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Navigating Agricultural Challenges in the Era of Climate Change: Insights, Innovations, and Sustainable Solutions

Zanib Javed
[1]*Islamia College Lahore
***Correspondence**: j_zanib@gmail.com
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Agriculture is at the forefront of climate change dynamics, contributing significantly to greenhouse gas emissions while grappling with the profound impacts of environmental shifts. Greenhouse agriculture, though enhancing crop efficiency, presents energy-intensive operations contributing to increased greenhouse gas emissions. Mitigation strategies involve transitioning to renewable energy sources and adopting Thermal Energy Storage systems. Sustainable agricultural practices gain traction, driven by research initiatives utilizing stable isotope techniques. Challenges posed by monoculture and extensive chemical fertilizer use underscore the need for circular economy principles and mixed farming approaches. Precision Agriculture and Precision Livestock Farming integrated with Decision Support Systems offer advanced solutions for optimized resource utilization and reduced emissions. The study delves into greenhouse gas emissions, identifying methane and nitrous oxide as major contributors to agriculture. Global efforts to reduce methane levels aim for a 45% reduction by 2030, crucial for climate mitigation. The Solution4Farming platform, utilizing AIoT, streamlines GHG emissions management, emphasizing the importance of precise data collection and user-friendly interfaces. Challenges in accurately measuring emissions call for sophisticated DSS tools, aligning with IPCC methodologies. The agriculture sector's contribution to total greenhouse gas emissions in the EU is analyzed, highlighting reductions since 1990. Energy consumption in EU agriculture shows a 6% increase in associated emissions from 2004 to 2018, with variations among member states. Emission structures reveal diesel oil as a predominant contributor. FADN data categorize farms based on emissions, emphasizing animal production as a significant source. Fuels dominate emissions from energy inputs, particularly in horticultural crops. The research concludes with recommendations for future enhancements to the Solution4Farming platform, emphasizing global relevance, AI advancements, and IoT applications. The study underscores the importance of innovative strategies, precision technologies, and sustainable practices in addressing the complex challenges posed by agriculture in the context of climate change.

Keywords: GHG Emissions, Livestock Farming, Horticultural Crops, Climate Mitigation.

Introduction:

Agriculture holds significant implications for climate change, embodying a dual role in its relationship with environmental shifts. On one hand, agriculture stands as a prominent contributor to greenhouse gas emissions, with research indicating that farms are accountable for approximately 16–27% of all anthropogenic emissions [1]. These emissions manifest across various stages of production, ranging from seed preparation to the harvesting and storage of final products. On the other hand, agriculture emerges as the economic sector most profoundly impacted by ongoing climate processes, necessitating large-scale adaptation measures. Globally, climate change presents a growing challenge for ensuring an adequate food supply to meet the needs of an expanding world population, marked by declining yields and escalating food prices

[2]. This is exemplified by the diminishing value of transferable stocks of cereals, a crucial food product determining food security, which declined from 74 days in 2002 to 54 days in 2011. Disparities in available food are pronounced across regions, with acute shortages prevalent in the world's poorest areas. On a global scale, 870 million people suffer from hunger, with the sub-Saharan region experiencing the most severe conditions, affecting nearly 30% of the population, and South Asia grappling with the challenge impacting 300 million people [3].

The complex scenario intensified with the onset of the COVID-19 pandemic. Climate change directly contributes to a reduction in agricultural production by altering weather patterns, reducing rainfall in many regions, and promoting extreme phenomena like storms, hail, and frosts. Additionally, it leads to the emergence of new pests and diseases without natural enemies, and periods of excessively high temperatures that are detrimental to crops, livestock, and human labor productivity. Notably, efforts to mitigate greenhouse gas emissions pose an additional risk to agriculture, prompting widespread discussions at political and social levels [4]. The significant emissivity of agriculture becomes a focal point in broader conversations, especially concerning the EU's ambitious goal of achieving climate neutrality by 2050, aiming for zero net emissions. In the context of modern agriculture, reliance on external industrial energy sources, primarily fossil fuels and electricity, has become indispensable. These sources not only power machinery directly but also play indirect roles in construction, mineral fertilizer extraction, and nitrogen compound synthesis. The dominance of non-renewable energy sources, particularly fossil fuels, not only contributes to greenhouse gas emissions but also accelerates environmental degradation. Consequently, there is a clear imperative to enhance energy efficiency and reshape its sourcing [5].

Recent projections indicate that the global population is anticipated to reach 9.8 billion by 2050, posing significant challenges to global food security and freshwater resources. The impact is exacerbated by the uneven distribution of the population in urban areas. Beyond population growth and pressure on freshwater sources, agricultural production faces threats from global warming and climate change. Addressing these multifaceted challenges underscores the necessity for investments in the agricultural sector to ensure food security and implement resource management strategies that mitigate the impact of climate change on agricultural production [6]. Greenhouses play a pivotal role in modern agriculture, offering controlled environments for crop cultivation irrespective of external weather conditions. However, the operation of greenhouses is energy-intensive, particularly in heating, cooling, and artificial lighting [7]. Modern greenhouse structures, characterized by low thermal mass and poor insulation, often result in higher energy demand and increased greenhouse gas emissions. Countries like the US, the Netherlands, China, and Saudi Arabia have significantly expanded greenhouse agriculture. As of 2017, China led the world in climate-smart farming, with 41,090 km2 under greenhouses [8].

The energy demand associated with greenhouse production can be mitigated through the adoption of renewable energy sources such as solar, biomass, and geothermal heat. Transitioning to renewables allows greenhouse operators to reduce CO_2 emissions linked to conventional fossil fuel-based energy sources. Moreover, Thermal Energy Storage (TES) systems can enhance the energy efficiency and sustainability of greenhouse cultivation. TES systems help decrease the heat demand of greenhouses and stabilize the indoor micro-climate for plants. This reduction in heat demand becomes crucial when renewable energy sources are employed, considering their intermittent nature. TES systems store excess energy during periods of high availability and release it during low-availability phases, ensuring a stable indoor climate for plant growth while minimizing energy consumption [9]. Efforts to reduce energy consumption in greenhouse cultivation through renewable energy sources and TES systems contribute to the sustainability and economic viability of these practices. Existing literature on net-zero emission buildings and zero-energy requirements has primarily focused on commercial and residential structures, overlooking the unique challenges posed by greenhouses [10]. The limited research addressing greenhouse structures is critical given the substantial increase in greenhouse acreage attributed to global warming and climate change [11].

The expansion of greenhouses brings both advantages and challenges to food security and the environment. On one hand, greenhouse production enhances efficiency and yields by regulating the microclimate and reducing the risk of insect and pest infestations. This efficiency has been demonstrated in the cultivation of capsicum, tomatoes, and other vegetables. On the other hand, intensive greenhouse agriculture contributes to global warming. Given these complexities, there is an urgent need for innovative strategies to achieve net-zero emissions and zero energy requirements in greenhouse operations [12]. Farmers are increasingly adopting sustainable agricultural methods to enhance productivity and concurrently mitigate greenhouse gas emissions. A series of research initiatives, orchestrated by the IAEA in collaboration with the Food and Agriculture Organization of the United Nations (FAO), employs stable isotope techniques to validate the efficacy of eco-friendly farming practices [13].

Large-scale commercial agriculture, often characterized by monoculture and extensive use of chemical fertilizers, poses challenges to ecosystems. Monoculture, the continuous cultivation of the same crop on a specific plot, results in diminished soil fertility over time. To counteract this decline, farmers resort to applying excessive amounts of chemical fertilizers, contributing to global nitrous oxide emissions at a rate of 1.2 million tons annually. Nitrous oxide is a greenhouse gas with a potency 260 times greater than carbon dioxide [14]. The sustainable agricultural practices under scrutiny in these research projects present cost-effective solutions for simultaneously increasing productivity and addressing climate change concerns. Greenhouse gases, or GHGs, pose a significant environmental threat that now jeopardizes the entire planet, presenting a challenging task for many scholars. This class of transparent gases, known as greenhouse gases, effectively captures and retains the Earth's thermal energy. The Earth's temperature increases due to the atmosphere's role as a thermal insulator, preventing radiation from escaping into space [15]. The Intergovernmental Panel on Climate Change (IPCC), a specialized organization dedicated to in-depth research on anthropogenic climate change, categorizes the following greenhouse gases fluorinated gases (HFC, PFC, SF6, and NF3), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The IPCC's sixth report, released in 2022, presents data illustrating changes in the distribution of greenhouse gas emissions resulting from human activities across different gases from 1990 to 2019 [16].

According to the IPCC, the primary sources of greenhouse gas emissions globally are the energy systems, industry, buildings, transportation, and AFOLU (agricultural, forestry, and other land use) sectors. By examining the EDGAR v5.0 database, researchers determined the global distribution of greenhouse gas emissions. Methane emerges as the main greenhouse gas emitted by livestock and agricultural crops. The sixth IPCC assessment highlighted the urgency of reducing methane levels [17]. The Global Monitoring Laboratory recorded an increase in methane levels between June 2021 and June 2022, reaching the highest reported value since the registry's establishment in 1984, at 17.64 parts per billion (ppb). The Climate and Clean Air Coalition's 2021 World Methane Assessment Report predicts a 45% reduction in methane emissions by 2030, potentially lowering global temperatures by 0.3°C. This reduction is also anticipated to decrease crop loss, mortality, and asthma attacks. Among human-related sources, plant cultivation and animal husbandry contribute 18% and 30% of methane emissions, respectively, with enteric fermentation during ruminant meal digestion accounting for 27% of the total. Nitrous oxide, also known as N_2O, is another prevalent agricultural gas ranking second to methane. The study underscores a concerning trend associated with climate change: anthropogenic emissions are the primary driver behind the 20% increase in N_2O levels observed in 2018. Major contributors to N_2O emissions in agriculture include the application of manure in the field, the use of synthetic fertilizers, and the presence of crop residues [18].

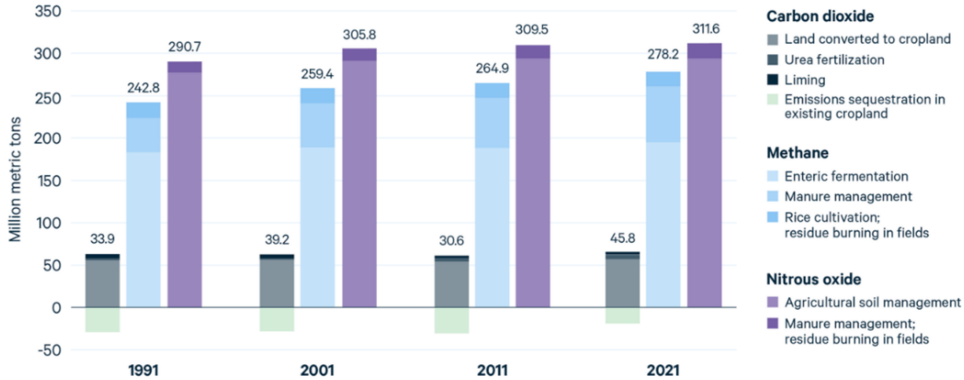

Figure 1: EPA Greenhouse Gas Inventory Data Explorer [19].

The escalating emissions of methane and nitrous oxide from the agriculture sector emphasize the need for innovative, cost-effective, and ecologically sustainable approaches to crop and animal management. Embracing the fundamental principles of the circular economy, such as sharing, reusing, minimizing waste, and enhancing resource utilization, should guide these strategies. The concept of mixed farms, leveraging the synergies between animal and plant husbandry, holds significant promise. Integrating horticulture with livestock farming, for instance, enables feeding sheep with inedible components of various horticultural plants, and their dung can be used as fertilizer for these plants [20]. The Fourth Industrial Revolution has profoundly impacted contemporary culture, transforming every aspect of human existence. The Internet of Things, a component of Industry 4.0, facilitates the interconnection of numerous small, portable devices to collect, store, transmit, analyze, and repurpose diverse data. In various sectors such as healthcare, industry, the military, and agriculture, the IoT has proven highly valuable. Agricultural IoT (AIoT) specifically focuses on applications related to farming [21].

Utilizing Artificial Intelligence of Things, farmers can swiftly gather a wealth of information about their fields and livestock, including weather conditions, livestock numbers, air quality, soil moisture content, and other relevant factors. This information enables farmers to assess their land's condition more effectively and manage resources to increase crop yield while minimizing environmental impact [22]. Artificial Intelligence of Things is closely associated with Precision Livestock Farming (PLF) and Precision Agriculture (PA), both intricately linked to the concept of a Decision Support System (DSS). Precision Agriculture, as defined by the International Society of Precision Agriculture (ISPA), involves a management strategy that collects, evaluates, and interprets data related to time, geography, and individuals. This data is then integrated to facilitate management decisions based on expected variability, aiming to optimize resource use, increase output, enhance quality, maximize profitability, and ensure long-term sustainability in agricultural production. On the other hand, Precision Livestock Farming (PLF) focuses on real-time animal monitoring, aiming to optimize agricultural resource utilization, effectively manage animal health, and significantly reduce greenhouse gas emissions [23]. A Wireless Sensor Network (WSN) is a network of strategically positioned sensors gathering data on various aspects such as crop conditions (soil moisture, water availability, fertilizer intake), livestock characteristics (size, food intake, sounds), and environmental parameters (temperature, greenhouse gas emissions, personnel and equipment locations). The subsequent section provides an in-depth analysis of relevant metrics and the methodologies employed for their quantification [24].

Data Processing Module:

This module undertakes tasks such as processing, organizing, sorting, storing, and transmitting the raw data collected by portable devices.

DSS (Decision Support System):

The data module feeds refined information streams to the Decision Support System. Utilizing modeling and simulation, the DSS assists users in selecting the optimal course of action.

Action:

Following a thorough evaluation of DSS recommendations, the end-user, including managers, administrators, and farmers, makes informed decisions.

Human-induced greenhouse gas emissions, primarily methane, and nitrous oxide constitute approximately 25% of all emissions from the Agricultural, Forestry, and Other Land Use (AFOLU) sectors. The emergence of AIoT provides new opportunities for tracking, organizing, and evaluating agricultural data, facilitating management optimization concerning greenhouse gas emissions and financial viability [25]. The Food and Agriculture Organization of the United Nations gathers and evaluates global statistics on greenhouse gas emissions from the agriculture sector. Analyzing recent data on methane and nitrous oxide emissions in various European countries between 2016 and 2020 indicates a consistent increase in both levels. CH_4 emissions primarily result from enteric fermentation, while N_2O emissions stem from synthetic fertilizers. It is crucial to acknowledge that variations in environmental, agricultural, ecological, and other variables contribute to emission differences between countries [26]. This article proposes a specially designed solution tailored to farmers, serving as an advanced decision support system to mitigate the environmental impact of mixed farm operations.

The selection of attributes for monitoring is vital when applying IoT in agriculture, facilitating the creation of a comprehensive and reliable database for effective management practices aligned with IoT architecture. Currently, there are no precise classifications of key indicators relevant to agriculture in the literature [27]. Understanding the complex system under investigation and its correlation with available resources and opportunities is crucial when implementing additional measures. The initial stage in constructing the DSS involves determining the system's primary objective, output, and input. The proposed Decision Support System (DSS) primarily outputs the Air Quality Index (AQI), potentially utilizing other metrics as inputs. The Air Quality Index gauges the degree of air pollution in a given location, calculated from reported contaminant levels, providing a comprehensive measure of air quality [11][28]. This program aims to establish air quality regulations in major urban areas and offer prompt guidance to those exposed to pollution levels exceeding recognized health guidelines. Modern greenhouse gas-focused Decision Support Systems (DSS) automatically calculate the carbon footprint as a secondary result, expressed as the amount of carbon dioxide equivalents emitted per kilogram of a product, such as milk. This figure includes methane and nitrous oxide emissions, along with carbon emissions [29].

After analyzing the latest IPCC report, it is concluded that animals predominantly produce methane (CH_4), and agricultural fields primarily generate nitrous oxide (N_2O), both significant greenhouse gases. Examining FAOSTAT data from the last five years for selected countries (Romania, Poland, Finland, and Spain) reveals that enteric fermentation and synthetic fertilizers are the main sources of these gases in designated locations. The ultimate goal is to compile a comprehensive set of indicators relevant to monitoring mixed farms, considering these indicators in making ecologically and economically sustainable management decisions. Enteric fermentation, occurring during ruminant digestion, produces methane, which is then released through belching or gas passage [30].

Reluctance to Embrace Novel Concepts:

The challenge of accurately measuring emissions from all potential sources on a farm poses significant obstacles for farmers seeking to quantify greenhouse gas emissions at the livestock farm level. This underscores the necessity for software-driven decision support systems specifically tailored to address GHG emissions. These cutting-edge devices are designed to furnish users with clear, concise information to enable the effective reduction of greenhouse gas releases during agricultural operations [31]. According to Alexandropoulos, Inc. and others, mixed farm DSS tools are divided into three groups based on the degree of evaluation. The first group consists of emission calculators assessing various forms of emissions solely at the farm level. The second category evaluates sustainability by combining financial metrics, profits, and cost and emission forecasts. The third category offers a comprehensive assessment of agricultural sustainability by considering environmental, social, and economic aspects of agriculture.

Several agricultural tools for assessing GHG emissions employ the IPCC 2006 methodology, utilizing Tier 1 or Tier 2 methods to compute emissions at the farm level. Tier 2 is often employed for calculating methane emissions due to enteric fermentation and considering other emission characteristics specific to each country [28]. While the IPCC's criteria for GHG emissions provide a comprehensive methodology with three levels for assessing emissions, it is just a small component of the broader and more thorough Life Cycle Assessment (LCA). LCAs encompass a wide range of environmental consequences, including pollution, resource depletion, ecosystem degradation, and GHG emissions, offering a more comprehensive assessment of the total environmental impact of a system or product throughout its life cycle. Studies demonstrate the application of IPCC techniques in combination with LCA, emphasizing the mutually beneficial connection between the two methodologies. Decision Support Systems (DSS) require input data at multiple levels to achieve a more accurate and thorough evaluation of agricultural sustainability, though there is a trade-off between complexity and the risk of decreased utilization by agricultural laborers. Outcome DSS focuses on quantifying GHG emissions and conducting extensive sustainability evaluations, categorizing emissions into three broad groups and providing visual representations. While existing DSS systems offer sustainability ratings indicating emission reductions, they often lack automatic suggestions for enhancing operations. Nevertheless, certain systems like KSNL and RISE provide consulting services by compiling reliable resources.

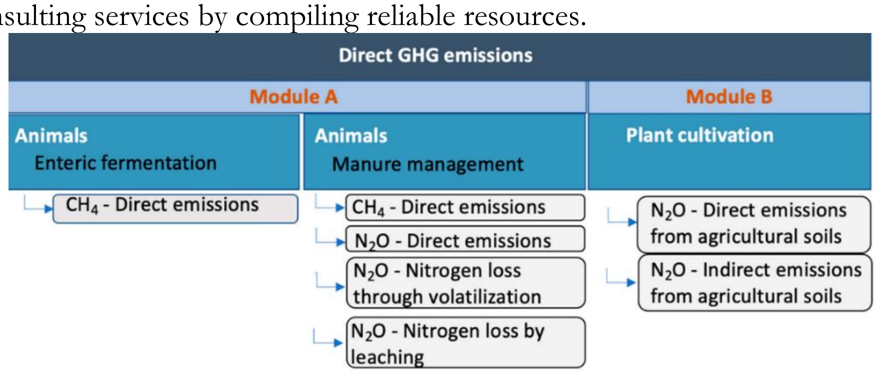

Figure 2: Direct GHG emission sources from animals (module A) and plant cultivation (module B) [32].

DSS tools utilize various techniques, including scenario analysis, contribution analysis, and progress tracking to aid in decision-making. Less common strategies include information exchange, action planning, benchmarking, and comparative assessment. Comparative tools like Cool Farm Tool and Overseer use automated comparison, while non-comparative technologies like Farm AC and BEK are employed for manual evaluations. Guides and user-friendly interfaces serve as instruments to facilitate information transfer. The specified requirements impose obligations on stakeholders within the agricultural Decision Support Solutions (DSS) industry [33].

Considerations such as user-friendliness and accessibility are paramount for stakeholders in the agricultural DSS industry. To prevent project cancellations, clear and achievable inputs at the farm level are crucial, with the presence of an extensive PDF manual and an intuitive user interface facilitating input processing. Ensuring compatibility of the financial aspects with sustainable agriculture practices is essential for adoption. The intended outcomes of these systems must be easily understandable and beneficial, ideally condensed into a comprehensive report highlighting issues like excessive greenhouse gas emissions and proposing workable solutions. Users relying on GHG emission calculators without access to comprehensive information or consulting services should have the experience to explore various mitigation strategies. DSS tools must include user instructions directing the understanding and assessment of different approaches, as well as the interpretation of results, to effectively address this challenge [34].

Challenges, restrictions, potential routes, and improvements in multiple Decision Support Systems (DSS), including those employing IPCC-recommended methodologies, point to a flaw in the approach, emphasizing the need for additional study into the reliability of these systems. Another disadvantage is the limited automation in DSS's GHG reduction programs. A well-designed DSS should offer users timely and pragmatic actionable suggestions, prioritizing accurate and succinct instructions over complex outputs, and empowering end users to make more informed choices about their operations. The future breakthrough in this field involves automating the assembly of greenhouse gas (GHG) mitigation plans using advanced modeling tools like multi-criteria optimization or continuous simulations, accurately representing the real-time dynamics of agricultural systems. Abundant data and powerful computer models are necessary to accurately depict the intricacy of agricultural systems [35]. Multi-criteria optimization involves achieving a harmonious balance between sustainability goals, such as boosting productivity while simultaneously lowering emissions and resource consumption. Techniques like Pareto front analysis and evolutionary algorithms can identify optimal trade-offs among competing objectives. Ongoing simulation allows the examination of complex interconnections among soil, climate, crop growth, and agricultural techniques. It can be utilized to simulate the impact of various management decisions on greenhouse gas emissions over time, aiding in the development of strategies to reduce emissions without compromising agricultural productivity.

Regular communication between data sources and tool developers can enhance productivity by facilitating the integration of upgrades and modifications. Updating datasets with the latest emission components and broadening their scope to encompass underrepresented geographical regions, such as the tropics, enhances the precision of findings. The use of emission estimation methodologies like Tier 2 approaches and the revised 2019 IPCC 2006 guidelines increases accuracy. Some models also employ machine learning techniques to replicate greenhouse gas production from cattle, classified as Tier 3 approaches by the IPCC. These models exhibit reduced prediction error, and greater complexity, and require a substantial volume of input data [36]. The Solution4Farming web application employs a multifaceted methodology to address various aspects of its deployment, user administration, data input integrity, processing, and visualization. The application prioritizes security by utilizing self-signed SSL certificates over the local corporate network, ensuring encrypted connections for data privacy. Robust user administration is facilitated through the "stream lit-authenticator" library, enabling users to create accounts with encrypted passwords securely stored in an application database. The system establishes a clear connection between farms and individual users, enhancing data management and accountability. With a focus on agricultural data input, the application provides a structured form for users to input soil and cattle consumption statistics, leveraging dynamic forms for different cattle categories. Session state management ensures the persistence of user-provided data across interactions. The SQLite database, enhanced with the "SQL Cipher" library for encryption, underpins the data structure, facilitating extraction and processing using SQL queries and Pandas Data Frames. Greenhouse gas calculation functions are comprehensive, addressing livestock, soil, and energy use emissions, with results stored in the session state. The application's data visualization capabilities, powered by the Plotly library, offer dynamic and interactive dashboards, enabling users to analyze trends, compare historical data, and assess greenhouse gas emissions relative to other farms. The methodology concludes with a thoughtful discussion on the significant impact of technology in agriculture, emphasizing the need for proactive technology policy and aligning with the broader societal shifts highlighted in recent research from the University of California [37].

Related Works:

The [38] conducted an extensive bibliometric analysis covering sustainable agriculture publications from 2000 to 2021, revealing insights into the current and future applications of artificial intelligence in sustainable agriculture. The study emphasizes the growing significance of AI in enhancing agricultural operations, visually represented using contemporary technologies like Biblioshiny and VOS viewer. The "Technology and Innovation Report 2021" by the United Nations Conference on Technology and Development (UNCTAD) underscores the urgency for developing nations to adapt to advancing technological changes. The report advocates fair usage principles and adaptability to ongoing technological advancements, particularly in emerging nations integrating into global technological progress.

In [39], researchers evaluate agricultural modeling tools for quantifying and mitigating greenhouse gas emissions in livestock systems. They assess advantages, constraints, and appropriateness for integrating adaptation techniques with climate change impact models, referencing sustainable agricultural strategies. The study encompasses examining the impact of agricultural practices on greenhouse gas emissions and proposing methodologies for field measurements. Solution4Farming is introduced as an advanced platform for managing greenhouse gas emissions in diverse agricultural environments, leveraging IoT and data analytics. The platform's strength lies in comprehensive data collection, offering farmers a thorough overview of emissions from their farms and enabling environmentally sustainable practices.

The Solution4Farming applications meet standards for reducing greenhouse gas emissions in modern agriculture, providing user-friendly interfaces and accurate results. However, limitations include excluding social and economic sustainability components. Future improvements aim to automate user input and expand the platform's scope, making it accessible globally and aligning with sustainability goals. The Solution4Farming platform, currently tailored to Romania's circumstances, demonstrates effectiveness but requires further development to accommodate a broader array of agricultural configurations and climatic conditions. Despite its limitations, the platform sets a benchmark for sustainable agriculture by integrating technological innovations with ecological principles. Future enhancements, such as expanding animal categories and incorporating IPCC emission factors, aim to make the platform a versatile tool for global sustainable agriculture [40].

The Solution4Farming platform has significantly advanced agricultural technology, particularly in managing greenhouse gas emissions. Leveraging the SQLite database and Stream lit framework reflects a purposeful choice for a seamless blend of user-friendliness and capability. Streamlit facilitates the quick deployment of data-driven, interactive web applications, aligning with the current trend of democratizing data analytics for farmers and stakeholders. SQLite, with its efficiency, is well-suited for handling agricultural data and ensures data security through encryption using the 'SQL Cipher' package, complying with international data protection regulations. The integration of the Stream lit authenticator library enhances the platform's user management system, increasing security and customization. This feature is vital to ensure that analytics generated from data input are tailored to each farm, providing personalized insights [28].

The Solution4Farming platform shows promising potential for future enhancement, with possibilities to include a wider array of farm types and climatic conditions, making it globally relevant. Incorporating diverse datasets covering various agricultural methods and climates can enrich its capabilities. Additionally, employing more advanced AI and machine learning methodologies for predictive analytics could provide farmers with proactive insights into prospective environmental consequences based on their existing farming techniques. Recent studies suggest the platform's potential for Internet of Things (IoT) applications in agriculture, allowing real-time data collection for faster and more precise insights into farming operations. This can optimize production forecasting, and resource allocation, and improve the accuracy of monitoring greenhouse gas emissions.

To ensure compatibility and expandability, the platform should handle varying quantities and complexities of data, considering the diversity of farms. Interoperability with different agricultural technology systems is crucial for seamless integration into modern farm environments. Improving the user interface and experience, along with educational materials, is essential to cater to a diverse user population with varying technical proficiencies. In conclusion, while the Solution4Farming platform currently demonstrates significant capability, ongoing development is crucial to align with the latest trends in agricultural technology. Continuous advancement can transform it into a vital tool for efficient and sustainable agriculture, contributing to the evolving landscape of agricultural practices.

Total Greenhouse Gas Emissions in Agriculture:

In 2018, the overall Green House Gas (GHG) emissions within the European Union (EU) reached 4.4 billion tonnes. Over the period from 1990 to 2018, the distribution of individual GHG sources within the EU remained consistent. Within the agricultural sector, the contribution varied between 1% and 14%, akin to the Industrial sector.

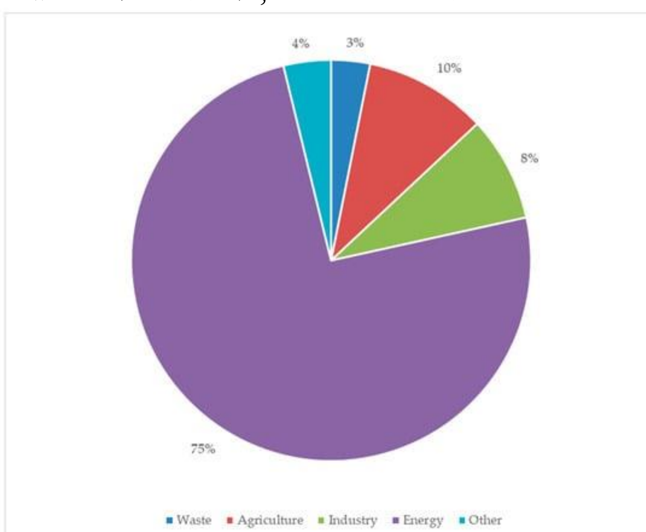

Figure 3: Structure of GHG emissions in the EU in 2018 by sector [1].

In absolute terms, agriculture releases an average of 436 million tonnes of greenhouse gases annually. Noteworthy is the fact that agricultural emissions decreased by 23% since 1990, attributed to factors such as a reduction in livestock numbers and constraints on nitrogen compound consumption. With the exception of Spain, each EU Member State demonstrated a reduction in GHG emissions between 1990 and 2018, with significant decreases observed in Germany, Romania, and Poland. However, on a global scale, the agricultural sector witnessed a 1.1% increase in GHG emissions. Poland, with annual GHG emissions totaling 416 million tons, ranks as the fifth-largest emitter in the EU. The composition of GHG emissions in Poland differs slightly from the EU average, with the energy sector dominating, accounting for over 80% of total emissions. Agriculture contributes 8% to the country's emissions, exhibiting a nearly one-third reduction in emissions from 1990 to 2018. This decline can be attributed to factors such as a decrease in livestock numbers, the restructuring of inefficient State Agricultural Farms, and a more efficient use of fertilizers based on market economy principles [5].

GHG Emission from Energy:

Inputs in Agriculture Between 2004 and 2018, energy consumption in EU agriculture increased by 3%, accompanied by a nearly 6% rise in emissions associated with this consumption. This indicates that, on average, the energy sources in the community had a higher greenhouse gas emission index. Greece, Bulgaria, and Ireland experienced the most significant reductions in agricultural energy consumption, with reductions of 76%, 33%, and 29%, respectively. Notably, Slovakia reduced energy consumption by one-fifth while simultaneously lowering emissions from this energy consumption by almost 40%, showcasing a shift toward low-emission energy sources, including renewables. Slovakia, along with Czechia and Slovenia, demonstrated the lowest emissivity of energy inputs in agriculture, significantly below the EU average. The volume of emissions resulting from energy consumption is directly influenced by both the quantity of energy used and the composition of energy carriers, each with varying greenhouse gas emissivity. Between 2004 and 2018, emissions in Poland, mirroring energy consumption trends, reached a minimum level of 11.18 million tonnes in 2015, followed by an increase, a pattern also evident in the broader Polish economy.

Emissions stemming from energy sources in agriculture are predominantly attributed to diesel oil, constituting half of the emissions in 2018. Additionally, bituminous coal contributes 34%, and electricity accounts for 11% of the emission structure. To identify opportunities for reducing both energy consumption and greenhouse gas emissions, a thorough investigation was conducted to pinpoint which types of farms emit the most greenhouse gases from energy carriers and where potential opportunities lie for primary reductions [41].

GHG Emissions from Energy Carriers Based on Farm Type:

As part of the research, GHG emissions were calculated for individual production types within the Polish Farm Accountancy Data Network (FADN) system. The calculations covered 15 emission streams, aggregated into categories related to Plant production, Animal production, and Fertilization, and broken down into Electricity and Fuels within the Energy category. The average GHG emission level across all FADN-covered Polish farms exceeded 207,000 kg per farm, with energy inputs contributing 24,000 kg, constituting 12% of total emissions. Farms engaged in livestock production, specifically dairy cows and granivorous animals, exhibited the highest total emission levels, reaching 311,000 kg and 430,000 kg of GHG per farm, respectively. This aligns with previous studies, underscoring animal production as a primary source of emissions. Permanent crop farms, mainly fruit-growing farms, demonstrated the lowest emission levels.

Fuels and electricity emerged as important emission sources in the surveyed farms, contributing to average emissions ranging from 11,700 kg of GHG in herbivorous animals to 194,500 kg in horticultural crops. The Energy category's share in the emission structure varied widely, ranging from 7% for dairy cows and herbivorous animals to 84% for horticultural crops. The substantial energy share in horticultural crops is attributed to the intensive production technology, particularly in greenhouse cultivation, which demands significant energy inputs. Fruit-growing farms, categorized under permanent crops, showed high emissions in the Energy category due to intensive fruit production necessitating various agrotechnical treatments, storage conditions, and post-harvest processes. Within the Energy category, fuels dominated, accounting for an average of 69% of emissions from energy inputs in the surveyed farms. Horticultural crops exhibited the highest share of fuels at 88%, while permanent crops had the lowest share at 41% of total emissions from energy sources [42].

Conclusion:

In conclusion, the intricate relationship between agriculture and climate change poses multifaceted challenges that demand urgent attention and innovative solutions. The agricultural sector not only contributes significantly to greenhouse gas emissions but is also profoundly impacted by the consequences of climate change, affecting global food security and resource sustainability. The escalating global population, anticipated to reach 9.8 billion by 2050, intensifies the pressure on food production and freshwater resources. Climate change further compounds these challenges, posing threats to agricultural production through changing weather patterns, extreme phenomena, and the emergence of new pests and diseases. This necessitates substantial adaptations in agricultural practices to ensure a secure and sufficient food supply. Greenhouse agriculture, while enhancing efficiency and yields, presents its own set of challenges, particularly in terms of energy consumption and associated emissions. Transitioning to renewable energy sources and implementing Thermal Energy Storage (TES) systems emerge as promising strategies to mitigate the environmental impact of greenhouse cultivation.

Furthermore, the critical role of Artificial Intelligence of Things (IoT) in Precision Agriculture and Precision Livestock Farming underscores the potential for technology-driven solutions in optimizing resource use, minimizing emissions, and promoting sustainability. The study of greenhouse gas emissions in agriculture, with a focus on methane and nitrous oxide, highlights the need for innovative and sustainable approaches to crop and animal management. Embracing circular economy principles and integrating horticulture with livestock farming present viable strategies to address emissions from different sources. The Solution4Farming platform exemplifies the intersection of technology and agriculture, offering a comprehensive approach to managing greenhouse gas emissions. While demonstrating promising capabilities, ongoing development is essential to align with evolving technological trends, ensuring compatibility, expandability, and global relevance. Overall, addressing the complex challenges in agriculture necessitates a holistic approach, incorporating technological advancements, sustainable practices, and international collaboration. The findings underscore the urgency of adopting innovative solutions to create a resilient and sustainable future for global agriculture amidst the realities of climate change.

References:

[1] P. Gołasa et al., "Sources of Greenhouse Gas Emissions in Agriculture, with Particular Emphasis on Emissions from Energy Used," Energies 2021, Vol. 14, Page 3784, vol. 14, no. 13, p. 3784, Jun. 2021, doi: 10.3390/EN14133784.

[2] N. Stern, "The structure of economic modeling of the potential impacts of climate change: Grafting gross underestimation of risk onto already narrow science models," J. Econ. Lit., vol. 51, no. 3, pp. 838–859, Sep. 2013, doi: 10.1257/JEL.51.3.838.

[3] J. C. Zachos, G. R. Dickens, and R. E. Zeebe, "An early Cenozoic perspective on greenhouse warming and carbon-cycle dynamics," Nature, vol. 451, no. 7176, pp. 279–283, Jan. 2008, doi: 10.1038/NATURE06588.

[4] R. Revelle and H. E. Suess, "Carbon Dioxide Exchange Between Atmosphere and Ocean and the Question of an Increase of Atmospheric CO2 during the Past Decades," Tellus, vol. 9, no. 1, pp. 18–27, Jan. 1957, doi: 10.3402/TELLUSA.V9I1.9075.

[5] W. R. Freudenburg and V. Muselli, "Global warming estimates, media expectations, and the asymmetry of scientific challenge," Glob. Environ. Chang., vol. 20, no. 3, pp. 483–491, Aug. 2010, doi: 10.1016/J.GLOENVCHA.2010.04.003.

[6] K. Brysse, N. Oreskes, J. O'Reilly, and M. Oppenheimer, "Climate change prediction: Erring on the side of least drama?," Glob. Environ. Chang., vol. 23, no. 1, pp. 327–337, Feb. 2013, doi: 10.1016/J.GLOENVCHA.2012.10.008.

[7] "View of Climate Change and Sustainable Development." Accessed: Feb. 22, 2024. [Online]. Available: https://journal.50sea.com/index.php/IJASD/article/view/422/499

[8] S. C. Sherwood and M. Huber, "An adaptability limit to climate change due to heat stress," Proc. Natl. Acad. Sci. U. S. A., vol. 107, no. 21, pp. 9552–9555, May 2010, doi: 10.1073/PNAS.0913352107.

[9] T. M. Lenton, V. N. Livina, V. Dakos, E. H. Van Nes, and M. Scheffer, "Early warning of climate tipping points from critical slowing down: Comparing methods to improve robustness," Philos. Trans. R. Soc. A Math. Phys. Eng. Sci., vol. 370, no. 1962, pp. 1185–1204, Mar. 2012, doi: 10.1098/RSTA.2011.0304.

[10] T. Slater, A. E. Hogg, and R. Mottram, "Ice-sheet losses track high-end sea-level rise projections," Nat. Clim. Chang., vol. 10, no. 10, pp. 879–881, Oct. 2020, doi: 10.1038/S41558-020-0893-Y.

[11] E. Kriegler, J. W. Hall, H. Held, R. Dawson, and H. J. Schellnhuber, "Imprecise probability assessment of tipping points in the climate system," Proc. Natl. Acad. Sci. U. S. A., vol. 106, no. 13, pp. 5041–5046, Mar. 2009, doi: 10.1073/PNAS.0809117106.

[12] R. Lal, "Carbon emission from farm operations," Environ. Int., vol. 30, no. 7, pp. 981–990, 2004, doi: 10.1016/J.ENVINT.2004.03.005.

[13] J. Hansen et al., "Ice melt, sea level rise and superstorms: Evidence from paleoclimate data, climate modeling, and modern observations that 2 °c global warming could be dangerous," Atmos. Chem. Phys., vol. 16, no. 6, pp. 3761–3812, Mar. 2016, doi: 10.5194/ACP-16-3761-2016.

[14] M. R. Turetsky et al., "Carbon release through abrupt permafrost thaw," Nat. Geosci., vol. 13, no. 2, pp. 138–143, Feb. 2020, doi: 10.1038/S41561-019-0526-0.

[15] D. B. Lobell, W. Schlenker, and J. Costa-Roberts, "Climate trends and global crop production since 1980," Science (80-.)., vol. 333, no. 6042, pp. 616–620, Jul. 2011, doi: 10.1126/SCIENCE.1204531.

[16] H. C. J. Godfray et al., "Food security: The challenge of feeding 9 billion people," Science (80-.)., vol. 327, no. 5967, pp. 812–818, Feb. 2010, doi: 10.1126/SCIENCE.1185383.

[17] W. D. Nordhaus, H. Houthakker, and R. Solow, "The Allocation of Energy Resources," Brookings Pap. Econ. Act., vol. 1973, no. 3, p. 529, 1973, doi: 10.2307/2534202.

[18] P. Cao, C. Lu, and Z. Yu, "Historical nitrogen fertilizer use in agricultural ecosystems of the contiguous United States during 1850-2015: Application rate, timing, and fertilizer types," Earth Syst. Sci. Data, vol. 10, no. 2, pp. 969–984, Jun. 2018, doi: 10.5194/ESSD-10-969-2018.

[19] "Agricultural Greenhouse Gas Emissions 101." Accessed: Feb. 17, 2024. [Online]. Available: https://www.rff.org/publications/explainers/agricultural-greenhouse-gas-emissions-101/

[20] D. Andriani, A. Wresta, T. D. Atmaja, and A. Saepudin, "A review on optimization production and upgrading biogas through CO 2 removal using various techniques," Appl. Biochem. Biotechnol., vol. 172, no. 4, pp. 1909–1928, 2014, doi: 10.1007/S12010-013-0652-X.

[21] M. M. Uddin and M. M. Wright, "Anaerobic digestion fundamentals, challenges, and technological advances," Phys. Sci. Rev., vol. 8, no. 9, pp. 2819–2837, Sep. 2023, doi: 10.1515/PSR-2021-0068.

[22] S. M. Ogle et al., "Climate and Soil Characteristics Determine Where No-Till Management Can Store Carbon in Soils and Mitigate Greenhouse Gas Emissions," Sci. Rep., vol. 9, no. 1, Dec. 2019, doi: 10.1038/S41598-019-47861-7.

[23] O. Yenigün and B. Demirel, "Ammonia inhibition in anaerobic digestion: A review," Process Biochem., vol. 48, no. 5–6, pp. 901–911, May 2013, doi: 10.1016/j.procbio.2013.04.012.

[24] A. J. Eagle et al., "Quantifying On-Farm Nitrous Oxide Emission Reductions in Food Supply Chains," Earth's Futur., vol. 8, no. 10, Oct. 2020, doi: 10.1029/2020EF001504.

[25] J. Carey, "While some tout 'renewable natural gas' as a way to mitigate climate change, others see a false solution," Proc. Natl. Acad. Sci. U. S. A., vol. 120, no. 28, Jul. 2023, doi: 10.1073/PNAS.2309976120.

[26] N. Brisson, P. Gate, D. Gouache, G. Charmet, F. X. Oury, and F. Huard, "Why are wheat yields stagnating in Europe? A comprehensive data analysis for France," F. Crop. Res., vol. 119, no. 1, pp. 201–212, Oct. 2010, doi: 10.1016/J.FCR.2010.07.012.

[27] V. Smil, "Energy and Civilization," Energy Civiliz., Dec. 2018, doi: 10.7551/MITPRESS/10752.001.0001.

[28] P. Veysset, M. Lherm, D. Bébin, M. Roulenc, and M. Benoit, "Variability in greenhouse gas

emissions, fossil energy consumption and farm economics in suckler beef production in 59 French farms," Agric. Ecosyst. Environ., vol. 188, pp. 180–191, Apr. 2014, doi: 10.1016/J.AGEE.2014.03.003.
[29] M. Fischer-Kowalski, "Energy in nature and society: general energetics of complex systems," Reg. Environ. Chang., vol. 9, no. 1, pp. 57–58, Mar. 2009, doi: 10.1007/S10113-008-0073-5.
[30] V. J. P. D. Martinho, "Energy consumption across European Union farms: Efficiency in terms of farming output and utilized agricultural area," Energy, vol. 103, pp. 543–556, May 2016, doi: 10.1016/J.ENERGY.2016.03.017.
[31] Z. Ramedani, S. Rafiee, and M. D. Heidari, "An investigation on energy consumption and sensitivity analysis of soybean production farms," Energy, vol. 36, no. 11, pp. 6340–6344, 2011, doi: 10.1016/J.ENERGY.2011.09.042.
[32] D. C. Popa et al., "A Platform for GHG Emissions Management in Mixed Farms," Agric., vol. 14, no. 1, p. 78, Jan. 2024, doi: 10.3390/AGRICULTURE14010078/S1.
[33] G. F. Sassenrath et al., "Technology, complexity and change in agricultural production systems," Renew. Agric. Food Syst., vol. 23, no. 4, pp. 285–295, 2008, doi: 10.1017/S174217050700213X.
[34] P. R. Bhagat, F. Naz, and R. Magda, "Artificial intelligence solutions enabling sustainable agriculture: A bibliometric analysis," PLoS One, vol. 17, no. 6 June, Jun. 2022, doi: 10.1371/JOURNAL.PONE.0268989.
[35] M. J. MacLeod et al., "Invited review: A position on the Global Livestock Environmental Assessment Model (GLEAM)," Animal, vol. 12, no. 2, pp. 383–397, Feb. 2018, doi: 10.1017/S1751731117001847.
[36] S. Pellerin et al., "Identifying cost-competitive greenhouse gas mitigation potential of French agriculture," Environ. Sci. Policy, vol. 77, pp. 130–139, Nov. 2017, doi: 10.1016/J.ENVSCI.2017.08.003.
[37] S. Coderoni and R. Esposti, "CAP payments and agricultural GHG emissions in Italy. A farm-level assessment," Sci. Total Environ., vol. 627, pp. 427–437, Jun. 2018, doi: 10.1016/J.SCITOTENV.2018.01.197.
[38] R. S. J. Tol, "On the Uncertainty About the Total Economic Impact of Climate Change," Environ. Resour. Econ., vol. 53, no. 1, pp. 97–116, 2012, doi: 10.1007/S10640-012-9549-3.
[39] S. Mohammed, K. Alsafadi, I. Takács, and E. Harsányi, "Contemporary changes of greenhouse gases emission from the agricultural sector in the EU-27," Geol. Ecol. Landscapes, vol. 4, no. 4, pp. 282–287, 2020, doi: 10.1080/24749508.2019.1694129.
[40] E. Kelly et al., "Sustainability indicators for improved assessment of the effects of agricultural policy across the EU: Is FADN the answer?," Ecol. Indic., vol. 89, pp. 903–911, Jun. 2018, doi: 10.1016/J.ECOLIND.2017.12.053.
[41] C. Lundström and J. Lindblom, "Considering farmers' situated knowledge of using agricultural decision support systems (AgriDSS) to Foster farming practices: The case of CropSAT," Agric. Syst., vol. 159, pp. 9–20, Jan. 2018, doi: 10.1016/J.AGSY.2017.10.004.
[42] D. B. Lobell, W. Schlenker, and J. Costa-Roberts, "Climate trends and global crop production since 1980," Science (80-.)., vol. 333, no. 6042, pp. 616–620, Jul. 2011, doi: 10.1126/SCIENCE.1204531/SUPPL_FILE/LOBELL.SOM.REVISED2.PDF.