauxite tail is not likely to be efficient. Similarly, finding a feasible way to recover alumina from residue is difficult because it would need either sintering or acid treatment which are less efficient and economical than the Bayer process itself. Recycling and production of several metals including iron, aluminium/alumina and titanium in a single plant could be the only feasible way to process bauxite residue.

There are several studies that examined procedures for the recovery of Fe, Al, and Ti, both separately and in combination. The primary goal of recovering multiple main metals is to increase value while minimizing residual solids generated (Thakur et al., 1983; Paramaguru et al., 2005). Other studies proved that pig iron, pigment grade TiO_2, and $Al_2(SO_4)_3$ could be produced by a progressive smelting and hydrometallurgy method. Pig iron could be recovered by smelting, solid state reduction and/or magnetic separation. While titanium oxide recovery is available by acidic (e.g. HCl) leaching (Ercag and Apak, 1997).

Atasoy (2007) compared Seydişehir (Turkey) and Aughinish (Ireland) residues and concluded that the red mud from Seydişehir would be more suitable for Fe recovery (Klauber C, et al., 2009).

Metal Recovery from Industrial Ash (Petroleum and Coal Combustion Ashes)

Industrial ashes are solid residues mostly produced due to combustion of petroleum, crude oil, coal or coke as fuel in the power plants or thermal treatment of various materials. Ash is generally classified into two types, bottom ash and fly ash. Fly ash is a fine powder rich in silica, alumina, metals, and other minerals, whereas bottom ash is coarser and accumulated at the bottom of boilers after coal combustion. (Xiao et al., 2010; Ziyadanogullan & Aydin, 2004)

Figure 3. A typical image of fly ash

Coals and petroleum are complex fossil fuels that contain two organic and inorganic matters. Other than carbon based organic matters, inorganic components consist of silicates, oxyhydroxides, sulphates and carbonates. Thus, coal (and petroleum in trace amount) rarely contains metals such as aluminium (Al), iron (Fe), uranium (U), nickel (Ni), Magnesium (Mg) vanadium (V), molybdenum (Mo), Tungsten (W), scandium (Sc), germanium (Ge), gallium (Ga) and rare earth elements (Xiao et al., 2010; Tolhurst 2015; Ma et al., 2021; Zhang et al., 2021; Arroyo et al, 2009).

There are several scientific investigations and business companies underway to extract metals from coal ash, where each use different methods and technologies (Tolhurst, 2015).

Metals are recycled from ashes using pyrometallurgical, hydrometallurgical, or combined approaches. Common methods for treating coal ash include direct leaching, roast-leaching, and autoclave leaching. Direct leaching typically employs sulfuric acid (H_2SO_4) as a leachant due to its cost-effectiveness, wide availability, and high efficiency in dissolving metals such as aluminium, iron, uranium, nickel, molybdenum, vanadium, and titanium. Autoclave leaching, conducted in an aqueous solution under elevated temperature and pressure, facilitates higher recovery rates (Ziyadanogullan & Aydin, 2004).

Several metal content such as Al, U, Ni, Mo, and V were recovered from asphaltite ash in a study that involved flotation of a sulfurized ash sample (by adding H_2S), followed by the separation of Al and U from the ash by ammonium carbonate $(NH_4)_2CO_3$ leaching and participation with ammonium chloride NH_4Cl. Sulfuric acid (H_2SO_4) solution leached the solid residue comprising Mo, V, Ni, Ti, and Fe, and solvent extraction was used to extract the organic phase of Mo; then, MoS_3 was obtained by adding H_2S (Ziyadanogullan & Aydin, 2004).

Ma et al. (2021) in their study investigate a clean and energy efficient method for recovery Al and Ti from coal fly ash, by using microwave heating in the presence of sulfuric acid and ammonium hydrogen sulphate (H_2SO_4 + NH_4HSO_4) mixture as extract followed by water leaching which more than 80% and 55% of aluminium and iron was extracted respectively. Compared to conventional acidic baking methods, this approach reduced energy usage and gas emissions while increasing the extraction efficiencies of Al and Ti metals (Ma et al., 2021).

In their review, Xue and Liu (2021) compared various treatment methods for fly ash containing heavy metals released from Municipal Solid Waste Incineration (MSWI) plants, which cause serious threats to human health and the environment, compared number of treatment techniques, including thermal treatment, hydrothermal treatment, pyrolysis process, solidification-stabilization and leaching process (Xue and Liu, 2021).

Sulfuric acid (H_2SO_4) is widely used as an industrial leaching agent due to its non-volatile nature and strong solubility for metals such as zinc (Zn), indium (In), and iron (Fe) in municipal solid waste incineration (MSWI) fly ash. However, additional heavy metal solidification methods are necessary, as lead (Pb), one of the most hazardous elements in MSWI fly ash, is insoluble in sulfuric acid (Nagib & Inoue, 2000). Conversely, other studies have demonstrated that hydrochloric acid (HCl) effectively dissolves both Zn and Pb from MSWI fly ash at high rates.

Kang et al. (2020) investigate the treatment of heavy metals in municipal solid waste incineration (MSWI) fly ash using four different leaching solutions—water, NaOH, KOH, and NH_4OH—followed by carbon dioxide (CO_2) uptake. They achieved remarkable results in the recovery of heavy metals and have shown that alkaline solutions can be used (Kang et al., 2020). Xiao et al (2010) studied recovery of vanadium in the form of Vanadium oxide (V_2O_5) and ferrovanadium (FeV) from petroleum fly ash. (Xiao et al., 2010).

Additionally, several studies have explored recovery of metals such as germanium (Ge) and gallium (Ga) from fly ashes. Arroyo et al, (2014) test varied extractants including oxalic acid, water, sulfuric acid (H_2SO_4), hydrochloric acid (HCl), sodium hydroxide (NaOH), calcium oxide (CaO). They achieve relatively high Ge extraction using H_2SO_4 and NaOH, long extraction time and low Ga leaching selectivity are two of the obstacles to the feasibility of the method (Arroyo et al., 2014).

Zhang and Xu (2017) in their study propose an effective and green recycling method which vacuum reduction and chlorinated distillation process used for purification Ge, thus high recovery rate of Ge recovery and producing high grade metallic germanium form ash is available (Zhang & Xu, 2017).

CONCLUSION

Metal recycling from industrial waste is essential for conserving natural resources, reducing environmental hazards, and advancing sustainable industrial approaches. The recovery of metals from materials such as electric arc furnace dust, Bayer process residues, and industrial ashes highlights the immense potential of industrial waste as a resource rather than a pollutant. Methods including hydrometallurgy, pyrometallurgy, and advanced processes demonstrate promising results in extracting metals efficiently, minimizing waste, and reducing environmental impacts of wastes. Although, these techniques have advanced significantly, issues like processing efficiency, economic viability, and by-product management still exist. Innovative and integrated approaches, including combined recovery methods and the development of green technologies, are crucial for overcoming these challenges.

This chapter emphasizes the importance of ongoing research and technological innovation in metal recycling to recycling industrial waste into a valuable product, for a more sustainable and green future.

REFERENCES

Arroyo, F., Font, O., Chimenos, J. M., Fernández-Pereira, C., Querol, X., & Coca, P. (2014). IGCC fly ash valorisation. Optimisation of Ge and Ga recovery for an industrial application. *Fuel Processing Technology*, 124, 222-227. https://doi.org/10.1016/j.fuproc.2014.03.004

Atasoy, A. (2007). The comparison of the Bayer process wastes on the base of chemical and physical properties. *Journal of thermal analysis and calorimetry*, 90, 153-158. https://doi.org/10.1007/s10973-005-7671-y

Çiftçi H., & Alandağ, S., (2014) Elektrik ark fırını (EAF) atıklarından metallerin geri kazanımında çevre dostu yöntemler (Environmentally friendly processes in metals recovery from electric arc furnace (EAF) wastes), *Recycling Industry*, 80

de Araújo, J. A., & Schalch, V. (2014). Recycling of electric arc furnace (EAF) dust for use in steel making process. *Journal of Materials Research and Technology*, 3(3), 274-279. https://doi.org/10.1016/j.jmrt.2014.06.003

Huang, K., Inoue, K., Harada, H., Kawakita, H., & Keisuke, O. (2011). Leaching behavior of heavy metals with hydrochloric acid from fly ash generated in municipal waste incineration plants. *Transactions of Nonferrous Metals Society of China*, 21(6), 1422-1427. https://doi.org/10.1016/S1003-6326(11)60876-5

Kang, D., Son, J., Yoo, Y., Park, S., Huh, I. S., & Park, J. (2020). Heavy-metal reduction and solidification in municipal solid waste incineration (MSWI) fly ash using water, NaOH, KOH, and NH_4OH in combination with CO_2 uptake procedure. *Chemical Engineering Journal*, 380, 122534. https://doi.org/10.1016/j.cej.2019.122534

Klauber, C., Gräfe, M., & Power, G. (2009). Review of bauxite residue “re-use” options. *Waterford, WA: CSIRO Minerals*, 1-77.

Lin, X., Peng, Z., Yan, J., Li, Z., Hwang, J. Y., Zhang, Y., Li, G., & Jiang, T. (2017). Pyrometallurgical recycling of electric arc furnace dust. *Journal of Cleaner Production*, 149, 1079-1100. https://doi.org/10.1016/j.jclepro.2017.02.128

Ma, Y., Stopic, S., Xakalashe, B., Ndlovu, S., Forsberg, K., & Friedrich, B. (2021). A cleaner approach for recovering Al and Ti from coal fly ash via microwave-assisted baking, leaching, and precipitation. *Hydrometallurgy*, 206, 105754. https://doi.org/10.1016/j.hydromet.2021.105754

Nagib, S., & Inoue, K. (2000). Recovery of lead and zinc from fly ash generated from municipal incineration plants by means of acid and/or alkaline leaching. *Hydrometallurgy*, 56(3), 269-292. https://doi.org/10.1016/S0304-386X(00)00073-6

Orhan, G. (2005). Leaching and cementation of heavy metals from electric arc furnace dust in alkaline medium. *Hydrometallurgy*, 78(3-4), 236-245. https://doi.org/10.1016/j.hydromet.2005.03.002

Paramguru, R. K., Rath, P. C., & Misra, V. N. (2004). Trends in red mud utilization–a review. *Mineral Processing & Extractive Metall. Rev.*, 26(1), 1-29. https://doi.org/10.1080/08827500490477603

Thakur, R. S., & Sant, B. R. (1983). Utilization of red mud. 2. Recovery of alkali, iron, aluminum, titanium and other constituents and the pollution problems. *Council of Scientific and Industrial Research*

Tolhurst, L. (2015). Commercial recovery of metals from coal ash. *2015 World of Coal Ash (WOCA) Conference in Nashvhille*, May 5-7, 2015

Xia, D. K., & Pickles, C. A. (1999). Caustic roasting and leaching of electric arc furnace dust. *Canadian metallurgical quarterly*, 38(3), 175-186. https://doi.org/10.1016/S0008-4433(99)00014-2

Xiao, Y., Mambote, C. R., Jalkanen, H., Yang, Y., & Boom, R. (2010). Vanadium recovery as FeV from petroleum fly ash. *Proceedings of the Twelfth International Ferroalloys Congress Sustainable Future, Helsinki, Finland*, 6-9.

Xue, Y., & Liu, X. (2021). Detoxification, solidification and recycling of municipal solid waste incineration fly ash: A review. *Chemical Engineering Journal*, 420, 130349.

Youcai, Z., & Chenglong, Z. (2017). *Pollution control and resource reuse for alkaline hydrometallurgy of amphoteric metal hazardous wastes*. Cham, Switzerland: Springer International Publishing.

Zhang, L., & Xu, Z. (2017). Application of vacuum reduction and chlorinated distillation to enrich and prepare pure germanium from coal fly ash. Journal of *Hazardous Materials*, 321, 18-27. https://doi.org/10.1016/j.jhazmat.2016.08.070

Xue, Y., & Liu, X. (2021). Detoxification, solidification and recycling of municipal solid waste incineration fly ash: A review. *Chemical Engineering Journal*, 420, 130349. https://doi.org/10.1016/j.cej.2021.130349

Zhou, H., Li, D., Tian, Y., & Chen, Y. (2008). Extraction of scandium from red mud by modified activated carbon and kinetics study. *Rare Metals*, 27(3), 223–227. https://doi.org/10.1016/S1001-0521(08)60119-9

Ziyadanoğullari, R., & Aydın, I. (2004). Recovery of uranium, nickel, molybdenum, and vanadium from floated asphaltite ash. *Separation science and technology*, 39(13), 3113-3125.

CHAPTER 3

WASTE MANAGEMENT AND SUSTAINABILITY IN GOLD PRODUCTION WITH AMALGAMATION PROCESS

Asst. Prof. Dr. Sadiye KANTARCI[1], Asst. Prof. Dr. İlhan EHSANİ[2]

DOI: https://dx.doi.org/10.5281/zenodo.14540659

---

[1] Şırnak University, Faculty of Engineering, Department of Mining Engineering, Şırnak, Türkiye. sadiyekantarci@sirnak.edu.tr, Orcid ID: 0000-0002-1024-0812

[2] Şırnak University, Faculty of Engineering, Department of Mining Engineering, Şırnak, Türkiye. ilhanehsani@sirnak.edu.tr, Orcid ID: 0000-0001-9741-8777

INTRODUCTION

Gold has held significant economic and cultural value for humanity throughout history. Today, it continues to be processed as a valuable mineral in many countries and has become a sector that supports economic development. Gold production is carried out using various methods. Currently, the most commonly used method for gold recovery is cyanidation. However, due to poverty and rising gold prices, many developing countries located in tropical regions prefer the amalgamation process using mercury (Hg) for gold (Au) recovery. Especially with the convergence of economic and social factors, amalgamation with mercury is widely used globally, particularly in artisanal and small-scale mining (ASGM), due to its low cost and ease of implementation (Valenzuela ve Fytas, 2002; Oraby, 2009). However, the amalgamation process also raises environmental and health concerns. Figure 1 shows the density map of primitive and small-scale miners using mercury for gold recovery worldwide.

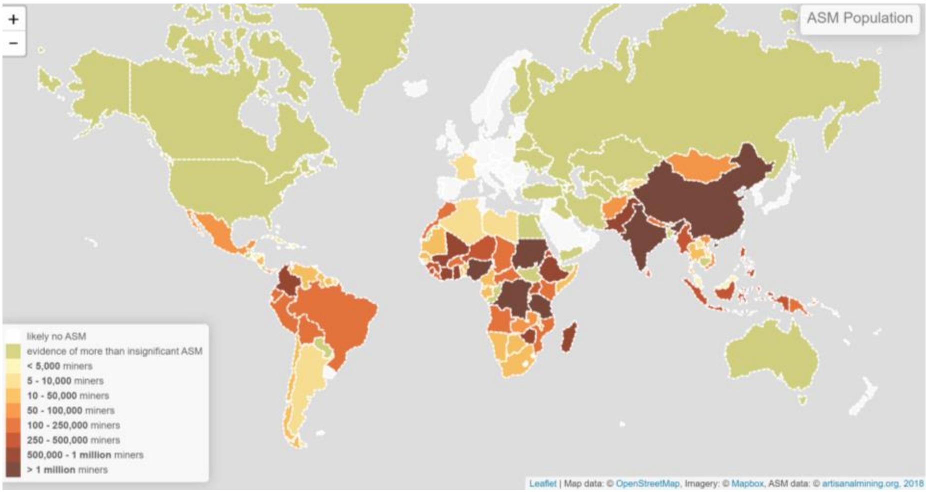

Figure 1. Density map of primitive and small-scale mines producing gold through amalgamation worldwide

Source: URL-1

Although officially banned in many countries, this method is preferred by many mining companies due to its low cost and simplicity of use (Esdaile & Chalker, 2018). This chapter will examine the gold production process through amalgamation, the environmental impacts and harms of mercury used in this process, waste management, and sustainability proposals.

DEFINITION AND PROCESS OF AMALGAMATION

The amalgamation technique, used for many years, has been a subject of research, but it is still not possible to say that the nature of amalgams is fully understood. There are various approaches suggesting that the process results from the surface tension difference between mercury, water, and gold, the difference in specific gravity, or the solvent nature of mercury, leading to the formation of valuable metal-Hg amalgams. Generally, the amalgamation process is a concentration process where gold and/or silver in free gold ores is mixed with mercury (Hg) in an amalgamation drum or table, resulting in the combination of the precious metal with mercury (Hg) to form mercury-laden metal (Hg).

In the amalgamation process, the wetting of gold with mercury is not a true alloying process, but rather a moderate absorption of the two elements occurs (Veiga et al., 1995). Mercury's surface tension is higher than that of water but lower than that of gold, which causes mercury to adsorb on the surface of gold particles. Additionally, due to differences in specific gravity, mercury acts as a dense medium, allowing lighter gangue materials to float on top and thus embedding the gold in mercury to form amalgam. The solubility of gold in mercury at 20°C is only 0.06% (Veiga et al., 2006). In summary, amalgamation is a process where gold and mercury undergo a chemical reaction to form a gold-mercury combination. This method is particularly used to separate gold from low-grade ores and free gold deposits.

Small mining operations employ a variety of operational techniques. The type of ore used by gold producers determines the typical amalgamation techniques utilized:

1. Whole ore amalgamation: Mercury is added to the ore during gravity concentration, transferred to the grinding circuit, or processed using copper plates.

2. Only gravity concentrates are amalgamated: In barrels or mixers, concentrates and mercury are combined. Washing the amalgam in ponds, riverbanks, or water wells separates it from heavy minerals (EPBC2010/5477, 2010).

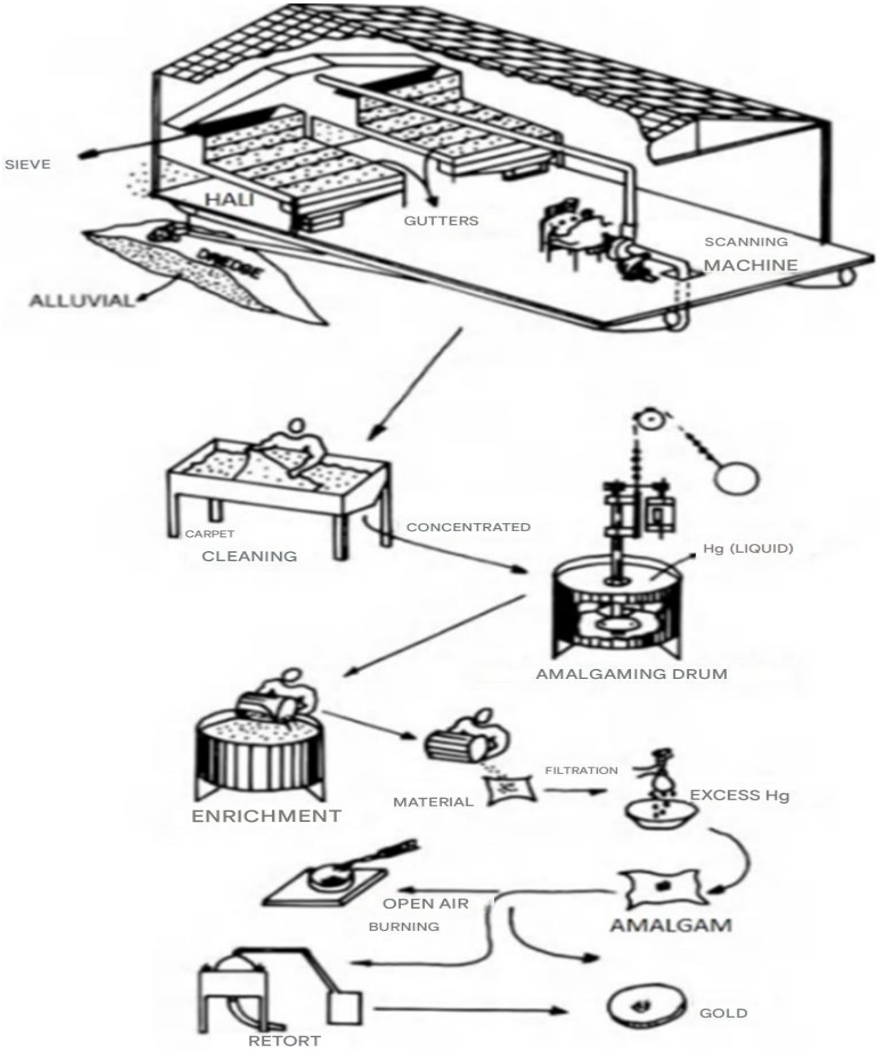

Figure 2. General flow chart for gold and silver production through amalgamation
Source: Lacerda & Salomans, 1998

The amalgamation process generally consists of several stages (Figure 2):

a) ***Preparation of the Mine:*** In the first stage, potential sources containing gold (rocks, sediments, etc.) are collected. These materials are then ground to reduce their size.

b) ***Mixing with Mercury:*** After being carried to amalgamation drums, the concentrate or pulverized material is combined with mercury and subsequently separated in circular pans. Alternatively, the powdered ore is floated in a slurry with water on slightly inclined plates, usually made of copper that has been amalgamated with mercury. Mercury interacts with gold particles to form amalgam. This stage is critical because the amount and quality of mercury used directly affects the amount of gold obtained.

c) ***Separation and Distillation****:* The mercury-gold amalgam is separated from other minerals and materials. When the obtained amalgam is heated, mercury vaporizes, resulting in impure gold bullion known as “Dore” (Figure 3) (Gunson, 2004). The remaining gold is obtained in pure form, while mercury creates side effects during this process.

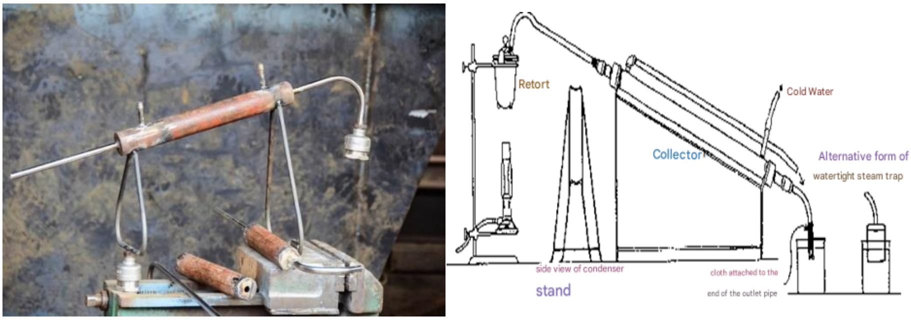

Figure 3. Image (left) and schematic image (right) of the distillation system used for mercury removal
Source: *URL-2, URL-3*

Figure 4. Appearance of amalgam before and after Hg removal in the distillation cell
Source: URL-4

AMALGAM WASTE

Gold and mercury combine to form a variety of compounds, such as $AuHg_2$ and Au_8Hg. There are three main gold-mercury compounds: $AuHg_2$, Au_2Hg, and Au_3Hg. At room temperature and 100°C, respectively, mercury can dissolve 0–14% and 0–65% of gold (EPBC2010/5477, 2010). However, due to the surface tension of gold compounds in the form of electrum (Au-Ag), amalgamation cannot be performed. Also, applying this method to small gold particles (<400 microns) is more difficulties. The presence of impurities (such as iron oxide, iron sulfide, tellurides, arsenic, antimony, and bismuth) in the environment complicates amalgamation and increases mercury consumption. The toxicity of mercury negatively affects human and environmental health, leading to a decline in the application of this process, which has been used since ancient times (Çilingir, 1996).

The use of this method has resulted in a significant amount of mercury (Hg)-contaminated waste. This waste is widespread around the world, but particularly concentrated in Africa and South America.

Mercury amalgamation is used in artisanal and small-scale gold mining by nearly 15 million workers in more than 70 countries. According to study done by Swain et al., (2007), artisanal mining activities in more than 50 developing countries produce between approximately 500 and 800 tons of gold annually, while this is not being officially documented. This amount corresponds to about 20-30% of global gold production (Swain et al., 2007; Velasquez-Lopez et al., 2011). Despite laws prohibiting mercury use, it is still widely used in small-scale gold mining. An estimated 1,000 tons of mercury are released into the biosphere each year, with an estimated 300 tons entering the atmosphere directly. Thus, it is estimated that gold mining facilities lose between 1 to 2 grams of mercury per gram of gold mined. Almost all the Hg consumed through these activities is somehow released into the environment. The leading consumers of Hg through these activities are believed to be Brazil, China, Colombia, Indonesia, Peru, the Philippines, Venezuela, and Zimbabwe (Swain et al., 2007). According to a study by Velasquez-Lopez et al (2011), amalgamation and gravity wastes contain 1.5-5 ppm gold and 150-350 ppm mercury. This situation highlights the significant Hg pollution in the waste resulting from gold production using Hg (Figure 5).

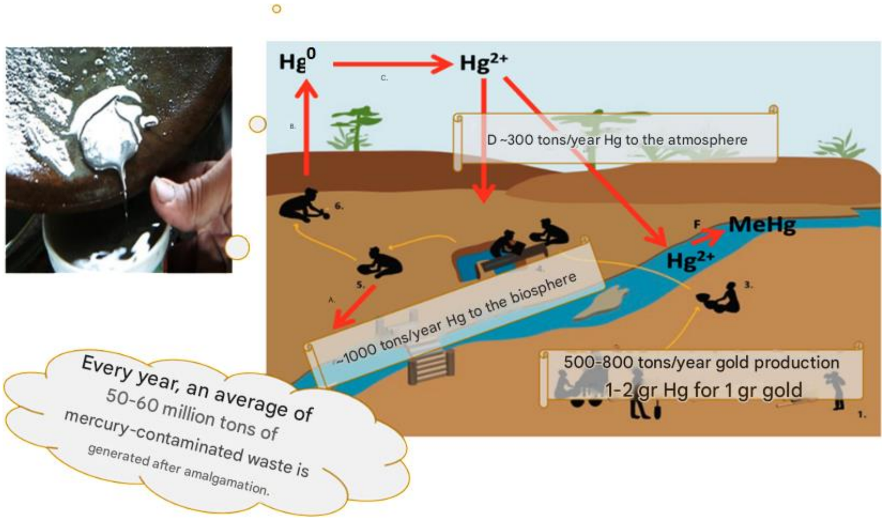

Figure 5. The extent of environmental impact of amalgamation waste

Environmental Effects and Toxicity of Mercury

In nature, mercury can be found in three different forms: elemental, inorganic, and organic. Which is known to be toxic and poses a danger in terms of environmental pollution and human health. Besides, the gold obtained through amalgamation has serious effects on the environment and human health. The most volatile form of mercury is metallic (elemental) one, which is present at room temperature as a liquid. When mercury combines with elements like chlorine, sulfur, or oxygen, it forms inorganic mercury compounds (mercury salts). The most commonly found inorganic mercury compounds include Hg-Sulfide complexes, $HgCl_2$, $HgCl^+$, $HgCl_3^-$, $HgCl_4^{2-}$, $Hg(OH)_2$, and Hg(OH)Cl. Organic mercury compounds, or organomercurials, are carbon-containing mercury compounds. Methyl mercury (CH_3Hg^+) is the most commonly found organic mercury compound (ATSDR, 1999; EPBC2010/5477, 2010; Tchounwou et al., 2012; Ullrich et al., 2001). Most mercury compounds with high vapor pressure are volatile, and mercury forms can be converted from one form to another and easily vaporized (Al-Malki, 2012; Coles & Cochrane, 2006). Mercury has high chemical and biological activity and tends to accumulate in living organisms. It creates a lot of harmful inorganic and organic bonds. When found as waste in the environment, it is quite difficult to eliminate (Antoszczyszyn & Michalska, 2016). The high evaporation property of elemental mercury at room temperature (Tchounwou et al., 2012), the ease of dissolution of mercury hydroxides in water (Cotton et al., 1999), and the relative stability of some organometallic compounds that can be easily broken down by certain living organisms (EPBC2010/5477, 2010) indicate that each type of mercury has its own toxic properties. However, mercury sulfide (HgS) or mercury selenide (HgSe) compounds are stable compounds with low solubility. Their solubility constants are 2.0×10^{-53} and 3.2×10^{-65}, respectively (Buketov et al., 1964; Coles & Cochrane, 2006; Jackson, 1986).

Mercury levels in the atmosphere are thought to be safe up to 0.05 mg Hg/m^3 (Coles & Cochrane, 2006). Mercury (Hg) is a neurotoxin that can be effective even in very small amounts, directly affecting the central nervous system and the kidney system. The type, form and duration of mercury (Hg) exposure determines the severity and type of mercury poisoning. Severe mercury (Hg) exposure, according to the World Health Organization (WHO), is when the amount of mercury excreted daily in urine exceeds 50 μg/day. In severe cases of mercury (Hg) poisoning, it affects the kidneys, nervous system, respiratory system, immune system, skin, mouth, teeth, and gums, and can lead to birth defects. Additionally, methyl mercury interferes with microtubule formation and protein synthesis in neurons. It interferes with DNA synthesis and changes the activity of cell membranes. As a result, it has highly toxic effects on the nervous system and can lead to coma and death in severe poisonings. Symptoms include cough, shortness of breath, fever, fatigue, gum inflammation, hallucinations, neurological symptoms, peeling of skin on hands and feet, and redness of the skin due to blood pooling in capillaries. If the blood mercury (Hg) concentration is below 10 μg/L in adults, it is considered normal for those with low occupational exposure (e.g., dentists) if the concentration is below 15 μg/L (URL-5, 2019).

In summary, mercury, a heavy metal, has the property of bioaccumulating. When released into the natural environment, it can harm ecosystems through water and soil. When mercury mixes with water sources, it can have toxic effects on organisms, particularly causing serious health issues in fish and other aquatic life.

WASTE MANAGEMENT AND SUSTAINABILITY

In the management of wastes originating from human activities, steps such as reducing waste generation at the source, ensuring reuse, preventing waste generation if possible and classifying wastes are important. The aim of waste management is to evaluate and evaluate these wastes without harming the environment and human health or to ensure their proper disposal. Therefore, despite the increase in the amount of waste, developing an effective and sustainable management strategy is becoming increasingly important.

Waste accumulation can cause environmental damage by polluting the air, water and soil and can pose major health risks to humans. The management of waste containing chemicals, including mercury, is a major concern. In addition, artisanal and small-scale gold mining (ASGM) contribute greatly to mercury pollution. Although ASGM is an important economic activity in many developing countries, it poses serious risks to both human health and the environment. The most serious of these risks is the unregulated release of mercury into the environment from mining activities. In this context, the "Minamata Convention on Mercury" was prepared under the leadership of the United Nations Environment Program (UNEP) regarding the importance of this issue. The scope of this agreement is related to the implementation of legislation restricting the use of mercury and controlling waste disposal and reducing the effects of mercury on the environment.

These issues need to be addressed in order to implement sustainable mining practices. Sustainable mining practices include various strategies to reduce the environmental impacts of waste resulting from the amalgamation process and improve waste management. These can be addressed under 5 headings: waste management and recycling, use of alternative technologies, education and awareness, policies and regulations, community participation and collaboration.

a) Waste Management and Recycling:

- For efficient waste management, it is important to collect and classify the amount and source of waste produced during the amalgamation process (Telmer & Veiga, 2009).

- In reducing mercury emissions, recycling mercury-containing waste will ensure that these wastes can be processed appropriately and reused (UNEP, 2013).

b) Use of Alternative Technologies:

- Other techniques that enable the recovery of gold without the use of mercury (e.g. G. leaching, gravity separation, etc. ought to be promoted to lower mercury consumption (Veiga et al., 2014).

- Cleaner production methods include the use of technologies that use fewer chemicals and use eco-friendly materials (Hinton et al., 2003).

- Ensuring the removal of mercury from the leach solutions formed after the leaching of mercury with cyanide by precipitation (Bucknam, 2004; Kantarcı & Alp, 2019, 2023; Misra et al., 1998)

c) Education and Awareness:

- Small-scale miners should be educated about the dangers of mercury use and substitution techniques to ensure the adoption of sustainable practices (Baker et al., 2016).

- Public education and awareness campaigns should be established regarding the negative effects of mercury and other hazardous wastes on the environment (Mäkelä et al., 2018).

d) Policies and Regulations:

- Developments in this field will be supported by the creation of certification schemes that encourage environmentally friendly mining methods (World Bank, 2017).

- Enacting legislation that restricts the use of mercury and controls waste disposal will help to lessen its effects on the environment (Minamata Convention, 2013).

e) Community Participation and Collaboration:

- Developing sustainable practices requires cooperation between the private sector, governments, and civil society organizations (Schmidt et al., 2019).

- Adoption of sustainable practices can be aided by involving local communities in decision-making processes (Bebbington & Bury, 2009).

In order to lessen the amalgamation process's negative environmental effects and promote environmental health, these sustainable mining techniques are essential.

CONCLUSIONS

Although the production of gold through amalgamation is an important source of income for small-scale miners, its negative effects on the environment and human health in the regions where mining is carried out cannot be ignored. The use of mercury and the damage caused by the waste to the environment and human health raise questions about the sustainability of this method. On the other hand, the fact that these wastes also contain gold with economic potential is also important in terms of their recovery as a secondary resource. Therefore, developing cleaner and more environmentally friendly methods is crucial for reducing environmental risks and protecting human health. In gold production, adopting sustainable practices such as social responsibility, use of innovative technologies, protecting the environment, providing economic benefits, compliance with legal regulations such as the Minimata Agreement can have positive results in many ways. To solve these problems, it is crucial for governments and the mining sector to cooperate in waste management to create a healthier environment and society.

REFERENCES

Al-Malki, A. R. (2012). *Development of Sorbent Materials to Remove Mercury from Liquid Hydrocarbons*. PhD Thesis, King Fahd University, Petrolium and Minerals, Dhahran, Saudi Arabia.

Antoszczyszyn, T., & Michalska, A. (2016). The potential risk of environmental contamination by mercury contained in Polish coal mining waste. *Journal of Sustainable Mining*, *15*(4), 191–196. https://doi.org/10.1016/j.jsm.2017.04.002

ATSDR. (1999). *Public Health Statement Mercury Public Health Statement Mercury*. Agency for Toxic Substances and Disease Registry. www.atsdr.cdc.gov/

Baker, R., May, J., & Duran, M. (2016). Artisanal and small-scale mining: A review of the environmental and social impacts. World Bank Group.

Bebbington, A., & Bury, J. (2009). Institutional challenges for mining and sustainability in Peru. Resources Policy, 34(1), 31-41. https://doi.org/10.1016/j.resourpol.2008.10.001

Bucknam, C. H. (2004). A green chemistry approach to mercury control during cyanide leaching of gold. *2004 SME Annual Meeting Preprints*, 667–673.

Buketov, E. A., Ugorets, M. Z., & Pashinkin, A. S. (1964). Solubility Products and Entropies of Sulphides, Selenides, and Tellurides. *Russian Journal of Inorganic Chemistry*, *9*(3), 292–294.

Çilingir, Y. (1996). Metalik Cevherler ve Zenginleştirme Yöntemleri. *D.E.Ü. Mühendislik Fakültesi Basımevi,* İzmir, Cilt 1.

Coles, C. A., & Cochrane, K. (2006). Mercury Cyanide Contamination of Groundwater From Gold. In *Sea to Sky Geotechnique* (pp. 1118–1122). http://www.engr.mun.ca/~ccoles/Publications/0227-231.pdf

Cotton, F. A., Wilkinson, G., Murillo, C. a., & Bochmann, M. (1999). Advanced Inorganic Chemistry, 6th Edition. In *Wiley-Interscience: New York*. https://doi.org/978-0-471-19957-1

EPBC2010/5477. (2010). Upper Goulburn Feral Mercury Recovery Project, Technical guidelines for the environmentally sound management of wastes consisiting of, containing or contaminated with Mercury - 5th draft. *Secretariat of the Basel Convention*, *January*, 12. http://www.chem.unep.ch/mercury/Sector-Specific-Information/Docs/waste/Basel_wastes_010110.doc%5Cnfile:///C:/Documents and Settings/clubb/My Documents/Basel_wastesl_010110.pdf

Esdaile, L. J., & Chalker, J. M. (2018). The Mercury Problem in Artisanal and Small-Scale Gold Mining. *Chemistry – A European Journal*, *24*(27), 6905–6916, https://doi.org/10.1002/chem.201704840.

Gunson, A. J. (2004). *Mercury and Artisanal and Small-Scale Gold Miners in Chine*. MSc thesis, Dept. Mining Engineering, University of British

Columbia. Vancouver, Canada.

Hinton, J. J., Veiga, M. M., & Beinhoff, C. (2003). The socio-economic impacts of artisanal and small-scale mining in developing countries. International Institute for Environment and Development (IIED).

Jackson, E. (1986). *Hydrometalurgical Extraction and Reclamation*. Ellis Horwood, England.

Kantarcı, S., & Alp, İ. (2019). Removal of mercury from cyanide solutions. *Karadeniz Chemical Science and Technology, 4*. https://dergipark.org.tr/tr/pub/kcst/issue/51487/584591

Kantarcı, S., & Alp, İ. (2023). Removal of mercury from cyanide leach solution using potassium amyl xanthate (PAX). *Separation and Purification Technology, 309*(December 2022). https://doi.org/10.1016/j.seppur.2022.123036

Lacerda, L. D., & Salomans, W. (1998). *Mercury from Gold and Silver Mining: A Chemical Time Bomb?* Springer-Verlag Berlin Heidelberg, New York.

Mäkelä, K., et al. (2018). Raising awareness of mercury pollution in artisanal gold mining. Finnish Institute for Occupational Health.

Misra, M., Lorengo, J., Nanor, J. B., & Bucknam, C. B. (1998). Removal of mercury cyanide species from solutions using dimethyl dithiocarbamates. *Minerals and Metallurgical Processing, 15*(4), 60–64.

Minamata Convention. (2013). Minamata convention on mercury. United Nations.

Oraby, E. A. (2009). Gold Leaching in Thiosulfate Solutions and Its Environmental Effects Compared With Cyanide. *Doktora Tezi, Curtin University of Technology, Scool of Engineering and Computing, Department of Civil Engineering*, 239. http://hdl.handle.net/20.500.11937/148

Schmidt, J., et al. (2019). Collaborative approaches to sustainable mining. GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit).

Swain, E. B., Jakus, P. M., Rice, G., Lupi, F., Maxson, P. A., Pacyna, J. M., Penn, A., Spiegel, S. J., & Veiga, M. M. (2007). Socioeconomic consequences of mercury use and pollution. *Ambio*, *36*(1), 45–61. https://doi.org/10.1579/0044- 47(2007)36[45:SCOMUA]2.0.CO;2

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Molecular, clinical and environmental toxicicology Volume 3: Environmental Toxicology. *Molecular, Clinical and Environmental Toxicology*, 101, 133–164. https://doi.org/10.1007/978-3-7643-8340-4

Telmer, K., & Veiga, M. M. (2009). World emissions of mercury from artisanal and small scale gold mining. In Global Mercury Project.

Ullrich, S. M., Tanton, T. W., & Abdrashitova, S. A. (2001). Mercury in the aquatic environment: A review of factors affecting methylation. *Critical Reviews in Environmental Science and Technology*, *31*(3), 241–293. https://doi.org/10.1080/20016491089226

United Nations Environment Programme (UNEP). (2013). Global mercury assessment 2013. UNEP Chemicals.

URL-1, http://artisanalmining.org/Inventory/, 28.12.2020

URL-2,https://www.theimpactfacility.com/retort-training-in-kakamega-keeping-safe-from-covid-19-and-mercury/,

URL-3, https://www.911metallurgist.com/mercury-amalgamation-gold-methods/)

URL-4,https://www.theimpactfacility.com/retort-training-in-kakamega-keeping-safe-from-covid-19-and-mercury/)

URL-5, https://www.centro.com.tr/wp-content/uploads/2018/12/Cıva-Zehirlenmesi.pdf, 14.12.2019

Valenzuela, A., & Fytas, K. (2002). Mercury Management in Small-Scale Mining. *International Journal of Mining, Reclamation and Environment*, *16*, 2–23.

Veiga, M. M., Hinton, J. J., & Sutherland, C. (2014). The role of alternative technologies in reducing mercury use in artisanal gold mining. United Nations Environment Programme (UNEP).

Veiga, M. M., Maxson, P. A., & Hylander, L. D. (2006). Origin and consumption of mercury in small-scale gold mining. *Journal of Cleaner Production*, *14*(3–4), 436–447. https://doi.org/10.1016/j.jclepro.2004.08.010

Veiga, M. M., Meech, J. A., & Hypolito, R. (1995). Educational measures to address mercury pollution from gold-mining activities in the Amazon. *Ambio*, *24*(4), 216–220.

Velasquez-Lopez, C. P., Veiga, M. M., Klein, B., Shandro, J. A., & Hall, K. (2011). Cyanidation of mercury rich tailings in artisanal and small-scale gold mining identifying. *Journal of Cleaner Production*, *19*, 1125–1133.

World Bank. (2017). Sustainable mining: A global perspective. World Bank Publications.

CHAPTER 4

A BRIEF REVIEW OF METAHEURISTIC OPTIMIZATION ALGORITHMS IN STRUCTURAL ENGINEERING: ENHANCING SUSTAINABILITY AND REDUCING CO_2 EMISSIONS

Asst. Prof. Dr. İbrahim Behram UĞUR[1]

DOI: https://dx.doi.org/10.5281/zenodo.14540667

---

[1] Şırnak University, Engineering Faculty, Civil Engineering Department, Şırnak, Türkiye. behramugur@sirnak.edu.tr, ORCID: 0000-0002-0950-4876

INTRODUCTION

The global construction sector has consistently been recognized as a major driver of environmental degradation, characterized by the extensive consumption of natural resources and the substantial emission of greenhouse gases (GHG) (Hong, Shen and Xue, 2016). According to recent estimates, approximately 39% of energy-related CO_2 emissions stem from the construction sector, primarily through the production and transportation of construction materials, and the operation of buildings. (Dean et al., 2016). This has led to a growing demand for innovative, environmentally sustainable solutions to mitigate the adverse effects of construction on climate change and natural resource depletion (Kc and Gautam, 2021).

In this context, metaheuristic optimization algorithms have emerged as indispensable tools for structural engineers aiming to reconcile economic, structural, and environmental goals. Unlike traditional optimization methods that require precise mathematical formulations and are often restricted to specific problems, metaheuristic algorithms are flexible, adaptable, and capable of solving complex, multi-objective problems. These characteristics make them well-suited for optimizing the design of structural systems where weight minimization, cost efficiency, and environmental impact reduction are paramount concerns.

This chapter explores the role of metaheuristic algorithms in promoting sustainability within structural engineering. Emphasis is placed on the integration of these algorithms in the design and optimization of steel, reinforced concrete (RC), composite, timber, and hybrid structures. Furthermore, the discussion highlights the significant environmental benefits achievable through these optimizations, including reduced embodied energy, lower carbon footprints, and more efficient resource utilization.

METAHEURISTIC OPTIMIZATION IN STRUCTURAL ENGINEERING: AN OVERVIEW

Metaheuristic algorithms are high-level problem-solving frameworks that iteratively refine potential solutions to find near-optimal results. They are particularly effective in handling large, non-linear, and multi-modal search spaces, often encountered in structural engineering problems. Unlike deterministic algorithms that may get trapped in local optima, metaheuristic approaches explore the solution space extensively, enhancing the likelihood of finding global optima.

Numerous metaheuristic algorithms, grounded in various conceptual frameworks, are documented in the literature. For the purposes of this review, a concise overview is provided, focusing on the most widely recognized and pertinent algorithms relevant to the objectives of this study, as outlined below:

Genetic Algorithms (GA): are metaheuristic methods inspired by genetics and the process of natural selection. They simulate the process of evolution by selecting, crossing over, and mutating candidate solutions (individuals) to obtain the best solution to a problem. The algorithm operates by generating an initial population of solutions, then calculating fitness values of each solution in the population, and then iteratively updating the population over several generations through processes such as selection, crossover, and mutation (Goldberg, 1989).

Particle Swarm Optimization (PSO): is a computational intelligence technique based on the social behavior of organisms, such as birds flocking or fish schooling. The algorithm employs a population of candidate solutions, termed particles, which explore the solution space. Each particle updates its position based on its own historical best position and the best position found by its neighbors, facilitating the convergence toward an optimal solution through a collaborative search process. Each particle adjusts its position based on its best-found solution and the best solution found by the entire swarm, allowing the algorithm to explore and exploit the search space. PSO is widely used for solving continuous and combinatorial optimization problems due to its simplicity and efficiency (Kennedy and Eberhart, 1995).

Simulated Annealing (SA): A metaheuristic method derived from the annealing process in metallurgy, where a material undergoes heating followed by controlled cooling to attain an optimal, stable configuration. In SA, potential solutions are treated like particles in a system that undergo a "heating" process (where higher energy states are allowed) and then "cooling" (where the system gradually settles into a low-energy state). The algorithm navigates the solution space by accepting both better solutions and worse ones with a specific probability to escape local optima, gradually narrowing the search for an optimal or near-optimal solution as the temperature decreases (Kirkpatrick, Gelatt, And Vecchi, 1983).

Gray Wolf Optimizer (GWO): A nature-inspired metaheuristic inspired by the social behavior and hunting strategies of gray wolves. It uses the roles of alpha, beta, delta, and omega wolves to guide the search process. The alpha wolf leads the search for optimal solutions, while the other wolves explore and refine potential solutions. GWO is widely used for solving complex optimization problems by simulating the wolves' encircling, hunting, and attacking behaviors (Nadimi-Shahraki, Taghian, and Mirjalili, 2021).

Crow Search Algorithm (CSA): A metaheuristic optimization algorithm inspired by the intelligent behavior of crows, particularly their food-searching strategies. The algorithm mimics the behavior of crows, where they explore and exploit the search space by iteratively adjusting their positions to find optimal solutions. CSA utilizes strategies like random exploration and local search to effectively balance exploration and exploitation, enhancing its efficiency in solving complex optimization problems (Askarzadeh, 2016).

Bonobo Optimizer (BO): Inspired by social behavior and mating strategies of bonobos, a species of great ape. The algorithm mimics the cooperative and competitive behaviors observed in bonobos, where individuals collaborate and compete for resources, with a focus on achieving optimal solutions through social interaction. The Bonobo Optimizer explores the search space by balancing exploration and exploitation, using a combination of cooperative moves and competitive strategies to guide the search process (Das and Pratihar, 2022).

Each of these algorithms is capable of addressing the complex interplay between structural efficiency, cost, and environmental impact, making them invaluable for advancing sustainable design practices in construction.

APPLICATIONS IN SUSTAINABLE STRUCTURAL SYSTEMS

Sustainable Design of Steel Structures

Steel structures are integral to modern construction due to their superior strength and durability. However, their production significantly contributes to global carbon emissions, necessitating the development of sustainable design strategies. Advanced optimization techniques have been employed to minimize CO_2 emissions, material usage, and construction costs while ensuring structural efficiency. The related studies are presented below:

- *Optimum Design of Sustainable Steel Structures*

Negarestani et al. (2024) explored the environmental and economic impacts of optimizing steel structures by analyzing the relationship between structural weight, carbon footprint, water consumption, and construction time. Utilizing the Gray Wolf Algorithm, they investigated how structural weight affects carbon and water footprints, as well as the duration and cost of construction. They also employed a multi-objective optimization algorithm to optimize three different building structures featuring various frame systems, each focusing on minimizing these objective functions (Negarestani et al., 2024).

The study found a direct relationship between the weight of the structure and the carbon dioxide emissions as well as water consumption during steel production. Reducing the weight of a structure by adhering to design limits not only improves serviceability and flexibility but also leads to significant reductions in CO_2 emissions and water consumption. However, the results indicated that the weight of the structure does not directly correlate with construction cost or time. Increasing construction costs did not result in lighter structures, and reducing weight did not necessarily reduce construction time.

Among the various frame systems studied, the structure composed of intermediate steel moment-resisting frames combined with the concentric bracing systems was found to be the most environmentally friendly, exhibiting the lowest water footprint, carbon emission, and the lightest weight among the analyzed structures. This frame system also proved to be the most cost-effective. On the other hand, the structure with simple steel moment-resisting frames had the minimum construction time, but it was more expensive and had a higher environmental impact.

These findings led to the conclusion that optimizing structural weight, particularly through the use of special concentric bracing, can result in a more sustainable and cost-efficient design. The study highlights the potential of metaheuristic algorithms, particularly the Gray Wolf Algorithm, in optimizing building structures for both environmental and economic objectives, promoting greener construction practices without compromising on performance or cost.

- *Carbon Emission Reduction for Truss Structures*

Lee at al. (2024) conducted a study focused on the optimal design of truss structures with the objective of minimizing carbon emissions, distinguishing their approach from previous research that primarily focused on other design factors. The study used the advanced Crow Search Algorithm (CSA), a metaheuristic, to evaluate carbon emissions generated by truss structures made from different materials, particularly comparing steel with timber. The analysis was conducted within the context of a construction located in the Republic of Korea, utilizing various truss designs with differing numbers of bars. The results showed that truss structures made from timber had lower carbon emissions compared to those made from steel. Moreover, within the timber structures, domestic timber produced fewer emissions than imported timber, suggesting that the source of timber plays a significant role in sustainability. The study emphasized the importance of considering carbon emissions during the design stage to achieve carbon neutrality in the construction industry. It was also noted that the weight of the structure directly correlated with carbon emissions, with heavier steel structures leading to higher emissions (Lee, Kim, and Lee, 2024).

The study advocates for the construction of timber structures, particularly using domestically sourced timber, to stabilize global climate changes and reduce carbon emissions in the construction field. Additionally, the study suggests that future evaluations should incorporate the entire life cycle of materials in the optimization process to provide more accurate and sustainable design solutions.

Sustainable Design of Reinforced Concrete Structures

Concrete is the most prevalent construction material globally; however, its production, particularly the manufacturing of cement, is a major source of global greenhouse gas emissions. Metaheuristic optimization offers innovative solutions for reducing these emissions by minimizing concrete consumption in building design, thereby reducing cement usage and associated carbon emissions. Relevant research contributions are outlined below:

- *Minimizing CO_2 Emission for Reinforced Concrete Structures*

Zaforteza et al. (2009) developed an approach for optimizing the design of reinforced concrete (RC) building frames, with the primary goal of minimizing the CO_2 footprint. This optimization was carried out using the Simulated Annealing (SA) algorithm, considering two main objectives: reducing CO_2 emissions and minimizing the cost of RC framed structures. The solutions were evaluated according to the Spanish Code for structural concrete, ensuring compliance with established standards. The methodology was implemented to a range of building frames, from 2 to 4 bays, with heights of up to 8 floors (Paya-Zaforteza et al., 2009).

The results from the SA algorithm show a close relationship between embedded CO_2 emissions and cost, with more environmental-friendly solutions available at a modest cost increase up to 2.77% higher than the lowest cost solutions. Conversely, the least expensive solutions resulted in a 3.8% increase in CO_2 emissions. The study concludes that the SA algorithm can effectively optimize structural designs for reduced CO_2 emissions while maintaining reasonable costs. Furthermore, it demonstrates the feasibility of achieving sustainable solutions with the SA algorithm in real-world building frame designs.

- *Optimizing Embodied Energy in Reinforced Concrete Structures*

Yeo and Gabai (2011) presented a study focused on optimizing the embodied energy in reinforced concrete structures, a critical aspect often overlooked in building design. While energy efficiency in building operation is widely recognized, the embodied energy, representing the energy consumed throughout the life cycle of materials used in construction, also plays a vital role in reducing overall environmental impact. The study applied structural optimization techniques, traditionally used to minimize cost or weight, to minimize embodied energy. They focused on optimizing the design of a basic reinforced concrete element, specifically a rectangular beam with fixed moment and shear capacities, in order to reduce its embodied energy. The results from the optimization indicated that it was possible to reduce the embodied energy by approximately 10%, at the cost of a 5% increase in material costs. The extent of the reduction in embodied energy was highly dependent on the cost ratio between steel reinforcement and concrete, which also included construction costs such as the installation of reinforcement and placement of concrete. The study highlights that by optimizing the design of structural members for embodied energy, a balance between energy efficiency and cost can be achieved. It recomemnds that future work should explore multi-objective optimization techniques, where both cost and embodied energy are considered simultaneously. They also propose including CO_2 or greenhouse gas emissions as additional indicators to further enhance the sustainability of structural designs. This approach sets the stage for more comprehensive and sustainable building designs by considering both operational and embodied energy factors (Yeo and Gabbai, 2011).

- *Multi-objective Optimization for Beam Design*

Santos et al. (2024) introduced a multi-objective optimization approach aimed at designing RC beams to decrease costs, CO_2 release, and concrete cracks, driven by the increasing scarcity of natural resources and the need for sustainable construction solutions. The study utilized the Non-dominated Sorting Genetic Algorithm (NSGA-II) for the optimization, considering conflicting objectives. The design variables included the beam's cross-sectional dimensions and the number of steel bars in the bottom layer, with varying spans and concrete strengths. The optimization resulted in Pareto frontiers that highlighted the most relevant parameters for each objective(dos Santos, Alves, and Kripka 2024).

The results revealed that solutions with minimum costs also corresponded to the lowest environmental impact, while greater beam width improved durability by minimizing cracks. Among the key findings, the height of the beams emerged as the most influential variable, with smaller heights optimizing both cost and environmental impact. However, to minimize cracks, an increase in beam height was necessary. The optimal width of the beam generally approached the lower limit specified by technical standards for cost and impact, while a larger base was favored for minimizing cracks to accommodate more steel bars.

Further analysis showed that concrete, which had the biggest effect on the environmental impact, was the smallest contributor to costs, while wooden formwork contributed the most to costs but had the least environmental impact. The study also found that higher concrete strength classes helped reduce costs but increased CO_2 emissions, especially for smaller spans. It is highlighted that the importance of evaluating environmental impacts based on CO_2 emissions from the cradle-to-gate phase.

- *Precast Prestressed Concrete Bridges*

Yepes et al. (2015) presented a methodology for the optimization of precast prestressed concrete (PC) road bridges with a double U-shaped cross-section, focusing on minimizing both cost and CO_2 emissions. To achieve this, they employed a hybrid Glowworm Swarm Optimization (SAGSO) algorithm, combining the strengths of Simulated Annealing (SA) for local search and Glowworm Swarm Optimization (GSO) for global search. The optimization process took into account various design variables, such as the materials, geometry, and reinforcement of both the slab and beam. It also included the use of high-strength concrete and self-compacting concrete in the beams. The results of the optimization provided useful guidelines for engineers designing PC precast bridges. A key finding was the strong relationship between cost and CO_2 emissions, where for every 1 Euro reduction in cost, approximately 1.75 kg of CO_2 emissions were saved. The study indicated that optimal solutions by minimizing costs also achieved favorable environmental outcomes, with minimal differences between the best possible environmental solution and cost-effective solutions. The study demonstrated that the hybrid SAGSO algorithm is an efficient tool for the optimum design of PC precast bridges, successfully balancing both cost and CO_2 emissions. The results highlighted that optimizing for CO_2 emissions typically required using larger volumes of concrete and adjusting reinforcement amounts, depending on whether cost or environmental impact was prioritized (Yepes, Martí, and García-Segura 2015).

Sustainable Composite Load-Bearing Structural Elements

Composite structures, which combine materials such as steel and concrete, represent a significant advancement in modern construction, offering superior strength, enhanced durability, and improved resistance to various environmental factors. These structures benefit from the unique properties of each material, such as the compressive strength of concrete and the tensile strength of steel, resulting in highly efficient load-bearing systems. This integration not only enhances structural performance but also opens new pathways for sustainable construction practices by reducing the overall material consumption and increasing the lifespan of structures. By employing optimization techniques, engineers can effectively balance multiple design objectives, including material efficiency, cost reduction, and environmental impact minimization. The pertinent studies are summarized as follows:

- *Minimizing CO_2 Emission for Prestressed Composite Beams*

Alves et al. (2024) conducted a study aimed at optimizing the design of prestressed steel-concrete composite beams with the primary objective of minimizing CO_2 emissions during the manufacturing phase. The research was grounded in Brazilian design standards and incorporated a range of design parameters, such as the steel beam dimensions, the type of steel decking for the slab, concrete compressive strength, and the number of tendons used. To address the optimization problem, the authors employed both the Self-Adaptive Bonobo Algorithm (SABO) and Particle Swarm Optimization (PSO) algorithms, with the results validated through comparison with both experimental and numerical data. A parametric analysis was carried out across span lengths aiming to define which geometric parameters have great significance influenced CO_2 emissions (Alves, Fiorotti, and Calenzani, 2024).

The results of the study revealed that prestressing is particularly beneficial for beams with spans exceeding 25 meters. The metal formwork and beam profile had substantial effects on final CO_2 emissions, with higher-strength concretes, although more CO_2-intensive, leading to reduced profile dimensions and lower overall emissions. Between the two optimization algorithms, SABO provided the best solutions, achieving emissions 9% lower than those obtained with PSO. The study further indicated that prestressing was particularly significant for beams with spans exceeding 27.5 meters for doubly symmetric profiles and 32.5 meters for monosymmetric profiles.

Regarding design failure modes, beams without tendons were primarily influenced by plastification from positive bending moments, while beams requiring tendons showed plastification due to both positive and negative bending moments. SABO algorithm offers effective solutions for minimizing CO_2 emissions in prestressed composite beam design, with the results highlighting the importance of prestressing for larger spans and the significant role of material selection in reducing the environmental impact of construction. The authors acknowledged the potential for further optimization using ultra-high-performance concrete and materials with higher strength and lower CO_2 emissions to achieve even more sustainable designs.

- *Optimum design of Concrete-filled Steel Columns*

Guimaraer et al. (2022) presented an investigation on optimizing the design of concrete-filled tubular columns, with a focus on minimizing both financial costs and CO_2 emissions during manufacturing. The optimization process adhered to the guidelines of related design code and was solved using a Genetic Algorithm (GA). The study examined three types of composite tubular columns under combined bending and compression, utilizing various cross-sectional shapes: Circular Hollow Section (CHS), Rectangular Hollow Section (RHS), and Square Hollow Section (SHS). The optimization considered two main objective functions: financial costs, expressed in Brazilian currency, and CO_2 emissions, measured in kilograms. Design variables included concrete strength and the potential inclusion of longitudinal rebar(Guimarães et al. 2022).

The results demonstrated that the most cost-effective and environmentally optimal design generally included a CHS profile, high-strength concrete, and no longitudinal rebar, except for cases involving unsymmetrical bending, where longitudinal reinforcement was deemed optimal. The optimization led to significant reductions in both production costs and CO_2 emissions, with savings of up to 48% in cost and 35% in CO_2 emissions compared to less favorable alternatives. Structural steel was found to have the greatest impact on both cost and emissions, contributing over 80% of the cost and emissions for columns without reinforcement, and more than 70% when longitudinal rebar was included. In contrast, concrete had the largest influence on CO_2 emissions, especially in columns with longitudinal reinforcement. The use of longitudinal reinforcement is only viable when the bearing capacity of the profile and concrete is surpassed, making it essential for certain design scenarios. The study also highlighted that higher concrete strength, although associated with higher CO_2 emissions, results in more efficient designs due to the structural resistance it provides when combined with the steel profile. The authors emphasized that the use of Genetic Algorithms (GA) for optimizing the design of these composite columns is an effective method for balancing cost, material consumption, and environmental impact, aligning with the growing demand for sustainable construction practices in the civil engineering sector.

- *Sustainable Design of Composite Truss Beams*

Erlacher et al. (2023) proposed a methodology for optimizing composite truss beams to minimize CO_2 emissions, using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). The optimization considered various design parameters, such as steel profiles, concrete strength, formwork, and truss height. Three truss models—Pratt, Howe, and Warren—were analyzed along with different profile types: double angles (DA), circular hollow tubes (CHT), and circular concrete-filled tubes (CCFT) (Erlacher, Calenzani, and Alves, 2023).

The Warren truss model, known for its equilateral triangle design, is a simple and efficient structure that evenly distributes loads across its members. This model, along with CCFT profiles, proved to be the most effective in reducing CO_2 emissions, particularly for longer spans. The Pratt truss, with vertical members in compression and diagonal members in tension, was also effective but slightly less efficient than the Warren model. The Howe truss, with its reversed configuration of compression and tension members, was the least efficient in terms of both cost and CO_2 reduction in the study.

The results showed that PSO generally outperformed GA in achieving the best solutions for minimizing both cost and emissions. The study highlighted that increasing concrete strength, while raising CO_2 emissions, helped reduce the use of steel, which ultimately lowered the overall carbon footprint of the structure. Additionally, the combined bending criterion played a crucial role in determining the optimal design, particularly influencing solutions with tubular profiles where bending moments were the dominant design factor.

CONCLUSION

Metaheuristic optimization has revolutionized structural engineering by enabling sustainable designs that maintain performance and cost-effectiveness. These advanced algorithms address complex challenges, such as reducing CO_2 emissions and optimizing resource use, contributing to the construction industry's sustainability goals. As the field evolves, the integration of environmental considerations in the design process through optimization will be crucial in shaping the future of construction. Future research should expand sustainability metrics, including energy consumption and material efficiency, to further refine optimization techniques and ensure they meet both performance and environmental goals, fostering a more sustainable built environment.

REFERENCES

Alves, É. C., Fiorotti, K. M., and Calenzani, A. F. G. (2024). "Reducing the Environmental Impact of Prestressed Composite Beams via SABO Algorithm." *Innovative Infrastructure Solutions* 9(12), 457.

Askarzadeh, A. (2016). "A Novel Metaheuristic Method for Solving Constrained Engineering Optimization Problems: Crow Search Algorithm." *Computers and Structures* 169. 1-12. doi: 10.1016/j.compstruc.2016.03.001.

Das, A. K., and Pratihar, D. K (2022). "Bonobo Optimizer (BO): An Intelligent Heuristic with Self-Adjusting Parameters over Continuous Spaces and Its Applications to Engineering Problems." *Applied Intelligence* 52(3). 2942-2974. doi: 10.1007/s10489-021-02444-w.

Dean, B., Dulac, J., Petrichenko, K., and Graham, P. (2016). "Towards Zero-Emission Efficient and Resilient Buildings.: Global Status Report."

Erlacher, G., Calenzan, A. F. G., & Alves, É. C. (2023). "Topological Optimization of Composite Trusses Considering CO_2 Emission via Metaheuristics Algorithms." *Revista IBRACON de Estruturas e Materiais* 16(6). e16606. doi: 10.1590/S1983-41952023000600006.

Goldberg, D. E. 1989. "Genetic Algorithms in Search, Optimization, and Machine Learning, Addison-Wesley, Reading" MA. (1989). *NN Schraudolph and J.,* 3.

Guimarães, S. A., Klein, D., Calenzani, A. F. G., and Alves, É. C. (2022). "Optimum Design of Steel Columns Filled with Concrete via Genetic Algorithm: Environmental Impact and Cost Analysis." *REM - International Engineering Journal.* 75(2). 117-125 doi: 10.1590/0370-44672021750034.

Hong, J., Shen, Q., and Xue, F. (2016). "A Multi-Regional Structural Path Analysis of the Energy Supply Chain in China's Construction Industry." *Energy Policy* 92, 56-68. doi: 10.1016/j.enpol.2016.01.017.

Kc, S., and Gautam, D. (2021). "Progress in Sustainable Structural Engineering: A Review." *Innovative Infrastructure Solutions* 6(2).

Kennedy, J. and Eberhart. R. (1995) "Particle Swarm Optimization." *1995 IEEE International Conference On Neural Networks Proceedings,* Vols. 1-6, Pp. 1942-48

Kirkpatrick, S., Gelatt, C. D. and Vecchi. M. P. (1983). "Optimization By Simulated Annealing." *Science* 220(4598), 671-80. doi: 10.1126/science.220.4598.671.

Lee, D., Jeonghyun K., and Seungjae L. (2024). "Optimal Design of Truss Structures for Sustainable Carbon Emission Reduction in Korean Construction." *Sustainability* 16(14), 5830.

Nadimi-Shahraki, M. H., Taghian, S., and Mirjalili, S. (2021). "An Improved Grey Wolf Optimizer for Solving Engineering Problems." *Expert*

Systems with Applications 166. 113917. doi: 10.1016/j.eswa.2020.113917.

Negarestani, M. N., Hajikandi, H., Fatehi-Nobarian, B., and Majrouhi Sardroud, J. (2024). “Design-Optimization of Conventional Steel Structures for Realization of the Sustainable Development Objectives Using Metaheuristic Algorithm.” *Buildings* 14(7), 2028.

Paya-Zaforteza, I., Yepes, V., Hospitaler, A., and Gonzalez-Vidosa, F. (2009). “CO_2-Optimization of Reinforced Concrete Frames by Simulated Annealing.” *Engineering Structures* 31(7). 1501-1508. doi: 10.1016/j.engstruct.2009.02.034.

dos Santos, N. R., Alves, E. C., and Kripka, M. (2024). “Towards Sustainable Reinforced Concrete Beams: Multi-Objective Optimization for Cost, CO_2 Emission, and Crack Prevention.” *Asian Journal of Civil Engineering* 25(1). 575-582. doi: 10.1007/s42107-023-00795-y.

Yeo, D.H., and Gabbai, R. D. (2011). “Sustainable Design of Reinforced Concrete Structures through Embodied Energy Optimization.” *Energy and Buildings* 43(8). 2028-2033. doi: 10.1016/j.enbuild.2011.04.014.

Yepes, V., Martí, J. V., and García-Segura, T. (2015). “Cost and CO_2 Emission Optimization of Precast-Prestressed Concrete U-Beam Road Bridges by a Hybrid Glowworm Swarm Algorithm.” *Automation in Construction* 49. 123-134. doi: 10.1016/j.autcon.2014.10.013.

CHAPTER 5

THE DEBATE SURROUNDING NUCLEAR POWER PLANTS: A CRITICAL ANALYSIS

Assoc. Prof. Ahmet TURŞUCU[1], Muhammed Said ULAŞ[2]

DOI: https://dx.doi.org/10.5281/zenodo.14540688

---

[1] Şırnak University, Engineering Faculty, Electric-Electronic Engineering, Şırnak, Türkiye. ahmettursucu@sirnak.edu.tr, Orcid ID: 0000-0002-4963-697X.

[2] Graduate School of Education, Sirnak University, Şırnak, Türkiye

INTRODUCTION

Nuclear power has long been a controversial topic, with proponents touting its potential as a clean and efficient energy source, while opponents raise concerns about safety, environmental impact, and radioactive waste.

The recent nuclear accident in Fukushima, Japan has reignited this debate, with many nations reconsidering their reliance on nuclear power (Gardoni et al., 2014). Proponents of nuclear power argue that it offers a viable solution to the growing global energy demand and the need to reduce greenhouse gas emissions (Taebi, B., 2011). They highlight the fact that nuclear energy can produce large amounts of energy from relatively small amounts of fuel, while generating minimal greenhouse gas emissions. Additionally, nuclear power can reduce a country's dependence on fossil fuels, which can be subject to geopolitical and price volatility (Taebi, B., 2011).

However, the opponents of nuclear power argue that the risks associated with nuclear energy, particularly the potential for catastrophic accidents and the long-term management of radioactive waste, outweigh the benefits. The Fukushima disaster, as well as previous incidents like Chernobyl and Three Mile Island, have eroded public trust in the safety of nuclear power plants (NPPs), making the public more skeptical of this technology.

As a result, the public's attitude towards nuclear energy has changed over time, with many communities opposing the construction of new nuclear power plants or nuclear waste repositories due to the perceived risks and the high social costs associated with their development.

NUCLEAR ENERGY

Nuclear energy is a type of energy released as a result of the splitting or merging of atomic nuclei. In a fission reaction, the splitting of these nuclei is achieved as a result of the bombardment of heavy radioactive materials with neutrons. A fusion reaction is a reaction that releases energy by the union of two smaller atomic nuclei. The use of the energy generated by fission and fusion reactions is called nuclear energy or nuclear energy.

The concept of nuclear energy dates back to 1895 with Wilhelm Rontgen. In 1939, it was seen that energy was released by the division of the atom (fission). After years of research, the first atomic weapon was made in 1945, and it gained a different dimension with the production of nuclear weapons during World War II. After the end of the war, the first nuclear power plant was built in the USA, and electricity began to be produced in the last days of December 1951. From the early months of the 1960s onwards, many countries, especially the USA and Japan, began to benefit from this technology at a high level.

Nuclear energy is used in many areas of our lives with nuclear reactions, apart from energy production. It is used primarily in the field of health; in medical applications, in industry; in the field of measurement and evaluation, etc., in agriculture; in the production of more qualified seeds, in the manufacture of weapons, in archaeological excavations; in the determination of the age of the remains. The concept of nuclear energy used in this thesis is accepted as nuclear power plants.

In order to meet the increasing energy deficit of developing and industrializing societies, energy generating facilities using fossil fuels have been and are being intensively utilized. However, as mentioned above, due to the risk of depletion of natural resources from which fossil fuels are obtained, the fact that these fuels are required in different areas such as heating and vehicle use, and the damage they cause to the environment as a result of not taking expensive precautions, their use has become a problem (Arlı et al., 2023). A renewable (sustainable) development requires both providing the energy produced in a more economical way and minimizing the damage to the environment we live in. When these are taken into consideration, it has become inevitable to search for new energy sources. At this point, the issue of nuclear energy production has come to mind as an alternative.

EFFECTS OF NUCLEAR POWER PLANTS ON CLIMATE CHANGE

As the world grapples with the urgent need to combat climate change, reducing greenhouse gas emissions has become a top priority for governments and organizations alike. Among the various energy sources available, nuclear energy stands out as a critical player in the transition to a more sustainable energy future. With the ability to produce large amounts of energy with minimal environmental impact, nuclear power plants offer a viable alternative to fossil fuels, which are notorious for their high carbon emissions. This article examines the fundamental role of nuclear power plants in reducing greenhouse gas emissions, focusing on their operational efficiency, comparative analysis of emissions, and the prospects of nuclear energy within global energy strategies.

The operational efficiency of nuclear power plants is a cornerstone in helping to reduce greenhouse gas emissions. Unlike fossil fuels, which often require extensive extraction and transportation processes that contribute to the overall carbon footprint, nuclear power produces a much higher energy output per unit of fuel. For example, a single nuclear reactor can generate about 1,000 megawatts of electricity, enough to power about 750,000 homes. In contrast, the same energy production from coal or natural gas would require much more significant amounts of these fuels. Nuclear power plants also have a relatively low land footprint compared to renewable energy sources such as wind and solar power plants, which often require large areas of land to produce equivalent energy levels. This is particularly important in densely populated areas where land use is a critical consideration. Nuclear power plants also provide continuous and reliable power generation without being affected by weather conditions that could disrupt solar or wind power production. This baseload capacity provides a stable electricity supply essential for modern economies and helps reduce reliance on fossil fuel-based power plants during periods of peak demand.

A thorough comparison of greenhouse gas emissions from nuclear energy and fossil fuels underscores the environmental benefits of nuclear power. It is essential to consider the entire life cycle of energy production, and studies have consistently shown that nuclear energy generates significantly lower carbon emissions compared to fossil fuels. According to research by the World Nuclear Association, nuclear energy's life cycle emissions stand at around 15 grams of CO_2 equivalent per kilowatt-hour, drastically lower than coal's 1,000 grams and natural gas's 450 grams. This substantial difference underscores nuclear energy's effectiveness in reducing greenhouse gas emissions. Additionally, nuclear energy plays a vital role in meeting international climate goals. The Intergovernmental Panel on Climate Change (IPCC) has recognized nuclear energy as a critical component in strategies to limit global warming to 1.5 degrees Celsius. By integrating nuclear energy into the energy mix, we not only mitigate emissions but also drive energy diversity, thereby enhancing energy security and stability.

Looking ahead, the future of nuclear energy in global energy strategies is driven by significant technological advances and changing policy frameworks that support its role as a clean energy source. Innovations such as small modular reactors (SMRs) promise to increase the safety, efficiency, and economic viability of nuclear power generation, making it more accessible and adaptable to a variety of energy needs. For example, SMRs can be installed in remote locations or regions with lower energy demand, providing a tailored solution for energy generation. In addition, many governments are increasingly recognizing the potential of nuclear energy to contribute to decarbonization efforts, leading to the creation of supportive policy frameworks and investment incentives. However, the success of nuclear energy in the public sphere depends largely on public perception and understanding. Educational campaigns that demystify nuclear technology address safety concerns, and highlight its environmental benefits are crucial to encouraging public acceptance. By increasing awareness and knowledge about nuclear energy, stakeholders can create a stronger foundation for its integration into the global energy landscape.

As a result, nuclear power plants play a crucial role in reducing greenhouse gas emissions, demonstrating operational efficiency, minimizing carbon output compared to fossil fuels, and promising future developments. As the world strives to meet ambitious climate goals, the integration of nuclear energy into the broader energy strategy is not only beneficial but essential (Simsek et al., 2021). By focusing on technological innovation, supportive policies, and effective public education, the full potential of nuclear energy can be realized, and the path to a cleaner, more sustainable energy future can be paved. The ongoing commitment to nuclear energy will undoubtedly remain a critical element in global efforts to combat climate change and achieve a carbon-neutral world.

DISCUSSION

Nuclear power plants play a significant role in reducing greenhouse gas emissions compared to fossil fuels (Tüylüoğlu & Türkan, 2023). Fossil fuels are the most significant contributors to environmental problems, including climate change as well as air and water pollution (Arı, 2023). In contrast, nuclear energy produces zero emissions during its operation, making it an environmentally friendly alternative (Duvar, 2024; Celebi et al., 2021). This stark difference in emissions highlights the importance of nuclear energy in the global energy landscape, especially as countries strive to meet climate goals. Nuclear energy's ability to provide reliable energy without the associated greenhouse gas emissions positions it as a critical player in the fight against climate change.

Examining the lifecycle emissions of nuclear energy further highlights its environmental benefits (Keskin, n.d.). While fossil fuel-based electricity generation has significant emissions throughout its lifecycle (from extraction to combustion), nuclear energy is mainly free of such emissions, the majority of which occur during construction and decommissioning (Tüylüoğlu & Türkan, 2023). However, these emissions are minimal compared to the carbon footprint of fossil fuels (Tursucu et al., 2019). By understanding the full scope of emissions associated with different energy sources, it becomes clear that nuclear energy offers a viable option for reducing overall greenhouse gas emissions and mitigating climate change impacts.

Studies have reported that magnetic and, more importantly, nuclear forces have significant effects on plant development. Although there is evidence of the existence of bacteria and microorganisms that are not affected by nuclear factors, the entire scientific world unanimously demonstrates that they have significant harmful effects on human life (Ulgen et al., 2017, 2020, 2021, 2023, 2024).

As the world moves towards a low-carbon energy future, nuclear energy can contribute significantly to achieving this goal (Duvar, 2024). With the increasing emphasis on energy efficiency and the phasing out of fossil fuels, the integration of nuclear energy with other low-carbon sources is vital for sustainable development (Topçu, 2018). Combining nuclear energy with renewables can help ensure a stable and reliable energy supply while minimizing carbon emissions. In this context, nuclear energy not only supports energy security but also aligns with broader climate initiatives aimed at reducing greenhouse gas concentrations in the atmosphere (Gardoni et al., 2014; Topçu, 2018; Dumrul et al., 2023).

CONCLUSION

Nuclear power plants (NPPs) are a vital source of electricity and energy production in the modern world when energy costs are at an all-time high. With the globe catching up to this technology and our country's high energy import costs combined with an annual budget deficit in the tens of billions of dollars, nuclear energy appears to be a vital alternative. In addition to all of this, the following can be used to summarize the conclusions that should be made regarding the energy production from NPPs, its effects on the environment, and the required safety measures:

- The use of nuclear power plants (NPPs) to generate nuclear energy is still up for discussion. Contrary to environmentalists' emphasis that nuclear energy is a disaster in this aspect, atomic energy experts and economists contend that nuclear energy is the safest and most effective energy source available. The notion that nuclear energy is extremely safe and efficient is prevalent when considering the instances provided in this study.
- The side radioactive waste products created by NPPs are stored using the proper techniques after being preserved for a period to lose their radioactivity. In addition to the ones currently in use, safer preservation techniques must be researched.
- Neighboring countries should emulate the construction of a nuclear power plant, as it is believed that there may be a variety of environmental damages in the areas where nuclear power plants are established, and that adverse effects and damages will also affect the environment in the event of an accident.
- Building artificial facilities that will be used as cooling water by the sea and in unpopulated areas seems to be a more cost-effective way to supply cooling water when building nuclear power stations. However, places by the sea are more popular for habitation and tourism. One factor that should be taken into account while identifying these locations is that they are remote and lack a residential area.
- Nuclear power plant operating organizations should adhere to these strict guidelines from the project stage onward, basing their design decisions on the fundamentals of "Detailed and Deep Safety" throughout the phases of building, design, and operation.

The general viewpoint and conclusions drawn from this investigation can be summed up as follows: Nuclear energy carries hazards, just like any other form of energy, but given the current global economic downturn and energy crises, as well as the country's own, it's inevitable that nuclear energy will play a significant role in our lives both now and in the future. Furthermore, it is anticipated that in the near future, the beneficial side of energy will prevail. After taking all of this into account, it has been determined that the policies pertaining to our nation's possession of this kind of energy are successful, appropriate, and crucial for both our society and our nation.

REFERENCES

Arı, F. (2023) Başlıca Enerji Kaynakları Ve Çevresel Etkilerinin Değerlendirilmesi. Dicle Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 13(26), 697-718. https://doi.org/10.53092/duiibfd.1340196

Arlı, F., Dumrul, H., & Taşkesen, E. (2023). Hydrogen Production from Solar Water Splitting Using Photocatalytic and Photoelectrochemical Technologies. BIDGE Publications.

Celebi, N. U. R. A. Y., Arlı, F., Soysal, F., & Salimi, K. (2021). Z-scheme ZnO@ PDA/CeO_2 heterojunctions using polydopamine as electron transfer layer for enhanced photoelectrochemical H_2 generation. Materials Today Energy, 21, 100765.

Dumrul, H., Fatih, A. R., & Taşkesen, E. (2023). Dust Effect on PV Modules: Its Cleaning Methods. *Innovative Research in Engineering. Duvar Publishing*.

Duvar, G. (2024). İklim değişimiyle mücadelenin yeni çözümü nükleere enerji mi?

Gardoni, P., Hillerbrand, R., Murphy, C., & Taebi, B. (2014). Panel-The ethics of nuclear energy in the post-Fukushima Era. In 2014 IEEE International Symposium on Ethics in Science, Technology and Engineering, 1-2. IEEE.

Keskin, M. T. Enerji Politikalarinin İklim Değişikliği ile Mücadeledeki Yeri, İklim Değişikliği Alanında Ortak Çabaların Desteklenmesi Projesi (iklimİN). İklim Değişikliği Eğitim Modülleri Serisi, 6.

Simsek, S., Uslu, S., Sahin, M., Arlı, F., & Bilgic, G. (2024). Impact of a novel fuel additive containing boron and hydrogen on diesel engine performance and emissions. *Energy sources, Part A: recovery, utilization, and environmental effects*, 46(1), 10846-10860. https://doi.org/10.1080/15567036.2021.1946621

Taebi, B. (2011). Ethics of nuclear power: How to understand sustainability in the nuclear debate. *Nuclear power-Deployment, operation and Sustainability*.

Topçu, F. H. (2018). Düşük karbon ekonomisine geçme (me): İklim değişikliği ve enerji politikaları bağlamında bir bakış. *Akdeniz İİBF*

Dergisi, 18(2018 Özel Sayısı), 115-154. https://doi.org/10.25294/auiibfd.463396

Tursucu, A., Haskul, M., & Ulgen, A. T. (2019). Non-Destructive Determination of Chemical Effects on Fluorescence Yields and Vacancy Transfer Probabilities of Tin Compounds. *Characterization and Application of Nanomaterials*, 2(1).

Tüylüoğlu, E. H., & Türkan, N. Nükleer Güç Santrallerinin Çevresel Etkileri. *OHS Academy*, 6(1), 50-58. doi: https://doi.org/10.38213/ohsacademy.1140898

Ulgen, C., & Turker, A. (2024). Impacts of three different magnetic field applications on seed germination and seedling development of Melissa officinalis L. *Biological Diversity and Conservation*, 17(1), 18-25.

Ulgen, C., Yıldırım, A. B., & Turker, A. U. (2017). Effect of magnetic field treatments on seed germination of melissa officinalis L. *International Journal of Secondary Metabolite*, 4(3, Special Issue 1), 43-49.

Ulgen, C., Yıldırım, A., & Turker, A. (2020). Enhancement of plant regeneration in lemon balm (Melissa officinalis L.) with different magnetic field applications. *International Journal of Secondary Metabolite*, 7(2), 99-108.

Ulgen, C., Yıldırım, A., & Turker, A. (2023). Melissa officinalis: Antibacterial and antioxidant potential, phenolic profile and enzyme activities. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi*, 26(5), 1075-1085.

Ulgen, C., Yildirim, A. B., Sahin, G., & Turker, A. U. (2021). Do magnetic field applications affect in vitro regeneration, growth, phenolic profiles, antioxidant potential and defense enzyme activities (SOD, CAT and PAL) in lemon balm (Melissa officinalis L.)? *Industrial Crops and Products*, 169, 113624.

CHAPTER 6

AN ENERGY STORAGE MONITORING SYSTEM IN PV ENERGY SYSTEM

Assist. Prof. Dr. Sahin GULLU[1], Assist. Prof. Dr. Engin EYCEYURT[2]

---

[1] Nevşehir Hacı Bektaş Veli Üniversitesi, Mühendislik – Mimarlık Fakültesi, Elektrik – Elektronik Mühendisliği Bölümü, Nevşehir, Türkiye. sahin.gullu@nevsehir.edu.tr, Orcid ID: 0000-0002-2997-172X

[2] Nevşehir Hacı Bektaş Veli Üniversitesi, Mühendislik – Mimarlık Fakültesi, Elektrik – Elektronik Mühendisliği Bölümü, Nevşehir, Türkiye. engineyceyurt@nevsehir.edu.tr, Orcid ID: 0000-0001-6828-9996

INTRODUCTION

Traditional AC power systems depend on synchronous generators. These generators mostly rely on fossil fuels, which is one of the reasons for global warming. Global warming and climate change since the 20th century are mainly due to carbon dioxide emissions that are supported observationally even though some research indicates that they are not because of human activities but nature itself (Jian-Bin et al., 2012). Norbert (Norbert, 2008) concludes that the scientific findings prove that human beings have an impact on earth's climate. In order to reduce greenhouse gases, especially carbon dioxide, from vehicles and power plants, we need to deploy available green technologies. It is evident that using renewable energy resources creates less carbon dioxide compared to fossil fuels. Therefore, battery technology and photovoltaic (PV) energy systems are possible green technologies that can be utilized along with synchronous generators.

These generators have high inertia, and they provide stable voltage and frequency (Lasseter et al., 2019; Rathnayake et al., 2021; Unruh et al., 2020). Additionally, the current handling capability of synchronous generators is six or more times the rated currents. However, renewable energy sources are intermittent, and they have low inertia issues. So, these energy systems do not have the ability to store kinetic energy whereas traditional AC power systems do. As a result, one of the biggest challenges is that renewable energy systems are more sensitive to sudden changes. To minimize or solve this challenge, energy storage systems are integrated into renewable energy systems.

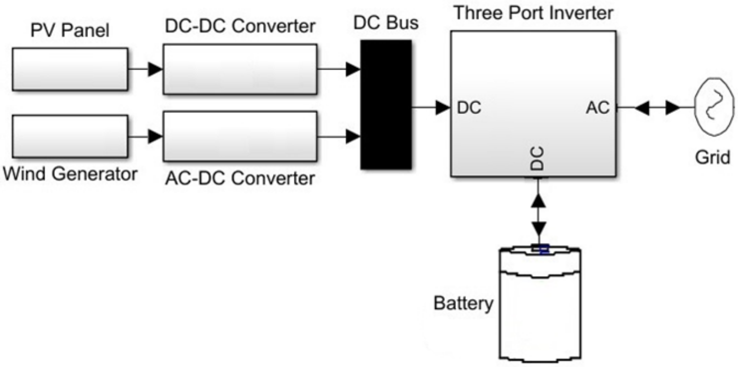

Figure 1. An example of battery integration in renewable energy systems.

As seen in Figure 1, batteries can directly be connected to the DC bus. However, it is better to utilize high voltage batteries to have low current levels to reduce the loss of power. Instead of the three-port inverter illustrated, a different multiport inverter might be used, which can be either unidirectional or bidirectional. In addition, multiport inverters could be single-stage inverters (Nilian et al., 2023) or dual-stage inverters (Rezai et al., 2023).

In energy storage systems, battery chemistries are usually lithium-ion and lithium-polymer. It can be said that lithium-ion batteries are more common in PV energy systems. It is because lithium-ion batteries are cheaper, and they have higher power density and higher charging cycles. Nevertheless, lithium-polymer batteries are safer, and they have less passive-discharge rate and better fast-charging capabilities. As a result, lithium-ion batteries are accepted as alternative energy sources to minimize the serious problems caused by fossil fuels such as environmental pollution and global warming. In addition, they have been continuously integrated on a large scale in PV farms, wind farms or electric vehicles. However, since they contain flammable components, they are susceptible to accidents caused by internal and external variables. For example, on July 2, 2018, in South Korea’s Yeongam Wind Farm and on April 19, 2019, at the APS Company in Arizona, USA, an energy storage system caught fire and exploded. Also, on April 16, 2021, in Fengtai District, Beijing, China at a PV energy storage station, a battery fire accident took place due to an internal short-circuit fault (Xu et al., 2024). In summary, an energy storage monitoring system or a battery monitoring system is crucial. In this chapter of the book, a monitoring system, which we call a battery alert system (BAS), is investigated and designed. Section 2 investigates which sensors and variables should be taken into consideration. Then, in Section 3, an example of a battery alert system (BAS) is modelled for increasing consumer safety and protection. After that, key highlights are summarized in the conclusion section.

POSSIBLE DAMAGES IN BATTERIES

The objectives of this section are to decide what sensors are required and how we are going to utilize those sensors to estimate the other variables that are crucial for battery safety.

Swelling, Thermal Runaway, and Explosion in Batteries

In batteries, it is certain that swelling is an indicator of decreased performance. But it does not instantly mean that the battery will catch on fire or will explode. It is a nature law that lithium-ion batteries will change shape in one form or another (Velazco et al., 2022).

Basically, gases make batteries swell up. It is obvious that batteries will be swelling during charging cycles and storage. However, it is important to decide how much swelling is normal. The oxidation of the electrolyte on the cathode surface will produce CO2, and the reduction of electrolyte on the anode surface will produce C_2H_4, CH_4, etc. (Li et al., 2020). This degradation is a natural part of how batteries work.

High temperatures can speed up the rate at which the electrolyte goop decomposes, which could contribute to gases building up inside a battery. Therefore, a temperature sensor must be present. During the discharge process, lithium near the surface of the negative electrode preferentially undergoes oxidative desorption due to the action of large currents. Therefore, the swelling force of the lithium-ion battery goes up when the charging cycle increases (Li et al., 2020). Thus, a current sensor and the calculation of the number of the charging cycle will help.

Even though overcharging and deep discharging create different chemical reactions, that electrolyte goop degrades when a battery is fully dead or overcharged. It is also shown that the open circuit voltage drops in batteries during the thermal runaway which is mainly short circuits of the electrodes (Galushkin et al., 2024). Then, a voltage sensor and the estimation of State-of-Charge (SoC) play a significant role in batteries safety.

Dropping mobile batteries may affect one part of the batteries, and then batteries might not be charged evenly across the battery cells that can cause swelling. So, shock sensors might be effective in this situation. According to (Michelini et al., 2023), irreversible swelling increases when State-of-Health (SoH) of batteries decreases. It means that SoH estimation should be a part of this research.

External heat source, overcharging and natural aging are the main sources of thermal runaway in batteries (Xu et al., 2024). As a result of that, an external temperature sensor is also required for this system. It was also found that aged batteries are more prone to thermal runaway, and the amount of smoke produced is greater. Then, a gas sensor can be beneficial.

Lithium batteries are also susceptible to explosions when the overpressure increases, and the higher battery capacity is more sensitive than the lesser battery capacity (Wei-Qing et al., 2024). This work shows that a pressure sensor can detect safety concerns.

In summary, voltage sensors, current sensors, temperature sensors, pressure sensors, shock sensors, gas sensors, estimation of SoC and SoH, and the number of charging cycles are important factors and variables.

DESIGNING BATTERY MONITORING SYSTEM

Depending on the applications, some of the sensors mentioned in the previous section may not be used. However, when designing Battery Allert System (BAS) in a PV energy system, nine variables are taken into consideration. They are voltage level, current value, temperature value, pressure level, shock level, gas level, estimation of SoC, SoH and charging cycles. The first six variables are taken from sensors, and the last three ones are estimated by an estimation method. Then, they are sent to BAS to decide whether those values are in the acceptable range or not.

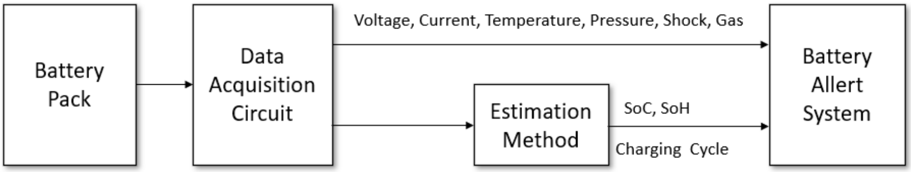

Figure 2. Block diagrams of a battery monitoring system.

In this section, as illustrated in Figure 2, an estimation method is designed in order to have the optimum energy monitoring system for the PV energy system that consists of 4.68 kW PV panels, 4.68 kW three-port inverter, and 12 kWh batteries. These values can be found in our previous work (Gullu, 2024). So, there are four main estimation methods: Characteristic parameters method, Ampere-hour integral method, Model-based filters method, and Data-driven method (Xiong, 2020).

Estimation Method Design

The characteristic parameters method performs an experiment to find a relationship between the battery characteristic parameter(s) and SoC before implementing the method. Then, SoC is estimated based on the lookup table that was created during the characteristic parameter test. Ampere-hour integral method uses Equation (1) that depends on the previous SoC value or initial SoC value ($SoC(\ t_0)$), the charging or discharging current value (I_T), the maximum available battery capacity (Q_{max}), and the coulomb efficiency (η_c). Therefore, this method is also called Coulomb counting method.

$$SoC(t) = SoC(\ t_0) - \frac{\int_{t_0}^{t} \eta_c \cdot I_T(x) \cdot dx}{Q_{max}} \qquad (1)$$

The model-based method needs a reliable model that uses Equivalent Circuit Model (ECM) or Electrochemical model or any other battery model. After establishing the battery model, the battery model's state-space equation, a filter and an algorithm are required to estimate the SoC. The data-driven method relies on the huge amount of data between the battery variables such as voltage, current, temperature and SoC. After that, it uses Machine Learning, Deep Learning, Neural Network models or other techniques that solve nonlinear problems to establish a mapping between battery variables and SoC.

When designing BAS, the characteristic parameter method is decided to be an optimum solution. This method uses offline data that maps the relationship between battery terminal voltage and SoC by using Open Circuit Voltage (OCV) test. Even though overtime the relationship between them needs to be calibrated, it is cheaper, easy to implement, and it has robust real-time performance.

In 12-kWh batteries, LG18650MH1 battery cells are planned to be utilized. Then, the OCV test for this battery cell is illustrated in Figure 3. A battery cell is discharged at 1C rate until the end-voltage (2.5 V) and the battery rests for 3 hours. This voltage is mapped to zero-percent SoC. Then, the battery is charged at 1C rate for 5 minutes and rests for 3 hours to save the voltage value. Charging the battery cell for 5 minutes and letting it rest for 3 hours continue until the battery terminal voltage reaches its maximum value (4.2 V) that corresponds to 100-percent SoC. As a result, the OCV test is performed to map between the terminal voltage and SoC of the battery cell as plotted in Figure 3.

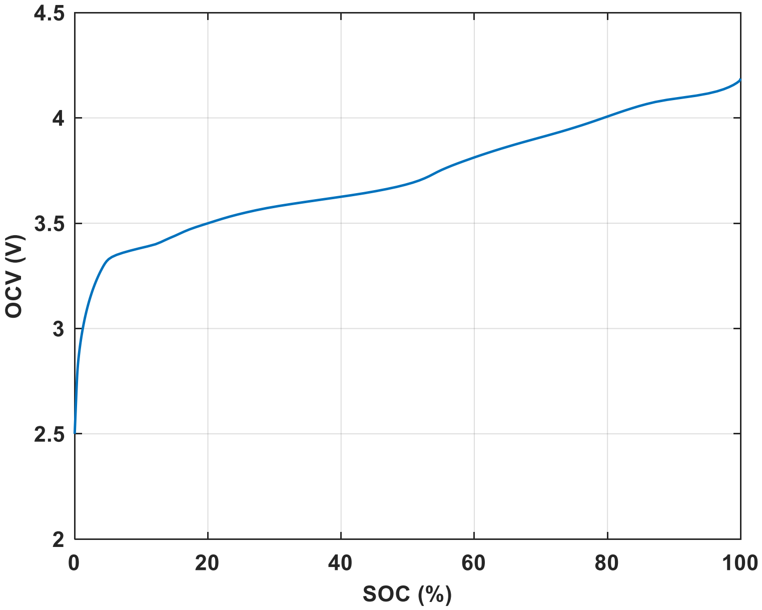

Figure 3. OCV test results for LG18650MH1 rechargeable lithium-ion battery cell.

SoH indicators are battery capacity and internal resistance, which reflect the energy and power capability, respectively. It is considered that the battery is not enough to meet the normal demand when the battery capacity goes down to 80% of the initial capacity. For battery power capability, the battery should be changed when the internal resistance value becomes double the initial value (Xiong et al., 2020). Electrochemical workstation or other AC excitation equipment is utilized to measure the capacity or ohmic resistance or impedance of a battery cell to estimate its SoH.

$$SoH(t) = \frac{\int_{t_0}^{t} \eta_c \cdot I_T(x) \cdot dx}{SoC(t) - SoC(t_0)} \tag{2}$$

Equation 2 uses the coulomb counting method to estimate SoH that is dependent on SoC and charging/discharging currents. It is also very important to define a good sampling period.

As the charging cycle increases, the fading trend of the battery capacity accelerates after about 1000 cycles, and the swelling force growth trend is also accelerated (Li et al., 2020). Therefore, the number of charging cycles should be counted by using the coulomb counting method in BAS design.

Battery Allert System Algorithm Design

Above 50 volts batteries are considered hazardous and require a work permit (Occupational Safety and Health Administration 2024; Harter et al., 2020). Therefore, the 12-kWh battery pack voltage should be less than 50 V. Based on this and the specifications in Table 1, the battery pack should include 3744 battery cells (13 in series and 288 in parallel). After considering internal and external variables of the battery pack, the BAS algorithm is shown in Figure 4.

Table 1. Specification of LG18650MH1.

Item	**Level**	**Specification**
Rated capacity	Average	3.2 Ah
Nominal Voltage	Average	3.7 V
Charge	Constant current	1550 mA
Charge	End current	50 mA
Charge	Max current	3100 mA
Charge	Constant voltage	4.2 V
Charge	Max voltage	4.205 V
Charge	Operating temperature	0 ~ 45 ^{o}C
Discharge	Constant current	620 mA
Discharge	Max current	10 A
Discharge	End voltage	2.5 V
Discharge	Operating temperature	-20 ~ 60 ^{o}C

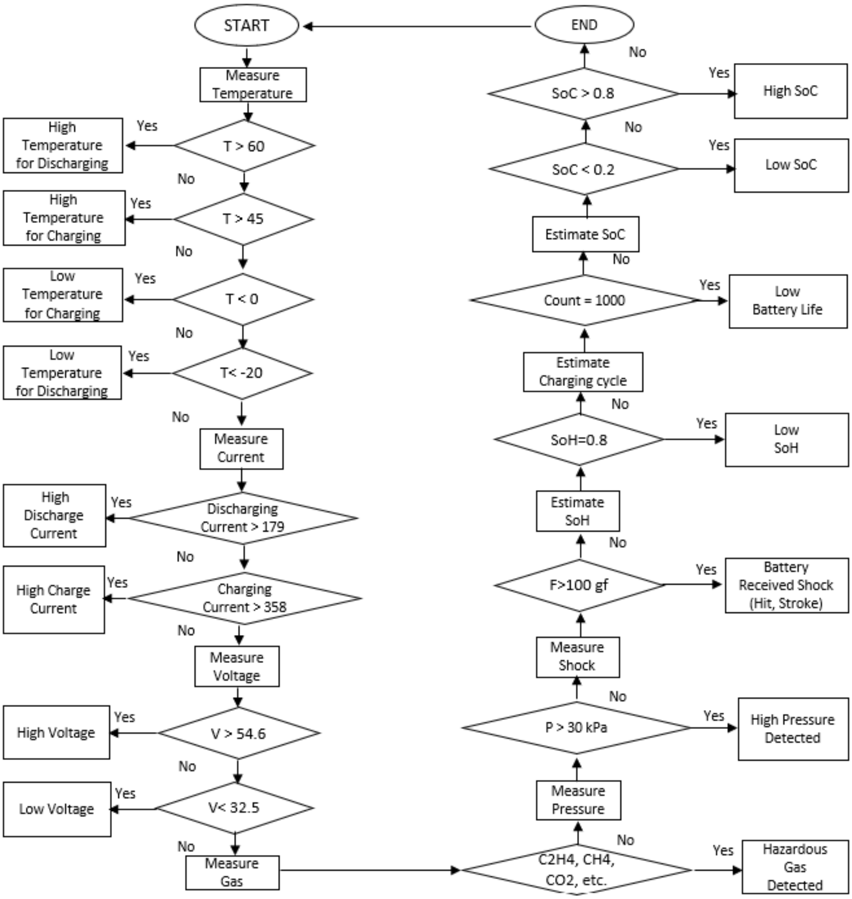

Figure 4. Battery Allert System (BAS) algorithm.

CONCLUSION

In this chapter of the book, batteries' internal and external variables are investigated. For swelling, thermal runaway and explosion detection, voltage sensors, current sensors, temperature sensors, pressure sensors, shock sensors and gas sensors are required for the PV energy system that consist of 4.68 kW solar panels, 4.68 kW three-port inverter, and 12 kWh lithium-ion battery pack. For estimation method, the characteristic parameters method for SoC is utilized by performing OCV test, and the coulomb counting method is applied to find SoH and the charging-cycle. Lastly, based on the battery pack design and the specification of LG18650MH1 rechargeable lithium-ion battery, the battery alert system's algorithm is designed.

REFERENCES

Jian-Bin, H., Shao-Wu, W., Yong, L., Zong-Ci, Z., & Xin-Yu, W. (2012). Debates on the causes of global warming. Advances in climate change research, 3(1), 38-44.

Norbert, S. A. (2008). The causes and effects of global warming and climate change. Economic Review, 34, 5-8.

Lasseter, R. H., Chen, Z., & Pattabiraman, D. (2019). Grid-forming inverters: A critical asset for the power grid. IEEE Journal of Emerging and Selected Topics in Power Electronics, 8(2), 925-935.

Rathnayake, D. B., Akrami, M., Phurailatpam, C., Me, S. P., Hadavi, S., Jayasinghe, G., ... & Bahrani, B. (2021). Grid forming inverter modeling, control, and applications. IEEE Access, 9, 114781-114807.

Unruh, P., Nuschke, M., Strauß, P., & Welck, F. (2020). Overview on grid-forming inverter control methods. Energies, 13(10), 2589.

Nilian, M., Rezaii, R., Safayatullah, M., Gullu, S., Alaql, F., & Batarseh, I. (2023, October). A Three-port Dual Active Bridge Resonant Based with DC/AC Output. In 2023 IEEE Energy Conversion Congress and Exposition (ECCE) (pp. 2537-2541). IEEE..

Rezaii, R., Ghosh, S., Safayatullah, M., & Batarseh, I. (2023, March). Design and Implementation of a Five-Port LLC Converter for PV Applications. In 2023 IEEE Applied Power Electronics Conference and Exposition (APEC) (pp. 2144-2148). IEEE.

Xu, Y., Wang, Y., Chen, X., Pang, K., Deng, B., Han, Z., ... & Chen, D. (2024). Thermal runaway and soot production of lithium-ion batteries: Implications for safety and environmental concerns. Applied Thermal Engineering, 248, 123193.

C. Velazco, 22 April 2022. [Online]. Available: https://www.washingtonpost.com/technology/2022/04/18/lithium-ion-battery-swelling-why/.

Li, Y., Wei, C., Sheng, Y., Jiao, F., & Wu, K. (2020). Swelling force in lithium-ion power batteries. Industrial & Engineering Chemistry Research, 59(27), 12313-12318.

Galushkin, N. E., Yazvinskaya, N. N., & Galushkin, D. N. (2024). Causes and mechanism of thermal runaway in lithium-ion batteries, contradictions in the generally accepted mechanism. Journal of Energy Storage, 86, 111372.

Michelini, E., Höschele, P., Heindl, S. F., Erker, S., & Ellersdorfer, C. (2023). Experimental investigation on reversible swelling mechanisms of lithium-ion batteries under a varying preload force. Batteries, 9(4), 218.

Xu, Y., Wang, Y., Chen, X., Pang, K., Deng, B., Han, Z., ... & Chen, D. (2024). Thermal runaway and soot production of lithium-ion batteries: Implications for safety and environmental concerns. Applied Thermal Engineering, 248, 123193.

Wei-Qing Peng, Song Guo, Zi-Wen Gao, Zi Wang, Jiao Geng, “Effect of explosion impact on the electrical performance and appearance of lithium-ion battery,” Journal of Loss Prevention in the Process Industries, Vol. 89, 2024, https://doi.org/10.1016/j.jlp.2024.105309.

Gullu, S. (2024). Analysis, Design and Optimization of Grid-Tied Photovoltaic Energy System.

R. Xiong, Battery Management Algorithm for Electric Vehicles, Singapore: China Machine Press and Spinger, 2020, pp. 108, https://doi.org/10.1007/978-981-15-0248-4.

"Occupational Safety and Health Administration," U.S. Department of Labor, [Online]. Available: https://www.osha.gov/laws-regs/standardinterpretations/2015-09-04#:~:text=However%2C%20OSHA%20considers%20all%20voltages, the%20resistance%20of%20the%20object. [Accessed 31 October 2024].

Harter, J. J., Mcintyre, T. J., & White, J. D. (2020). Electrical Safety Practices Developed for Automotive Lithium Ion Battery Dismantlement (No. ORNL/TM-2019/1366). Oak Ridge National Lab.(ORNL), Oak Ridge, TN (United States)..

CHAPTER 7

ENERGY EFFICIENCY STRATEGIES USING ARTIFICIAL INTELLIGENCE

Asst. Prof. Dr. Engin EYCEYURT[1], Asst. Prof. Dr. Sahin GULLU[2]

DOI: https://dx.doi.org/10.5281/zenodo.14540705

---

[1] Nevşehir Hacı Bektaş Veli Üniversitesi, Mühendislik –Mimarlık Fakültesi, Elektrik – Elektronik Mühendisliği Bölümü, Nevşehir, Türkiye. engineyceyurt@nevsehir.edu.tr, Orcid ID: 0000-0001-6828-9996

[2] Nevşehir Hacı Bektaş Veli Üniversitesi, Mühendislik – Mimarlık Fakültesi, Elektrik – Elektronik Mühendisliği Bölümü, Nevşehir, Türkiye. sahin.gullu@nevsehir.edu.tr, Orcid ID: 0000-0002-2997-172X

INTRODUCTION

The demand for electrical energy that we have been using for approximately the last 200 years has been increasing exponentially as a result of technological developments and the spread of these technologies. To meet the increasing demand, the number of renewable energy systems is increasing, and the energy efficiencies of current and future systems are enhancing. Renewable energy systems also have positive outcomes for environmental contamination due to their near-zero CO_2 emission rates (Mostafa et. al, 2022, Ibrahim et. al, 2020, Kotsiopoulos et. al, 2021).

In 2019, energy production, transportation and industry sectors contributed to more than 80% of global CO2 emissions. Although developments in renewable energy technologies have managed to reduce the environmental impacts of energy production, the same success cannot be said to have been achieved in the transportation and industry sectors. This situation reveals that energy systems should not be limited to using only renewable resources, but also that energy storage technologies should be developed, and existing energy resources should be managed more efficiently (Rangel-Martinez et. al, 2021).

Interest in buildings has increased due to growing concerns about environmental and energy issues, as buildings utilize around 40% of all energy. As a result, improving energy efficiency, particularly in commercial buildings, has become imperative. Furthermore, energy systems must be flexible due to the increasing use of integrated sustainable energy sources and energy conversion technologies in buildings. Nevertheless, it is still unknown whether the present sustainable improvements truly result in lower-end energy use and more energy flexibility. The idea of nearly/net-zero energy buildings (nZEB) has been promoted due to related legislation that has set goals for structures (Walker et. al, 2020).

Energy efficiency and resource management have become crucial in the age of globalization and fast industrial growth in order to handle the growing complexity of environmental and economic issues. In addition to lowering operating expenses, effective management promotes environmental sustainability. Technological developments have expanded the potential to enhance resource management and energy efficiency. Better forecasting, quicker and more accurate data analysis, and the automation of intricate procedures are all made possible by AI, and these developments can greatly enhance resource management effectiveness. By offering more flexible and responsive solutions based on thorough data analysis and machine learning, artificial intelligence holds promise for resolving these problems (Kristian et. al, 2024).

AI METHODS FOR ENERGY EFFICIENCY

Machine Learning

Data analytics gave rise to machine learning (ML). ML uses a variety of mathematical models to forecast outcomes for particular activities. Researchers, engineers, and data scientists use it extensively because of its many uses, which include anomaly detection, image recognition, data estimation, and email filtering. ML algorithms can be used for forecasting energy consumption in households and industries. They also can be used for identifying energy inefficiencies in real-time and designing energy-efficient solutions. A detailed explanation of some of the ML algorithms will be provided in this section (Eyceyurt et. al, 2022).

Linear Regression

Linear regression looks for a linear relationship between the dependent variable ($\breve{y}$) and the number of independent variables ($\breve{x}$). Equation (1) indicates the formula that is used to forecast a linear regression line (Egi & Eyceyurt, 2022).

$$\breve{y}_i = \breve{\beta}_0 + \breve{\beta}_i x_i + \breve{e}_i \qquad \text{Equation (1)}$$

The linear regression algorithm's intuition is to find the optimal values for coefficients $\breve{\beta}_0$ and $\breve{\beta}_i$. To generate conclusions for coefficients $\breve{\beta}_0$ and $\breve{\beta}_i$, the cost function and slope are crucial. Equation (2) represents the algorithm for minimizing the value of the cost function.

$$minimize \frac{1}{n}\sum_{i=1}^{n}(y_i - \breve{y})^2 \qquad \text{Equation (2)}$$

Gradient Descent

Gradient descent is an ML technique that essentially starts with a given initial point and constantly moves its steps in the direction of the gradient in order to minimize the cost function as seen in Algorithm 1.

Algorithm 1 Gradient Descent Mechanism

```
for i= 0, 1, 2, 3 …. n
$g_i \leftarrow \nabla_f\ (x_i\ )$
$x_{i+1} \leftarrow x_i - t_i g_i$
end of loop
```

where x_i is the independent variable, g_i is the dependent variable's gradient, and i is the number of iterations. Figure 1a illustrates the gradient descent iterative operation. Equation (1) indicates that there are two coefficients, $\breve{\beta}_0$ and $\breve{\beta}_1$, which are shown as contour levels. Gradient descent begins at x_0, travels to x_1, then to x_2, and finally converges to the ideal value. The global minimum is indicated by the middle of the circles, which is the ideal optimum value. The local minimum is also displayed in Figure 1b, which could lead to inaccurate forecasts. To get the optimal coefficients that lead to the global minimum, gradient descent performs an iterative update (Eyceyurt et. al, 2022).

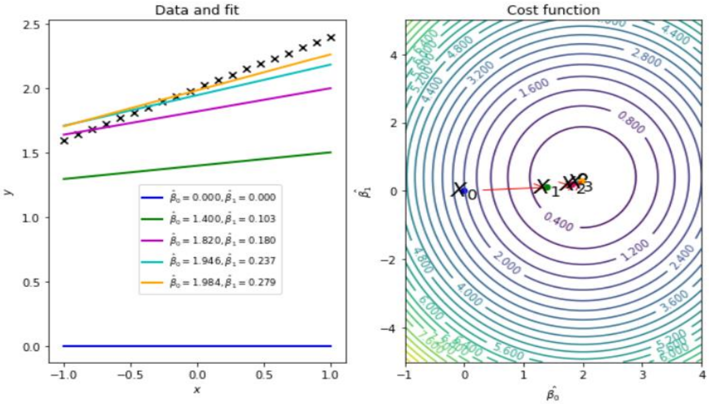

Figure 1. Gradient Descent algorithm illustration

The gradient descent method uses a number of factors, including the starting point x_0, step size t_i, and halting condition, to determine its course during the iterative process. A poor decision could result in a local minimum rather than a global minimum because these criteria are interconnected. Additionally, to prevent the over-fitting issue, a gradient descent algorithm should employ the regularization approach known as early stopping. Nevertheless, using such methods results in a bigger generalization error since learning performance improves with each iteration. Therefore, it seems sensible to avoid the early halting and maintain f (x_i,) to be as near to the global minimum as feasible (Eyceyurt et. al, 2022).

Gradient Boosting Regressor

A strategy used for base learners of machine learning tools like classification and regression is called "boosting." Boosting is a technique for combining several weak models into one and a doping factor for weak iterative models. Various boosting methods select the best option for the following iteration and show the amount of misclassification. Concentrating on cases that were incorrectly classified mostly reduces prejudice. Gradient Boosting Regression (GBR) is the boosting approach used in this study. Since the gradient descent approach is used to minimize the cost function, the GBR makes use of gradient terms for prediction. Although the GBR and linear regression differ slightly, the accuracy of GBR is noticeably higher. Decision trees (DT) are used and the error between the predicted and actual readings is calculated by the GBR. We refer to this inaccuracy as residual. Features are mapped to this residual by the GBR, which trains weak models. It integrates them with the input of the current model after obtaining the residual. This iterative procedure enhances the overall model prediction and moves the model closer to the actual value (Eyceyurt et. al, 2022).

K-Nearest Neighbors (KNN)

The KNN algorithm is aN ML technique designed to address issues with regression, pattern recognition, and classification. Additionally, it is a non-parametric method that has a wide range of applications. Similar qualities should be near the chosen data points, according to the KNN algorithm. A key factor in prediction accuracy is the number of nearest neighbors, or K. The

Manhattan distance formula, as shown in Equation 3, is typically used to determine the distance vectors ($D_{KNN}(x_i, y_i)$).

$$D_{KNN}(x,y)=\sum_{i=1}^{n}|x_i - y_i| \qquad \textit{Equation (3)}$$

The optimal k number is determined using a cross-validation approach and the Root Mean Square Prediction Error (RMSPE). The average of the k closest data points is then used to make the goal forecast. Equation (4) displays the RMSPE mathematical formula (Zhan et. al, 2022).

$$RMSPE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \breve{y}_i)^2} \qquad \textit{Equation (4)}$$

Deep Learning

In essence, deep learning is a kind of machine learning in which human neural cells are mimicked by artificial neural networks (ANNs). The large number of ANN layers is implied by the term "deep." Therefore, learning will be deeper as the number of layers rises (Egi & Eyceyurt, 2022). Therefore, large and complicated datasets, such those produced by smart grids and Internet of Things devices, are best handled by deep learning (DL) models. Convolutional neural networks (CNN), deep belief networks (DBN), stacked auto-encoders (SAE), recurrent neural networks (RNN), and generative adversarial networks (GAN) are the five general categories into which commonly used DL models can be broadly categorized. In numerous deep learning applications and image classification tasks, manually created CNNs have demonstrated remarkable effectiveness (Zhan et. al, 2022). A demonstration of deep neural network is given in Figure 2.

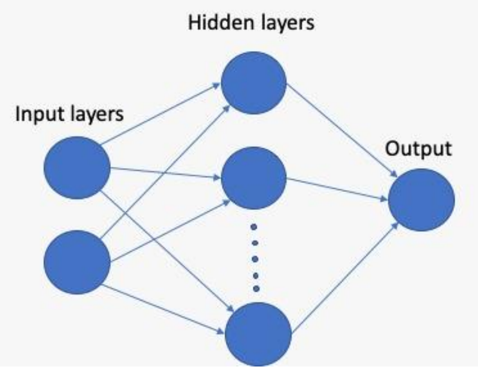

Figure 2. Demonstration of artificial neural network

Deep learning is used for predicting renewable energy generation from weather data, optimizing building energy systems using smart sensors, and detecting anomalies in energy systems, such as equipment faults.

APPLICATIONS OF AI IN ENERGY EFFICIENCY

Smart Grids

Renewable energy technologies are becoming increasingly widespread due to their environmental friendliness and low operating costs. However, renewable energy sources cannot constantly produce the same amount of energy, and their unbalanced energy creates various problems. The constant change in energy demands at certain times of the day requires energy systems to have a more flexible, reliable, and dynamic structure. Traditional energy production and storage systems sometimes cannot meet these needs and cause problems such as large-scale power outages and fluctuations (Wen et. al, 2024). The increasing use of renewable and sustainable resources has also led to the development of smart grid technologies. Smart grids optimize energy production, distribution, and consumption processes to increase energy efficiency. These systems increase the adaptability, efficiency, and reliability of power systems by integrating sensing, communication and control capabilities. The primary benefits of smart grid technology are reducing energy losses, increasing the integration of renewable energy sources, and ensuring the active participation of customers in energy systems. Smart grids leverage AI to optimize energy distribution, integrate renewable sources, and ensure grid stability (Wen et. al, 2024).

A. Raza and his colleagues performed mathematical modeling and simulation of the Markov chain on super smart grid systems that optimize long-scale energy distribution and reduce energy losses. Researchers who use HVDC instead of HVAC in their systems state that they have adapted the HVDC system to their models because the energy transportation distance would be too long and there are significant losses in HVAC systems (Raza et. al, 2024).

W. Udo et al. stated in their studies that smart grids supported by machine learning algorithms with advanced sensor and communication structures increase energy efficiency. They also claimed that the system would perform an efficient power operation by making future load predictions using past data (Udo et. al, 2024). In addition, N. Thilakarathne and his team give information about the efficiency and reliability of energy distribution with the superior communication and computational capabilities of their smart grid supported by machine learning algorithms (Neranjan et. al, 2024).

S. Touzani and his friends used synthetic data and used deep reinforcement learning (DRL) model in PV system to reduce the electricity requirement of smart grids. They stated that the costs of their systems using DRL decreased by 39.6% compared to traditional methods (Tauzani et. al, 2024).

Building Energy Management

Buildings consume approximately 40% of global energy, making them a prime target for efficiency improvements (Walker et. al, 2020). Therefore, reducing energy consumption in buildings and increasing their efficiency will greatly affect the overall result. AI systems in buildings can analyze energy data to recommend upgrades such as better insulation or LED lighting.

Energy estimation algorithms used in smart homes can provide energy savings by optimizing energy consumption (Fu et. al, 2022; Alzoubi et. al, 2022; Bourhnane et. al, 2020). In a study, the electricity demands of 47 commercial buildings were estimated using various machine learning algorithms using data collected over a period of 3 years. In the study where 2 years of data were used for training and 1 year of data for testing, it was seen that boosted-tree, random forest, and ANN models gave the best estimates (Walker et. al, 2020). A. Gupta et al. used deep reinforcement learning to control the heater, one of the most energy-consuming systems in a home and achieved both 30% temperature comfort and 12% energy savings compared to traditional thermostats (Gupta et. al, 2021). In another study, S. Yang and his colleagues have developed a system that saves 36.7% of electricity by controlling the air conditioner and cooling fan with adaptive machine learning (Yang et. al, 2020). M. Zekic-Susac et al. perform machine learning based public building energy efficiency improvement system. In their research, the IoT network of the public building is used with 3 different ML algorithms to increase energy efficiency. As a result, 13.6% energy efficiency is obtained with the random forest technique (Zekić-Sušac, et. al, 2021).

Industrial Strategies

AI is revolutionizing energy-intensive industries by optimizing production lines and improving equipment maintenance. It can identify inefficiencies in manufacturing and adjust operations in real-time and detect early signs of equipment failure, reducing downtime and energy waste. The fourth industrial revolution, or Industry 4.0, is the idealized state of an economy that uses highly automated processes to manufacture goods or render services. One of the most alluring goals for achieving increased energy efficiency with Industry 4.0 technologies is energy savings. Using cloud computing and Big Data, an energy management system called Energy Cloud was also implemented to track energy usage across several industrial locations. Using a self-aware machine in the framework of Industry 4.0 could also lower processing costs by conserving energy (Teng et al., 2021).

Edge computing is a service, much like big data and cloud computing, except it is much closer to the customer. The goal is to give users the impression that the content feedback and online speed are very quick. The issue of high latency, network instability, and poor bandwidth in the conventional cloud computing approach is one that edge computing is crucial to resolving. 5th Generation mobile networks systems (5G), which brings lower latency and higher bandwidth, is used in S. Zhao's study to make energy efficient resource allocation (Zhao et al., 2023). In another research, Egi & Eyceyurt developed a system that can select the location of base stations in the most efficient way by combining 3D point cloud and 2D maps using deep learning. This system allows base stations to be positioned in a way that they can operate with the least amount of energy, taking into account the effects of trees and man-made structures on mobile phone signal levels.

CONCLUSION

Addressing global issues including resource scarcity, climate change, and rising energy consumption requires energy efficiency. Energy efficiency tactics have historically depended on manual interventions and static models, which frequently fall short in addressing the complexity of contemporary energy systems. AI provides a dynamic approach to energy management through its skills in automation, optimization, and predictive analysis. This chapter addresses practical applications, highlights important research needs, and gives an overview of how AI techniques are being used to increase energy efficiency.

REFERENCES

Mostafa, N., Ramadan, H. S. M., & Elfarouk, O. (2022). Renewable energy management in smart grids by using big data analytics and machine learning. *Machine Learning with Applications*, *9*, 100363.

Ibrahim, M. S., Dong, W., & Yang, Q. (2020). Machine learning driven smart electric power systems: Current trends and new perspectives. *Applied Energy*, *272*, 115237.

Kotsiopoulos, T., Sarigiannidis, P., Ioannidis, D., & Tzovaras, D. (2021). Machine learning and deep learning in smart manufacturing: The smart grid paradigm. *Computer Science Review*, *40*, 100341.

Rangel-Martinez, D., Nigam, K. D. P., & Ricardez-Sandoval, L. A. (2021). Machine learning on sustainable energy: A review and outlook on renewable energy systems, catalysis, smart grid and energy storage. *Chemical Engineering Research and Design*, *174*, 414-441.

Walker, S., Khan, W., Katic, K., Maassen, W., & Zeiler, W. (2020). Accuracy of different machine learning algorithms and added-value of predicting aggregated-level energy performance of commercial buildings. *Energy and Buildings*, *209*, 109705.

Kristian, A., Goh, T. S., Ramadan, A., Erica, A., & Sihotang, S. V. (2024). Application of ai in optimizing energy and resource management: Effectiveness of deep learning models. *International Transactions on Artificial Intelligence*, *2*(2), 99-105.

Eyceyurt, E., Egi, Y., & Zec, J. (2022). Machine-learning-based uplink throughput prediction from physical layer measurements. *Electronics*, *11*(8), 1227.

Egi, Y., & Eyceyurt, E. (2022). Classified 3D mapping and deep learning-aided signal power estimation architecture for the deployment of wireless communication systems. *EURASIP Journal on Wireless Communications and Networking*, *2022*(1), 107.

Zhan, Z. H., Li, J. Y., & Zhang, J. (2022). Evolutionary deep learning: A survey. *Neurocomputing*, *483*, 42-58.

Wen, X., Shen, Q., Zheng, W., & Zhang, H. (2024). AI-driven solar energy generation and smart grid integration a holistic approach to enhancing renewable energy efficiency. *International Journal of Innovative Research in Engineering and Management*, *11*(4), 55-66.

Raza, A., Liaqat, M., Adnan, M., Iqbal, M. S., Jingzhao, L., & Ahmad, I. (2024). SAARC super smart grid: Navigating the future-unleashing the power of an energy-efficient integration of renewable energy resources in the saarc region. *Computers and Electrical Engineering*, *118*, 109405.

Udo, W. S., Kwakye, J. M., Ekechukwu, D. E., & Ogundipe, O. B. (2024). Smart grid innovation: machine learning for real-time energy management and load balancing. *International Journal of Smart Grid Applications*, *22*(4), 405-423.

Neranjan Thilakarathne, N., Mohan, K. K., Surekha, L., & Hussain, A. (2021). Smart Grid: A Survey of Architectural Elements. *Machine Learning and Deep Learning Applications and Future Directions. J. Intell. Syst. Internet Things*, *3*, 32-42.

Touzani, S., Prakash, A. K., Wang, Z., Agarwal, S., Pritoni, M., Kiran, M., ... & Granderson, J. (2021). Controlling distributed energy resources via deep reinforcement learning for load flexibility and energy efficiency. *Applied Energy*, *304*, 117733.

Fu, Q., Han, Z., Chen, J., Lu, Y., Wu, H., & Wang, Y. (2022). Applications of reinforcement learning for building energy efficiency control: A review. *Journal of Building Engineering*, *50*, 104165.

Alzoubi, A. (2022). Machine learning for intelligent energy consumption in smart homes. *International Journal of Computations, Information and Manufacturing (IJCIM)*, *2*(1).

Bourhnane, S., Abid, M. R., Lghoul, R., Zine-Dine, K., Elkamoun, N., & Benhaddou, D. (2020). Machine learning for energy consumption prediction and scheduling in smart buildings. *SN Applied Sciences*, *2*(2), 297.

Gupta, A., Badr, Y., Negahban, A., & Qiu, R. G. (2021). Energy-efficient heating control for smart buildings with deep reinforcement learning. *Journal of Building Engineering*, *34*, 101739

Yang, S., Wan, M. P., Chen, W., Ng, B. F., & Dubey, S. (2020). Model predictive control with adaptive machine-learning-based model for building energy efficiency and comfort optimization. *Applied Energy*, *271*, 115147.

Zekić-Sušac, M., Mitrović, S., & Has, A. (2021). Machine learning based system for managing energy efficiency of public sector as an approach towards smart cities. *International journal of information management, 58,* 102074.

Teng,S. Y., Touš, M., Leong, W. D., How, B. S., Lam, H. L., & Máša, V. (2021). Recent advances on industrial data-driven energy savings: Digital twins and infrastructures. *Renewable and Sustainable Energy Reviews, 135*, 110208.

Zhao, S. (2023). Energy efficient resource allocation method for 5G access network based on reinforcement learning algorithm. *Sustainable Energy Technologies and Assessments*, *56*, 103020.

CHAPTER 8

ROLE OF GREEN CHEMISTRY IN PROTECTING THE ENVIRONMENT

Prof. Dr. Khalid Mahmood KHAWAR[1]

DOI: https://dx.doi.org/10.5281/zenodo.14540713

---

[1] Yozgat Bozok University, Department of Agriculture and Food Hemp Research Institute, Yozgat, Türkiye, k.mahmood.khavar@bozok.edu.tr, Orcid ID: https://orcid.org/0000-0001-5110-6014

INTRODUCTION

The chemical industry is one of the most powerful and diverse parts of all manufacturing industries (Jenck, et al.2004, Clark and Macquarrie 2002, Anastas and Warner 1998). The chemicals are used to produce healthcare products in industries related to pharmaceuticals, food & fertilizers, pesticides, and herbicides in agriculture textile, transport, aerospace, soaps & detergents, shipping, electronics, ammunitions, building & road materials, aerospace, and many other areas (Commoner, 2013, Theodore, and Kunz, 2005). We can say that starting from the last quarter of the 18th century to the 2025, the chemical industry has seen many ups and downs and now it is considered as 'central discipline' that links all branches of science including medicine, agriculture, biology, physics and material sciences, and all branches of basic and applied sciences, until to date (Downs, and Vogel 1993, National Academies of Sciences, 2022). . All powerful countries have virtually very strong base in chemical manufacturing industries and have a very large share in the economies of industrially developed countries. (Downs, and Vogel 1993). It is well established that demand for people in this century has increased in this century, and this has opened a very difficult time chemistry or producing diverse chemicals. Scientists and economists know that the demand for chemical products is constantly growing (Das, and Ghosh, 2024, Zhu, 2024).

Some states are emerging in South, far East and western countries with large populations and economies (Shu, et al. (2024). They seek to improve standards of life and increase high standards of the healthcare sector, living in the housing sector, comfortable clothing and using utility in consumer goods equivalent to the people enjoying in the most developed western countries. This has induced unprecedented and huge pressure on all types of chemical industry, so the chemicals used should be considerably clean, safe, sustainable, made according to the biosafety rules considering compatibility with the environment (Lobel, et al. 2024) in line with 12 principles of green chemistry as mentioned below (United States Environmental Protection Agency, Basics of Green Chemistry, 2017, Krasnodebski, (2024).

Figure 1. Using of green chemicals for extraction chemicals

PRINCIPLES OF GREEN CHEMISTRY

Prevention

Preventing waste is better than cleaning or treating it after its creation. Therefore, there is need to redesign the chemical processes in factories to reduce production of hazardous wastes to stop, avoid or minimize pollution (prevention is better than cure) Or the industrial design should reduce or stop production of waste.

Atom Economy

Synthetic methods should be designed to process maximized use of all materials into the final product by maximizing atom economy improving yield and efficiency by increasing chemical transformations which is described as:

$$\text{Atom Economy\%} = \frac{\text{No. of incorporated atoms}}{\text{No. of atoms in the reactants}} \times 100$$

Less Hazardous Chemical Syntheses

Wherever possible, synthetic methods should be used to generate new compounds avoiding toxicity or using low toxicity to environment for human health by replacing safer alternatives using green technology selecting low risk reagents producing safer byproducts.

Designing Safer Chemicals

New chemical products should have minimum toxicity and must be safe to use and must be with minimum or no toxicity and produce safer compounds for human health.

Safer Solvents and Auxiliaries

The auxiliary substances like separation agents, solvents, etc. should be innocuous (Namieoenik and Wardencki 2000) when used if possible, during chemical synthesis and generate nontoxic compounds for human health following the principles of green chemistry.

Design for Energy Efficiency

Chemical reactions and energy requirements should be recognized for environmental and economic impacts and be minimized using synthetic green chemistry methods at ambient temperature and pressure.

Use of Renewable Feedstocks

Renewable raw materials or feedstock should be used whenever technically and economically possible by using renewable raw material assuring production.

Reduce Derivatives

Minimize or avoid unnecessary derivatizations or steps, which generate waste. Therefore, it is better to avoid protection/deprotection, and temporary process modifications, as they require additional reagents by increasing steps and generate wastes. More selective and good alternatives synthetic procedures must be used following green chemistry principles to avoid unnecessary derivatization whenever possible to avoid generation of waste.

Catalysis

Catalytic reagents must be selective and should be superior to stoichiometric reagents. It is well known that small amounts of catalysts are used to carry out a selective reaction and are preferred as stoichiometric reagents, they reduce reagent base waste, avoid side reactions leading adoption of green clean technology. They should be softer catalysts e.g. zeolites.

Design for Degradation

Chemical compounds must be selected to break down them into harmless products preventing their persistence in the environment. Designing of degradable environment friendly products is desired. These chemicals must have small half to breakdown must not be harmful for humans in long run.

Real-time analysis for Pollution Prevention

The development of analytical methodologies is highly important for real-time to check and-monitor process check/avoid formation of hazardous compounds and must be further developed process monitored carefully. Their methods of analysis and monitoring tools should be carefully designed to avoid the creation of harmful waste.

Inherently Safer Chemistry for Accident Prevention

Chemical process safety involves selecting appropriate substances and their form to minimize potential accidents like releases, explosions, and fires avoiding and minimizing accidents like the Bhopal Gas Tragedy in Indian state of Madhya Pardesh.

The people are aware of a large number of risks and mistakes involved with the ever-increasing development of chemical industries due to positive role of social and print and electronic media and is constantly raising voice against environmental pollution, and other problems etc (Wang, and Wu 2024). The people have also awareness about countless benefits related to the development of chemical industries in a number of sectors and branches (Oliveira, et al.2024). The people are talking about use of different chemicals in their life which has deteriorated in last >50 years (Dey, et al. 2024). Most of the chemical industries are counted and ranked equal to or ranked alongside unpopular, narcotics (heroin, opium, marijuana and hashish etc.), tobacco and nuclear power industries (Ratshonka, 2024).

Moreover, if the statistics about enrolment of high school and universities is compared, there is remarkable decrease in the numbers of students who apply to read chemical engineering, chemistry, subjects, and all related basic science subjects; a reasonable correlation could be seen for these trends (Love 2024). It is very important to see that we are not seeing further reduction in agriculture-based industries that produce food and feedstock, where the interest of the young students is persistent. The young people seeking careers in chemistry (Warner, 2024). We know that we live in period where product manufacturing could take place on one side of globe and marketing could occur on the other side of the globe because the developing countries are expanding their industrial base with remarkable speed (Stewart-Koster, et al. 2024, Lefevre-Arbogast, et al. 2024). This is becoming persistently possible since the manufacturing and transport costs are costs are cheaper, which is also becoming a source of pollution production (Singla, et al.2024). The developing countries are competing with markets in the developed countries and meeting their demands for different chemicals operating efficiently using raw materials. They are producing chemicals at reduced costs with low levels of waste (Aharoni, and Hirsch 2024, Adeoye, 2024). Disposal of growing pollution and waste could add to the economic burden. Some countries in the EU have started taxing the waste and finding pollution (Imran et al. 2024). These countries are also encouraging measures to reduce pollution and increase greener manufacturing of chemicals. This chapter consider the importance of green manufacturing by describing some challenges offered by chemistry-based industries very carefully about introduction of innovations and Technologies used in the industry forward in the following years using concept of green chemistry to improve the living conditions on this planet making it a safe place to live reduce the risks human trespass due to unsafe use of chemical products describing the principles of green chemistry. The measures to waste minimization less polluting and oxidation reactions using H2O2 are described and reduced effects on the environment (Sato et al. 1998, Miyah, et al. 2024). Manufacture of pharmaceuticals is invariably related to high levels of waste. There is need to develop practice of green chemistry by designing commercial catalysts for production of reduced wastes. the use of renewable feedstocks in chemical production, and the bioproduction of chemicals in industry. This measure will lead to the chemical industry of the present century being remarkably different from the one that developed in the last century. The measures will end up in lowering emissions to water, land and air. which will be highly compatible with environment (Wang, et al. 2024). Rekha Panda, et al. (2024).) and describe more interesting tools in sonochemistry. by sonochemical synthesis, using ultrasound for environmental protection in combination with sono and electrochemistry. Microwave-assisted reactions can be used to reap additional proved benefits of alternative energy sources

(Fernández, et al. 2024). Organic synthesis using pressurized microwave systems is desired. Use of photons in photochemistry offers several advantages over traditional reactions including lower reaction temperatures and control of reaction selectivity (Ali, et al. 2024). Fuel cells represent one of the most exciting and often cited examples of possible cleaner energy technologies for the future. fuel cell applications in transport, stationary power generation and battery replacement applications (Tariq, et al. 2024, Qasem, et al. (2024). Alternative solvents should be considered as the future of fuel cells and should be considered as the major entry in the green chemistry toolkit. They have enormous research (San José, et al. 2024). The use of water, supercritical fluids, and ionic liquids should be considered. Supercritical fluorous biphasic systems carbon dioxide, and supercritical water need detailed considerations (Dupont et al. (2024). More study and discussion cover the use of supercritical CO_2 for catalyst recycling, product separation and simultaneous use of the fluid as a reagent and solvent (Nunes, et al. 2024). Fluorous biphasic systems could make the ingenious system of inventions for green chemistry (Ponnumsamy, et al. (2024). Finally, study of the relationship between fluorous and supercritical CO_2 media could show economic feasibility for fluorous biphasic chemistry (Baricelli, et al. 2024). The concept of green chemistry is widely accepted in technology and in principles globally (Krasnodębski, 2024) good number of green chemistry examples and has crossed lines of economic environmental, and societal benefits there are larger challenges ahead (Huang, et al. 2024). The chemical industry of the twenty-first century will accept and embrace the principles of green chemistry through higher atom efficiency with better utilization of raw materials, with less waste, and safer reactions (Chandy, et al. 2024).

Benefits

Environment: Several chemicals are mixed and released into environment on purpose (like pesticides to kill insects and weeds) while others are sent to the environment accidentally or unintentionally (like emissions of motorcars, and factories). Paradoxically the green chemicals could be recycled or broken down into nonhazardous chemical compounds. They minimize pollution or do not pollute the environment and deteriorate ecosystems. They are not hazardous for human health and eliminate persistently toxic chemical compounds into food chain; and degrade rapidly. They add no or little hazards to drinking and recreational water.

They increase the safety of laborers in chemical sector leading to low risks of mishaps (like explosions or fires). These practices will lead to safe future products like pharmaceuticals, insecticides and others. Economy: they have positive effects on the economy requiring less feedstock by doing away with expensive remediation. quicker manufacturing, saving energy and water.

CONCLUSION

Developing countries are producing chemicals at lower costs, increasing pollution and economic burden. EU and many other countries are taxing waste or making laws to discourage reduction of pollution, using greener manufacturing practices. Green chemistry practices include waste minimization. Green chemistry is a revolutionary and emerging technology. Nano-fertilizers, nano pesticides as well as plant transformation gene delivery applied to agriculture have the potential to disrupt many of the great problems facing humanity in the coming days. It is expected that use of renewable feedstocks, bioproduction, sonochemistry, microwave-assisted reactions, organic synthesis, photons, fuel cells, and alternative solvents will improve living conditions and standards of life in the future.

REFERENCES

Adeoye, O. B., Addy, W. A., Ajayi-Nifise, A. O., Odeyemi, O., Okoye, C. C., & Ofodile, O. C. (2024). Leveraging AI and data analytics for enhancing financial inclusion in developing economies. *Finance & Accounting Research Journal*, *6*(3), 288-303.

Agarwal, P., Goyal, A., & Vaishnav, R. (2018). Chemical hazards in pharmaceutical industry: An overview. *Asian J. Pharm. Clin. Res*, *11*, 27-35.

Aharoni, Y., & Hirsch, S. (2024). The competitive potential of technology-intensive industries in developing countries. In *Standing on the Shoulders of International Business Giants* (pp. 373-391).

Ali, S. K., Althikrallah, H. A., Alluhaibi, M. S., Hawsawi, M. B., Hakami, O., Shariq, M., ... & Hussain, M. (2024). Electrochemical and Photocatalytic Synthesis of Organic Compounds Utilizing a Greener Approach. A review. *Molecular Catalysis*, *559*, 114087.

Anastas PT and Warner JC. “Green Chemistry: Theory and Practise”. Oxford University Press, Oxford 2.1 (1998): 155. United States Environmental Protection Agency, Basics of Green Chemistry (2017).

Chandy, M., Hill III, T., Jimenez-Tellez, N., Wu, J. C., Sarles, S. E., Hensel, E., ... & Conklin, D. J. (2024). Addressing Cardiovascular Toxicity Risk of Electronic Nicotine Delivery Systems in the Twenty-First Century:“What Are the Tools Needed for the Job?” and “Do We Have Them?”. *Cardiovascular Toxicology*, *24*(5), 435-471.

Clark JH. , Macquarrie DJ. , Handbook of Green Chemistry and Technology, Blackwell, Abingdon, 2002

Commoner, B. (2013). The environmental cost of economic growth. In *Energy, economic growth, and the environment* (pp. 30-65). RFF Press.

Das, S. K., & Ghosh, G. K. (2024). Soil hydro-physical properties affected by biomass-derived biochar and organic manure: a low-cost technology for managing acidic mountain sandy soils of northeastern region of India. *Biomass Conversion and Biorefinery*, *14*(5), 6621-6635

Dey, S., Veerendra, G. T. N., Babu, P. A., Manoj, A. P., & Nagarjuna, K. (2024). Degradation of plastics waste and its effects on biological ecosystems: A scientific analysis and comprehensive review. *Biomedical Materials & Devices*, *2*(1), 70-112.

Downs, J. J., & Vogel, E. F. (1993). A plant-wide industrial process control problem. *Computers & chemical engineering*, *17*(3), 245-255.

Downs, J. J., & Vogel, E. F. (1993). A plant-wide industrial process control problem. *Computers & chemical engineering*, *17*(3), 245-255.

Dupont, J., Leal, B. C., Lozano, P., Monteiro, A. L., Migowski, P., & Scholten, J. D. (2024). Ionic Liquids in Metal, Photo-, Electro-, and (Bio) Catalysis. *Chemical Reviews*, *124*(9), 5227-5420.

Huang, X., Auffan, M., Eckelman, M. J., Elimelech, M., Kim, J. H., Rose, J., ... & Alvarez, P. J. (2024). Trends, risks and opportunities in environmental nanotechnology. *Nature Reviews Earth & Environment*, *5*(8), 572-587.

Imran, M., Jijian, Z., Sharif, A., & Magazzino, C. (2024). Evolving waste management: The impact of environmental technology, taxes, and carbon emissions on incineration in EU countries. *Journal of Environmental Management*, *364*, 121440.

Jenck, J. F., Agterberg, F., & Droescher, M. J. (2004). Products and processes for a sustainable chemical industry: a review of achievements and prospects. *Green Chemistry*, *6*(11), 544-556.

Krasnodebski, M. (2024). The bumpy road to sustainability: Reassessing the history of the twelve principles of green chemistry. *Studies in History and Philosophy of Science*, *103*, 85-94.

Lefevre-Arbogast, S., Chaker, J., Mercier, F., Barouki, R., Coumoul, X., Miller, G. W., ... & Samieri, C. (2024). Assessing the contribution of the chemical exposome to neurodegenerative disease. *Nature Neuroscience*, 1-10.

Lobel, B. T., Baiocco, D., Al-Sharabi, M., Routh, A. F., Zhang, Z., & Cayre, O. J. (2024). Current challenges in microcapsule designs and microencapsulation processes: A review. *ACS applied materials & interfaces*, *16*(31), 40326-40355.

Love, T. S. (2024). A closer look at the relationship between course enrollment size and accident occurrences in hands-on engineering design-based STEM courses. *International Journal of Technology and Design Education*, 1-26.

Miyah, Y., El Messaoudi, N., Benjelloun, M., Georgin, J., Franco, D. S. P., Acikbas, Y., ... & Sillanpää, M. (2024). MOF-derived magnetic nanocomposites as potential formulations for the efficient removal of organic pollutants from water via adsorption and advanced oxidation processes: A review. *Materials Today Sustainability*, 100985.

Namieoenik J and Wardencki.W "Solvent less sample preparation techniques in environmental analysis". Journal of High Resolution Chromatography 20.2 (2000): 297.

National Academies of Sciences, Engineering, and Medicine. (2022). *New Directions for Chemical Engineering*. National Academy of Sciences, Washington, DC (United States).

Oliveira, J. R., Tusset, A. M., Andrade, D. I., Balthazar, J. M., Pagani, R. N., & Lenzi, G. G. (2024). Action plans study: Principles of green chemistry, sustainable development, and smart cities. *Sustainability*, *16*(18), 8041.

Ponnumsamy, V. K., Al-Hazmi, H. E., Shobana, S., Dharmaraja, J., Jadhav, D. A., Piechota, G., ... & Kumar, G. (2024). A review on homogeneous and heterogeneous catalytic microalgal lipid extraction and transesterification for biofuel production. Chinese Journal of Catalysis, 59, 97-117.

Qasem, N. A., & Abdulrahman, G. A. (2024). A recent comprehensive review of fuel cells: history, types, and applications. *International Journal of Energy Research*, *2024*(1), 7271748.

San José, E., de la Viuda, M. R., Carmona, F. J., Soto, C., Palacio, L., Prádanos, P., ... & Tena, A. (2024). Green dipolar aprotic solvents for the dynamic polycondensation of high-performance polyimide membranes. *Green Chemistry*.

Sato K., et al. "A "Green" Route to Adipic Acid: Direct Oxidation of Cyclohexenes with 30 percent hydrogen peroxide". Science 281 (1998): 1646.

Shu, T., Liao, X., Yang, S., & Yu, T. (2024). Towards sustainability: Evaluating energy efficiency with a super-efficiency SBM-DEA model across 168 economies. *Applied Energy*, *376*, 124254.

Stewart-Koster, B., Bunn, S. E., Green, P., Ndehedehe, C., Andersen, L. S., Armstrong McKay, D. I., ... & Zimm, C. (2024). Living within the safe and just Earth system boundaries for blue water. *Nature Sustainability*, *7*(1), 53-63.

Tariq, A. H., Kazmi, S. A. A., Hassan, M., Ali, S. M., & Anwar, M. (2024). Analysis of fuel cell integration with hybrid microgrid systems for clean energy: A comparative review. *International Journal of Hydrogen Energy*, *52*, 1005-1034.

Theodore, L., & Kunz, R. G. (2005). *Nanotechnology: environmental implications and solutions*. John Wiley & Sons.

Wang, J., Zhao, W., Zhang, Z., Liu, X., Xie, T., Wang, L., ... & Zhang, Y. (2024). A journey of challenges and victories: a bibliometric worldview of nanomedicine since the 21st century. *Advanced Materials*, *36*(15), 2308915.

Wang, X., & Wu, L. (2024). Intergenerational differences in the environmental concerns of plastic waste business owners: environmental knowledge, environmental risk exposure, and community connection as mediators. *Humanities and Social Sciences Communications*, *11*(1), 1-13.

Warner, J. T. (2024). *The handbook of lithium-ion battery pack design: Chemistry, components, types, and terminology*. Elsevier.

Zhu, Y. P. (2024). *Chinese materia medica: chemistry, pharmacology and applications*. CRC press.

CHAPTER 9

GREEN BIOTECHNOLOGICAL APPLICATIONS IN AGRICULTURE

Assoc. Prof. Dr. Mortaza HAJYZADEH[1], Assoc. Prof. Dr. Yunus EGI[2]

DOI: https://dx.doi.org/10.5281/zenodo.14540719

---

[1] Department of Field Crop, Faculty of Agriculture, Şırnak University, Şırnak 73000, Türkiye. m.hajyzadeh@gmail.com, Orcid ID: 0000-0002-8808-6974

[2] Department of Electrical and Electronics Engineering, Faculty of Engineering, Şırnak University, Şırnak 73000, Türkiye. yunusegi@sirnak.edu.tr, Orcid ID: 0000-0001-5185-8443

INTRODUCTION

Population growth in recent years, severe water scarcity, degradation of usable agricultural land, unsustainable energy consumption, weather, temperature and precipitation changes, deficiency in waste management, problems such as ever-increasing food demand pose challenges to agricultural production and threaten global food security. It is important to integrate new models and technologies into the conventional agricultural system in order to reduce the negative effects of poverty and economic crises that come with these challenges. Technological applications in agriculture have evolved significantly to increase yield and quality to meet global food demand. An exponential increase in the use of plant breeding, chemical fertilizers, pesticides, herbicides, irrigation, and other yield-enhancing inputs has significantly boosted food production to meet the needs of a growing population (Evenson and Gollin, 2003). However, the increasing intensity of agricultural production and the accompanying, cultivation-oriented growth models lead to environmental degradation, ecosystem deterioration, and depletion of natural resources. The reason is the serious health problems that develop due to the frequent use of chemicals and drugs, various environmental damage resulting from unsustainable agricultural applications, and the production of approximately 25% of global greenhouse gas emissions that lead to climate change, carbon emissions, and the degradation of natural capital (IPCC, 2019). Due to yield consumption and environmental concerns, the development of green innovations and the use of smart agricultural systems became more crucial (Sundmaeker et al., 2016).

In addition to eliminating the difficulties in strategic sectors such as agriculture and production, a new strategy is needed to promote food security. These strategies can be possible with the use and development of sustainable agricultural technologies and innovative ideas and can also be evaluated as the main factor of economic growth and social transformation (Rockström et al., 2017). This type of agriculture - based environmentally friendly technology is called Green Technology.

Environmentally friendly innovative technologies play an important role in the development of sustainable agriculture by contributing to environmental concerns with their development (Arenhardt et al., 2016). Such environmental technologies and innovations are generally called "clean technologies". Green technology or clean technologies are trying to mitigate the negative effect of fossil fuels, pollutants, and chemicals on the environment. These technologies and innovations can help close the gap between growth and sustainability as they reduce negative impacts on the environment and improve productivity, efficiency and operational performance. The general purpose of these smart agricultural technologies is to apply the input with the right methods within the scope of feasibility studies and to solve the negativities experienced in agricultural production (Abdel-Fattah et al., 2021). Accordingly, it is to bring innovation and changes in daily life by meeting the needs of the generation without harming biodiversity and to minimize rural environmental concerns with the use of green technology. The main goal of the green technologies applications in agriculture is to look for an alternative to achieve the sustainability of Mother Nature, the development of the best application model, and the design of technology that will save the environment without compromising growth. The cutting-edge green technologies are wind energy, bioenergy, biofuel, biogas, biomass, micro and small hydroelectric, improved geothermal energy, bio-transgenic, organic agriculture, water mill and solar energy, etc. Besides, smart agricultural technologies that have been rapidly developing in recent years; advanced sensors, drones and satellite images support green technologies. These use renewable resources, increase cost and resource efficiency, develop and support economic growth, reduce production costs, increase resilience against environmental challenges, and play an important role in the production of agricultural output, resulting in higher production lands and clean environment and healthy products. These environmentally friendly applications help the agricultural sector to cope with possible crises and create a sustainable agricultural economy, and maintain financial stability, while also contributing to the protection and efficient use of water and other resources, reducing chemical impacts and increasing agricultural productivity. Green innovation offers innovative solutions and opportunities for employment, growth, development and the economy. Especially in the last decade, there has been a significant increase in research on these green applications that reduce the damage caused by agriculture, which has become a major threat to human life, to the environment and provides economic profitability (Fliaster and Kolloch, 2017).

GREEN AGRICULTURAL BIOTECHNOLOGY

A significant portion of the world's population earns its living through agricultural activities, especially in developing countries, that cause an increase in greenhouse gas emissions, pollution of resources and waste due to the use of agricultural drugs, fertilizers and chemical substances. These pollutants negatively affect human health, biodiversity, ecology and the environment (Rockström et al., 2017). Therefore, it is necessary to create and increase effective and innovative green methods to make a transition to sustainable development (Schaltegger et al., 2017). The field of agricultural biotechnology, as a potential solution utilizes living organisms for this purpose. It focuses on improving agricultural applications, crop productivity, the quality of agricultural products, and optimizing the use of resources. It involves methodology of scientific principles tissue culture, genetic engineering and molecular biology such as transgenic plant, genome editing, protoplast fusion, polyploidy, and others to enhance plants for agricultural green biotechnology. Overall, biotechnology plays an important role in minimizing excessive agricultural drugs, especially pesticides, to meet environmentally friendly production demands (Grung et al., 2015).

A Revolutionary Green Technology for Environmental and agricultural Sustainability: Genetically Modified Crop

Trans-genetic plant production technology has provided revolutionary progress in the production of genetically modified organisms (GMOs) since its emergence in the 1990s. This process is based on recombinant DNA technology, and the desired agricultural characteristics are given to the target plant species by adding foreign genes. Thanks to this technology, it has become possible to develop crops with high yields, increased nutritional value and tolerance to various environmental stress conditions. Although GMO plant production is a subject of debate, it makes significant contributions to increasing agricultural productivity and improving global food security (Garland & Curry, 2022). Modern agricultural biotechnology methods offered by recombinant DNA technology make it possible to transfer desired agricultural characteristics to target plant species in a much shorter time, in a controlled and specific manner, compared to traditional breeding techniques. Moreover, the need for parent plants to be closely related, along with the laborious and time-consuming processes and limiting factors such as uncontrolled genetic mutations associated with traditional methods, has led to the rapid adoption and pioneering of modern biotechnological techniques.

Thanks to genetically modified organisms (GMOs), agricultural products are made more resistant to environmental stresses such as diseases and pests, contributing to the reduction of the use of agricultural drugs such as chemical herbicides and pesticides, optimizing nutritional needs and developing rich nutritional profiles.

In addition, the other technology that is the most important agenda of plant breeding is CRISPR/Cas9 (clustered regularly interspaced short palindromic repeats) system is among the groundbreaking environmentally friendly applications in agricultural production. In short, CRISPR/Cas9 technology creates incisions in the plant genome through Cas proteins, leading to precise gene editing and the breeding of new plant varieties with desired characteristics (Hamdan et al., 2023). However, it has been revealed that these varieties are more productive, more durable and have improved nutritional value compared to classical methods. Obtaining plants that are resistant to pests and diseases and have improved nutritional value can make significant contributions to the protection of resources such as soil and water and to the reduction of environmental pollution and health risks by minimizing the use of pesticides, chemical fertilizers and other harmful substances that pollute the environment. The CRISPR/Cas9 technology improves the revival of endangered plant species and the promotion of genetic diversity. Currently, CRISPR/Cas9 technology has been used to improve approximately 120 crops, including staple crops such as rice (Yuyu et al., 2020; Alam et al., 2022), wheat (Gupta et al., 2023) and potato (Alok et al., 2023; Cardi et al., 2023).

Thus, GM and CRISPR/ Cas technologies assist green technology applications in line with sustainable development goals by producing precise, efficient and cost-effective solutions in agricultural production on a global scale. However, it is important that these technologies are align with ethical rules, concerns arising from public awareness and risk assessments.

Microbial Fertilizers in Green Biotechnology

The most important factor in increasing the efficiency of agricultural production is the application of chemical fertilizers. Although the widespread use of chemical fertilizers is important in increasing the crop yield, it damages the soil profile, physicochemical properties and microbial community structure and limits the sustainable development of agriculture (Szilagyi-Zecchin et al. 2016). Nitrate leakage, residues of inorganic fertilizers such as sodium nitrate and ammonium chloride can cause groundwater pollution and the production of greenhouse gases. These negativities can threaten the basis of agricultural production in the long term. In order to cope with these problems, it has become necessary to develop sustainable and environmentally friendly alternatives. In this context, increasing the efficiency of microorganisms by using natural and beneficial microorganisms such as bacteria, fungi, actinomycetes, including algae , as well as metagenomics and similar innovative biotechnological approaches has supported the development of microbial fertilizers.

Microbial fertilizers, as biological fertilizers, contain a wide variety of microorganisms. These fertilizers increase the diversity of beneficial microorganisms such as fungi and bacteria in the soil by preserving the structure of the soil and the balance of microbial communities, alleviating soil compaction and balancing productivity (Liu et al. 2022). Biofertilizers support ecosystem health by causing less damage to the environment than chemical fertilizers and are more reliable because they are used in smaller amounts. Besides, these fertilizers can quickly adapt to the environment, show their effects in a short time, have a low risk of turning into pathogens or resistant pests, and contribute to agricultural sustainability since they do not show any negative effects on soil, plant and animal life (Suyal et al. 2016).

Some rhizosphere microorganisms contained in microbial fertilizers can fix atmospheric nitrogen (bacteria), increase the solubility of potassium and phosphorus in the soil (fungi) and release them, and make them available to plants for water and essential nutrients (Nanaware et al. 2024). These microorganisms regulate the pH of the soil, increase the organic carbon content and increase plant tolerance to diseases. Due to their environmentally friendly organic structure, they have an important role in terms of reducing dependence on chemical fertilizers and supporting the biodiversity of the soil.

Rhizobacteria (PGPR) as a green environmental technology

Plant Growth Promoting Rhizobacteria (PGPR) found in microbial fertilizers have a significant place in sustainable agricultural practices

(Kloepper et al. 1989) and growth in a wide range with many plant species (Compant et al. 2005). PGRP can function as defense regulators as well as supporting plant growth by immobilizing nutrients, decomposing soil nutrients, and converting them into usable forms by plants (Kloepper et al., 1980). By making free nitrogen in the soil usable by plants, PGRPs can contribute to the prevention of environmental pollution via minimizing the use of nitrogenous fertilizers.

In addition, they can be effective in combating climate change by reducing greenhouse gas emissions. Phosphorus, potassium and some insoluble micronutrients in the soil can be solubilized and be used more efficiently (Ahemad and Kibret , 2014). Soil pH can be balanced with organic acids such as citric acid, gluconic acid, etc. (Seshadri et al., 2000). The uptake of nutrients such as iron in the soil by plants can be increased through Siderophores synthesized (Liu et al., 2014; Rai and Nabti , 2017). These microorganisms play a key role in synthesizing phytohormones essential for plant growth and development, while also inducing the ACC Deaminase enzyme, which reduces ethylene production in plants under stress (Glick et al., 2007). PGPR Pantocin facilitates the management of diseases by exhibiting antipathogenic activity through the production of various antibiotics and growth inhibitors such as bacteriocins, including oomycin, and allows the reduction of agricultural chemical inputs (Kloepper et al. 1980; Richardson and Simpson 2011; Fernando et al. 2005). Furthermore, due to the protective enzymes they synthesize and show biopesticide effect and provide product protection, therefore, they can be an alternative to the dependence on synthetic fertilizers and pesticides (Banerjee et al. 2006). (De Andrade et al. 2023; Hasan et al. 2024; Egamberdieva et al 2019).

CONCLUSION

The development of biotechnological methods plays a key role in ensuring agricultural sustainability. Biotechnology-supported green technologies can transform agricultural industries into not only a more efficient but also an environmentally friendly production model. These innovative approaches have the potential to contribute to global food security by offering environmentally friendly alternatives while minimizing environmental impacts. These green agricultural biotechnology innovations can revolutionize agriculture, providing both economic and environmental gains. In this context, they can increase soil fertility, improve yield and quality, and promote plant growth while minimizing negative environmental impacts. As a result, biotechnology has tremendous potential in transforming traditional agriculture into a more sustainable and green agriculture.

REFERENCES

Abdel Fattah, A. R., Daza, B., Rustandi, G., Berrocal-Rubio, M. Á., Gorissen, B., Poovathingal, S., ... & Ranga, A. (2021). Actuation enhances patterning in human neural tube organoids. *Nature communications*, *12*(1), 3192.

Ahemad, M., & Kibret, M. (2014). Mechanisms and applications of plant growth promoting rhizobacteria: current perspective. Journal of King saud University-science, 26(1), 1-20. doi: 10.1016/j.jksus.2013.05.001.

Alam, M. S., Kong, J., Tao, R., Ahmed, T., Alamin, M., Alotaibi, S. S., ... & Xu, J. H. (2022). CRISPR/Cas9 mediated knockout of the OsbHLH024 transcription factor improves salt stress resistance in rice (Oryza sativa L.). *Plants, 11*(9), 1184.

Alok, A., Chauhan, H., Kaushal, N., Aiana, & Singh, K. (2023). Rapid and efficient CRISPR/Cas9-mediated genome editing in potato via hairy root induction. *In Vitro Cellular & Developmental Biology-Plant*, *59*(1), 83-94.

Arenhardt, D. L., Battistella, L. F., & Grohmann, M. Z. (2016). The influence of the green innovation in the search of competitive advantage of enterprises of the electrical and electronic Brazilian sectors. *International Journal of innovation management*, *20*(01), 1650004.

Banerjee, M. R., Yesmin, L., Vessey, J. K., & Rai, M. (2006). Plant-growth-promoting rhizobacteria as biofertilizers and biopesticides. Handbook of microbial biofertilizers. Food Products Press, New York, 137-181.

Cardi, T., Murovec, J., Bakhsh, A., Boniecka, J., Bruegmann, T., Bull, S. E., ... & Van Laere, K. (2023). CRISPR/Cas-mediated plant genome editing: outstanding challenges a decade after implementation. *Trends in Plant Science*, *28*(10), 1144-1165.

Compant, S., Duffy, B., Nowak, J., Clément, C., & Barka, E. A. (2005). Use of plant growth-promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action, and future prospects. Applied and environmental microbiology, 71(9), 4951-4959.

de Andrade, L. A., Santos, C. H. B., Frezarin, E. T., Sales, L. R., & Rigobelo, E. C. (2023). Plant growth-promoting rhizobacteria for sustainable agricultural production. Microorganisms, 11(4), 1088.

Egamberdieva, D., Wirth, S., Bellingrath-Kimura, S. D., Mishra, J., & Arora, N. K. (2019). Salt-tolerant plant growth promoting rhizobacteria for enhancing crop productivity of saline soils. Frontiers in microbiology, 10, 2791.

Evenson, R. E., & Gollin, D. (2003). Assessing the impact of the Green Revolution, 1960 to 2000. science, 300(5620), 758-762.

Fliaster, A., & Kolloch, M. (2017). Implementation of green innovations–The impact of stakeholders and their network relations. *R&d Management*, *47*(5), 689-700.

Fernando, W. D., Nakkeeran, S., & Zhang, Y. (2005). Biosynthesis of antibiotics by PGPR and its relation in biocontrol of plant diseases. PGPR: biocontrol and biofertilization, 67-109.

Garland, S., & Curry, H. A. (2022). Turning promise into practice: Crop biotechnology for increasing genetic diversity and climate resilience. PLoS Biology, 20(7), e3001716.

Glick, B. R., Cheng, Z., Czarny, J., & Duan, J. (2007). Promotion of plant growth by ACC deaminase-producing soil bacteria. *New perspectives and approaches in plant growth-promoting Rhizobacteria research*, 329-339.

Grung, M., Lin, Y., Zhang, H., Steen, A. O., Huang, J., Zhang, G., & Larssen, T. (2015). Pesticide levels and environmental risk in aquatic environments in China—A review. *Environment International*, *81*, 87-97.

Gupta, S. K., Vishwakarma, N. K., Malakar, P., Vanspati, P., Sharma, N. K., & Chattopadhyay, D. (2023). Development of an Agrobacterium-delivered codon-optimized CRISPR/Cas9 system for chickpea genome editing. *Protoplasma*, *260*(5), 1437-1451.

Hamdan, M. F., Hensel, G., Alok, A., & Tan, B. C. (2023). Genome editing and biotechnological advances for crop improvement and future agriculture. Frontiers in Plant Science, 14, 1132821

Hasan, A., Tabassum, B., Hashim, M., & Khan, N. (2024). Role of plant growth promoting rhizobacteria (PGPR) as a plant growth enhancer for sustainable agriculture: A review. Bacteria, 3(2), 59-75. https://doi.org/10.3390/bacteria3020005.

Huang, J., Pray, C., & Rozelle, S. (2002). Enhancing the crops to feed the poor. Nature, 418(6898), 678-684.

IPCC. (2019). Climate Change and Land. Geneva: Intergovernmental Panel on ClimateChange.

Kloepper J.W., Lifshitz R., Zablotowicz R.M. (1989). Free-living bacterial inocula for enhancing crop productity. Trends in Biotechnology. 7(2):39-44. doi: https://doi.org/10.1016/0167-7799(89)90057-7.

Kloepper, J. W., Leong, J., Teintze, M., & Schroth, M. N. (1980). Enhanced plant growth by siderophores produced by plant growth-promoting rhizobacteria. Nature, 286(5776), 885-886. doi: 10.1038/286885a0.

Liu, H., Li, S., Qiang, R., Lu, E., Li, C., Zhang, J., & Gao, Q. (2022). Response of soil microbial community structure to phosphate fertilizer reduction and combinations of microbial fertilizer. Frontiers in Environmental Science, 10, 899727.

Liu, J., Chakraborty, S., Hosseinzadeh, P., Yu, Y., Tian, S., Petrik, I., Bhagi A., & Lu, Y. (2014). Metalloproteins containing cytochrome, iron–sulfur, or copper redox centers. Chemical reviews, 114(8), 4366-4469. doi: 10.1021/cr400479b

Nanaware, J. P., Pathade, A. G., & Sarkale, P. S. (2024). Microbial Biotechnology for the Production of Sustainable Biofertilizers: Challenges and Opportunities. NATURALISTA CAMPANO, 28(1), 244-251. ISSN: 1827-7160.

Rai, A., & Nabti, E. (2017). Plant growth-promoting bacteria: Importance in vegetable production. Microbial strategies for vegetable production, 23-48. doi:10.1007/978-3-319- 54401-4_2.

Richardson, A. E., & Simpson, R. J. (2011). Update on microbial phosphorus. Soil microorganisms mediating phosphorus availability. Plant Physiol, 156(989) 996, 111-175448.

Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., ... & Smith, J. (2017). Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio*, 46, 4-17.

Schaltegger, S., Burritt, R., & Petersen, H. (2017). *An introduction to corporate environmental management: Striving for sustainability*. Routledge.

Seshadri, S., Muthukumarasamy, R., Lakshminarasimhan, C., & Ignacimuthu, S. (2000). Solubilization of inorganic phosphates by Azospirillum halopraeferans.

Sundmaeker, H. (2016). Accelerating system development for the food chain: A portfolio of over 30 projects, aiming at impact and growth.

Suyal, D. C., Soni, R., Sai, S., & Goel, R. (2016). Microbial inoculants as biofertilizer. Microbial Inoculants in Sustainable Agricultural Productivity: Vol. 1: Research Perspectives, 311-318.

Szilagyi-Zecchin, V. J., Mógor, Á. F., & Figueiredo, G. G. O. (2016). Strategies for characterization of agriculturally important bacteria. Microbial Inoculants in Sustainable Agricultural Productivity: Vol. 1: Research Perspectives, 1-21.

Yuyu, C., Aike, Z., Pao, X., Xiaoxia, W., Yongrun, C., Beifang, W., ... & Yingxin, Z. (2020). Effects of GS3 and GL3. 1 for grain size editing by CRISPR/Cas9 in rice. *Rice Science*, 27(5), 405-413.

İKSAD
Publishing House

ISBN: 978-625-378-024-1