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Application strategy for sustainable livestock production with farm animal algorithms in response to climate change up to 2050: A review

Sang-O Park

Institute of Animal Life Science, Kangwon National University, Chuncheon, Republic of Korea

Corresponding author: bspark@kangwon.ac.kr

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Abstract: Global warming caused by climate change can increase heat stress and greenhouse gas (GHG) emissions, leading to food problems and livestock crises. Thus, pre-emptive responses are required to mitigate the food problems and livestock crises. The potential of a livestock crisis caused by global warming highlights the need for sustainable livestock production in response to climate change using a farm animal algorithm in order to address the population increase and avoid food problems in the future. In particular, the demand for animal-based foods has increased. Such a climate change threatens the livestock environment, production, reproductive efficiency, animal behaviour and welfare, while increasing the heat stress, livestock malodours, and GHG emissions. For these reasons, it is necessary to understand the concurrent mechanisms related to these effects of global warming, animal nutrition, animal feeding and management, animal heat stress and *in ovo* injection, and carbon neutral livestock. Climate-smart livestock systems are being implemented to overcome the livestock crisis caused by climate change and to maintain sustainable livestock production. This review emphasises the importance of sustainable livestock production using farm animal algorithms in response to a future livestock crisis caused by climate change in 2050.

Keywords: carbon neutral; livestock crisis; heat stress; *in ovo*; smart livestock

It is predicted that global warming caused by climate change will continuously aggravate a loss of biological diversity, water shortages, a decrease in food production, and malnutrition. It is forecast that crop production and livestock farming will face unsuitable climatic environments (by more than 10% by 2050 and 30% by 2100), so the food problem is emerging as an urgent pending issue (Havlik et al. 2014; Zurbrugg 2020; Portner et al. 2022). If the earth's surface temperature rises by 1.5 °C due to climate change, approximately 1 billion people in the world could be more frequently exposed to life-threatening heat waves. A 5 °C increase in the temperature could place up to 60% of the species on the verge of irreversible extinction (FAO 2015; Plumer and Fountain 2021; Portner et al. 2022). By 2050, the world's population will increase to 9.9 billion people, approximately 2 billion more than in 2020, while consumption of food, especially animal-based foods, will increase by more than 60% (UN 2013; Deloitte 2017; FAO 2017; Neethirajan and Kemp 2021). It is predicted that global warming will have a significantly negative impact on food security, and that between 5 and 170 million people will be at risk of starvation by 2080 (Wiokas 2008; BP 2016).

Farm animals are important global assets that cover 30% of the Earth's land surface area and have a value of at least 1.4 trillion USD (de Haan

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2006; FAO 2021). Risks caused by climate change may become an even more serious issue for a world population that is heavily dependent on livestock production with regard to food security (Havlik et al. 2014; Rojas-Downing et al. 2017; FAO 2021). Since livestock crises caused by climate change may decrease livestock farming and the quality of animal foods, leading to a food crisis, a climate response strategy is needed to maintain sustainable livestock production (Havlik et al. 2014; Rojas-Downing et al. 2017; Adamides et al. 2020; Fawzy et al. 2020; Moran and Blair 2021).

Livestock malodours and heat stress (HS) caused by climate change in livestock production may affect the livestock feeding and environmental management, animal behaviour and welfare, lowering the quality of animal growth performance and animal foods (FAO 2015; Rojas-Downing et al. 2017; Wang et al. 2021; Wen et al. 2021). To ensure the sustainable growth of livestock farming given the climate change crisis, a strategy to connect future megatrends, such as the convergence of Information and Communication Technologies (ICT), with animal life science is needed to proactively address the pending issues including globalisation, population growth, population ageing, food and water shortages, increased consumption of high quality animal-based food, animal behaviour and welfare, livestock diseases, livestock malodours, and greenhouse gas (GHG) emissions (Hidosa and Guyo 2017; Rojas-Downing et al. 2017; Park 2021; Zammit and Park 2021). The food industry is responsible for 30% of the global energy consumption and 22% of the GHG emissions (Rojas-Downing et al. 2017; Dawkins 2021). ICT enables the feasibility of a climate response farm animal algorithm for productivity improvement in sustainable livestock production. Livestock farming, animal behaviour and welfare, high quality animal-based foods, animal diseases, safe processing, and marketing strategies are huge challenges to livestock farmers in responding to climate change. Carbon neutral livestock has emerged as a new issue with regard to the reduction of GHG emissions (Havlik et al. 2014; Wilson 2019; FAO 2022; Portner et al. 2022). To achieve the goal of carbon neutral livestock, climate-smart livestock systems combining ICT, which is the core of the 4th industrial revolution, and animal agriculture is being realised in various livestock farming fields (Neethirajan and Kemp 2021; Park 2021). A climate-smart livestock system can maximise the establishment of such a strategic basis to create economic benefits while significantly reducing the impacts of climate change on the livestock and animal food production. Such a climate-smart livestock system can solve food issues, livestock malodours, and the intensity of GHG emissions by integrating younger generations that are early adapters into livestock farming (Freeman and Mungai 2021; Neethirajan and Kemp 2021; Park 2021). It is possible to improve the animal behaviour and welfare and livestock production simultaneously by monitoring and remotely controlling the inside and outside environments of animal dwellings and the behaviour of all farmed animals with an intelligent network system that connects an automated device to the internet to be controlled by a mobile phone (Okada et al. 2013; Anisi et al. 2014; Xu et al. 2014; Goud and Sudharson 2015; Hoste et al. 2017; Park 2021). In the review, the importance of the convergence of animal models and sustainable livestock production using farm animal algorithms as a response strategy to future livestock crises caused by climate change in 2050 was emphasised.

Climate change and livestock production

Heat stress and livestock feed resources

One of the most obvious and important impacts of climate change and HS on livestock farming is transmitted by changes in feed resources. HS in livestock animals due to climate change and global warming occurs when environmental conditions with a heat wave during the summer challenge the homeostatic mechanism of the animals' body temperature regulation (Nawab et al. 2018; Gonzalez-Rivasa and Warnera 2020; Park 2021; Zammit and Park 2021) (Figure 1).

The environmental temperature has a significant impact on the body temperature regulation of animals, water availability, livestock production, reproduction and health, and animal diseases (FAO 2015; Hidosa and Guyo 2017; Rojas-Downing et al. 2017; Wen et al. 2021). HS caused by global warming has an impact on livestock farming through its influence on the water shortage, livestock feed resources, livestock malodours, GHG emissions, animal behaviour and welfare, animal diseases, and loss of biological diversity. A strategy for de-

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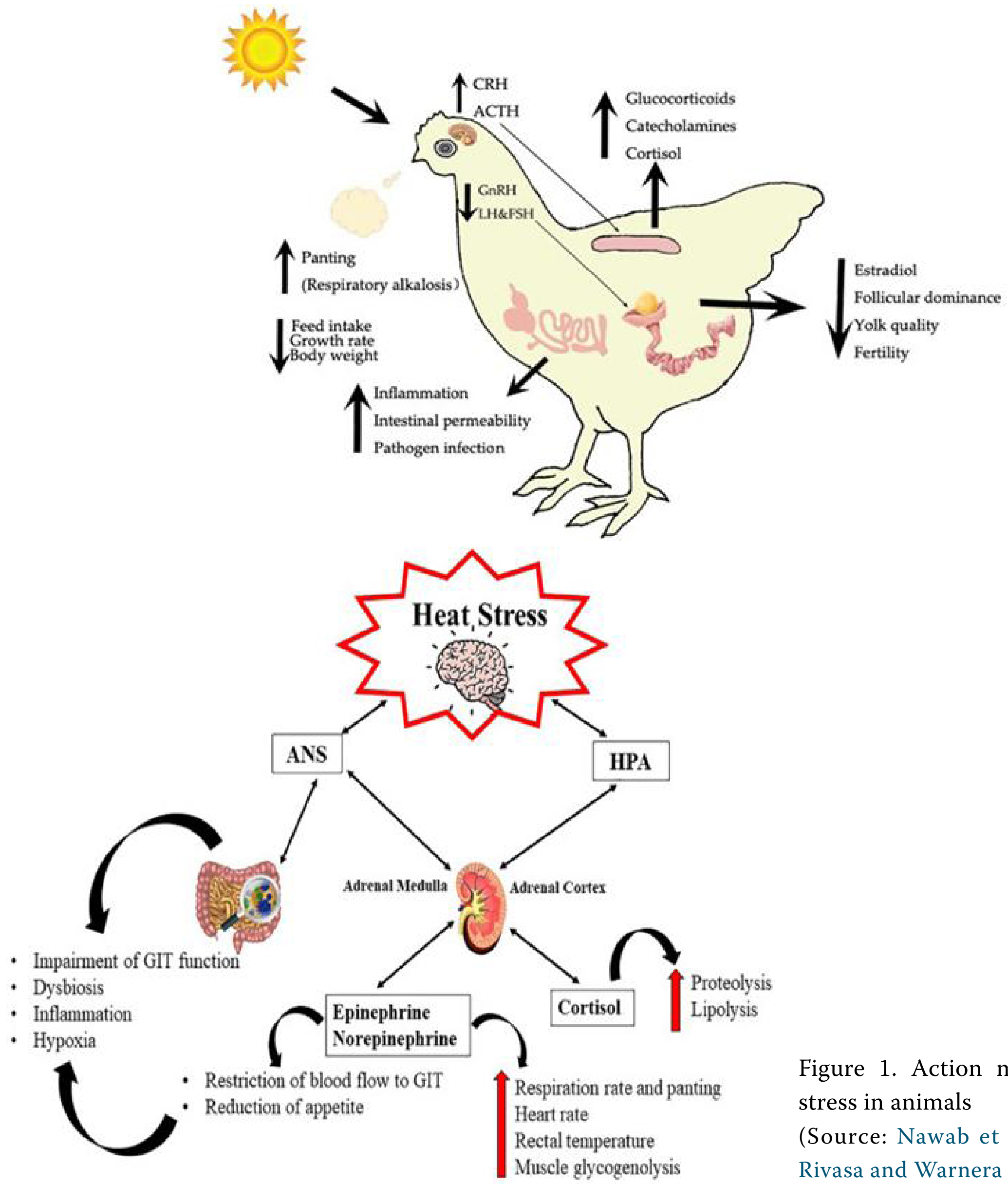

Figure 1. Action mechanisms of heat stress in animals
(Source: Nawab et al. 2018; Gonzalez-Rivasa and Warnera 2020)

veloping a low methane feed and low-carbon and eco-friendly livestock production for sustainable livestock production is, thus, needed (FAO 2015; Hidosa and Guyo 2017; Rojas-Downing et al. 2017; Portner et al. 2022). Climate change affects livestock farming through the impairment of the feed intake, nutrient metabolism, and immune response mechanisms (Havlik et al. 2014; Hidosa and Guyo 2017; Fawzy et al. 2020; Moran and Blair 2021). The impacts on livestock feed resources may, although indirect, have significant impacts on livestock farming, the grazing land's transport capacity, an ecosystem's buffering capacity and sustainability, grain prices, feed trade, changes in the feed supply options, GHG emissions, and grazing management (Ji and Park 2015; Deloitte 2017; Hidosa and Guyo 2017; Rojas-Downing et al. 2017; Fawzy et al. 2020; Moran and Blair 2021). Climate change directly and indirectly affects livestock farming and animal health as well as the forage and feed crop yields in various ways. The forage quantity and quality are affected by temperature increases, CO_2, and changes in the precipitation. The adverse impacts on forage crops and pastures also lead to indirect damage to the production of animal foods, including dairy products and meat products, etc. It was predicted that changes in the soil, water, and air due to climate change will reduce the forage crops and pasture production, animal reproduction, and animal food production, and the global milk production

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will decrease by 10% due to drought if the global temperature rise by 1 °C (Havlik et al. 2014; FAO 2015; Hidosa and Guyo 2017; Zurbrugg 2020).

Heat stress and livestock malodours

HS caused by global warming leads to continuous civil complaints due to livestock malodours, and, at the same time, reduces livestock farming due to metabolic disorders, immunity, and animal stress (FAO 2015; Rojas-Downing et al. 2017; Wang et al. 2021) (Figure 2). Livestock animals are quite vulnerable to HS as these animals have to live in an open animal house exposed to the external environment with a large amount of feed intake and manure excretion (Nardone et al. 2010; Renaudeau et al. 2012; Park 2021; Zammit and Park 2021). HS results in decreased animal welfare, livestock production, meat quality, fertility, and increased disease and mortality for all livestock animal species (Gonzalez-Rivasa and Warnera 2020; Godde et al. 2021; Thornton et al. 2022). HS may lead to a 73% and 60% decrease in beef cattle and swine body weight gain, respectively, a 32% decrease in dairy cow milk production, and a 16% decrease in egg production (Portner et al. 2022). Climate change directly affects livestock farming and decreases the quality of animal-based foods through the HS caused by heat waves and high humidity during the summer, and, at the same, time affects feed crop cultivation due to global warming and increases the emergence of livestock diseases through indirect vulnerability (Rojas-Downing et al. 2017; Fawzy et al. 2020; Moran and Blair 2021).

Recently, Park (2021) and Zammit and Park (2021) reported the action mechanism of complex probiotics related to farm animals, high quality animal food production, and the removal of livestock malodours and GHG emissions as a climate response livestock nutrition strategy. When animals consume complex probiotics, the protein bioavailability is increased through the activation of the function of the small intestine villi, and the calcium bioavailability increases as the action of the microorganisms is activated, improving swine and broiler chicken production, egg production, egg quality, and eggshell thickness. It fundamentally blocks the generation of ammonia, the source of bad odours, by reducing the amount of protein that is excreted in the poultry manure due to it not being degraded by hydrolytic enzymes in the small intestine. In addition, in a ground-breaking discovery, it was found that when Hanwoo (Korean

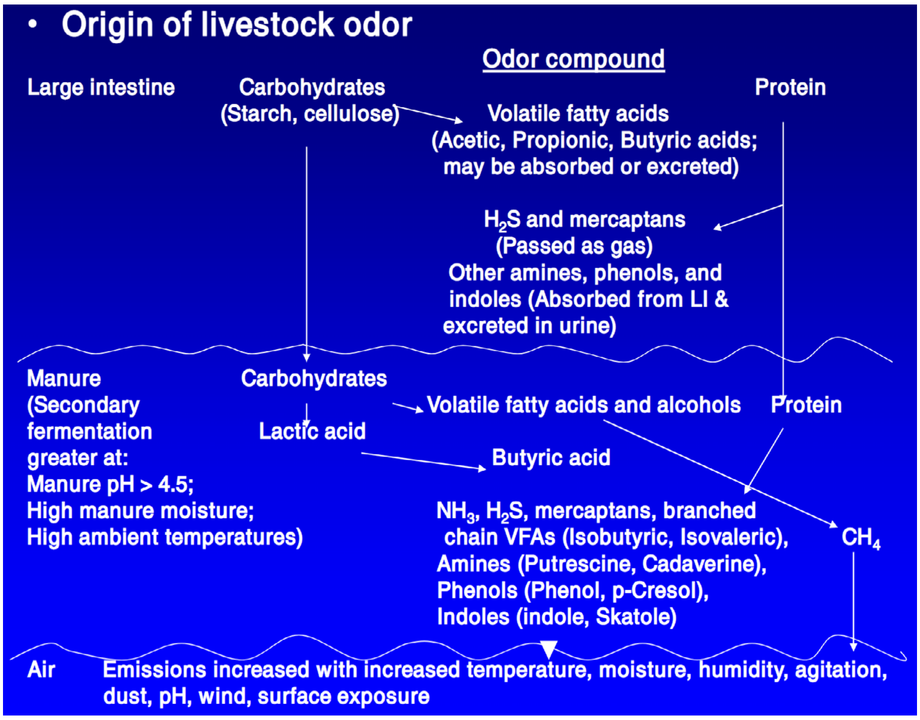

Figure 2. Mechanisms of livestock malodours from animal manure under heat stress
(Source: https://studylib.net/doc/10127580/odor)

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native cattle) were fed a fermented flaxseed diet by complex probiotics, the n-9 fatty acid (oleic acid, 18:1n-9) in the beef loin was strengthened by more than 6% compared to the commercial Hanwoo beef loin (46%), and, at the same time, the production of ruminal methane bacteria was strongly suppressed (Wanjoo Hanwoo farmers Chunrabookdo Republic of Korea 2020–2021, unpublished). It can be predicted that this result will make an important contribution to the removal of livestock malodours and the realisation of carbon neutral livestock, and more related studies are needed in the future (Park 2021; Zammit and Park 2021; FAO 2022) (Figure 3).

GHG emissions and carbon neutral livestock

Carbon neutral (net zero), which is the GHG reduction goal by 2050 for food security and a sustainable society given the climate crisis and global warming, has become an important issue (Havlik et al. 2014; Horrillo et al. 2020; FAO 2022). Carbon neutral is the concept of reducing the GHG emissions caused by human activities as much as possible, and absorbing and removing the emitted GHG by forests, etc., so that actual net GHG emissions become zero. A target to suppress the temperature increase to 1.5 °C compared to pre-industrial levels was set in the Paris Agreement in 2015, and the goal

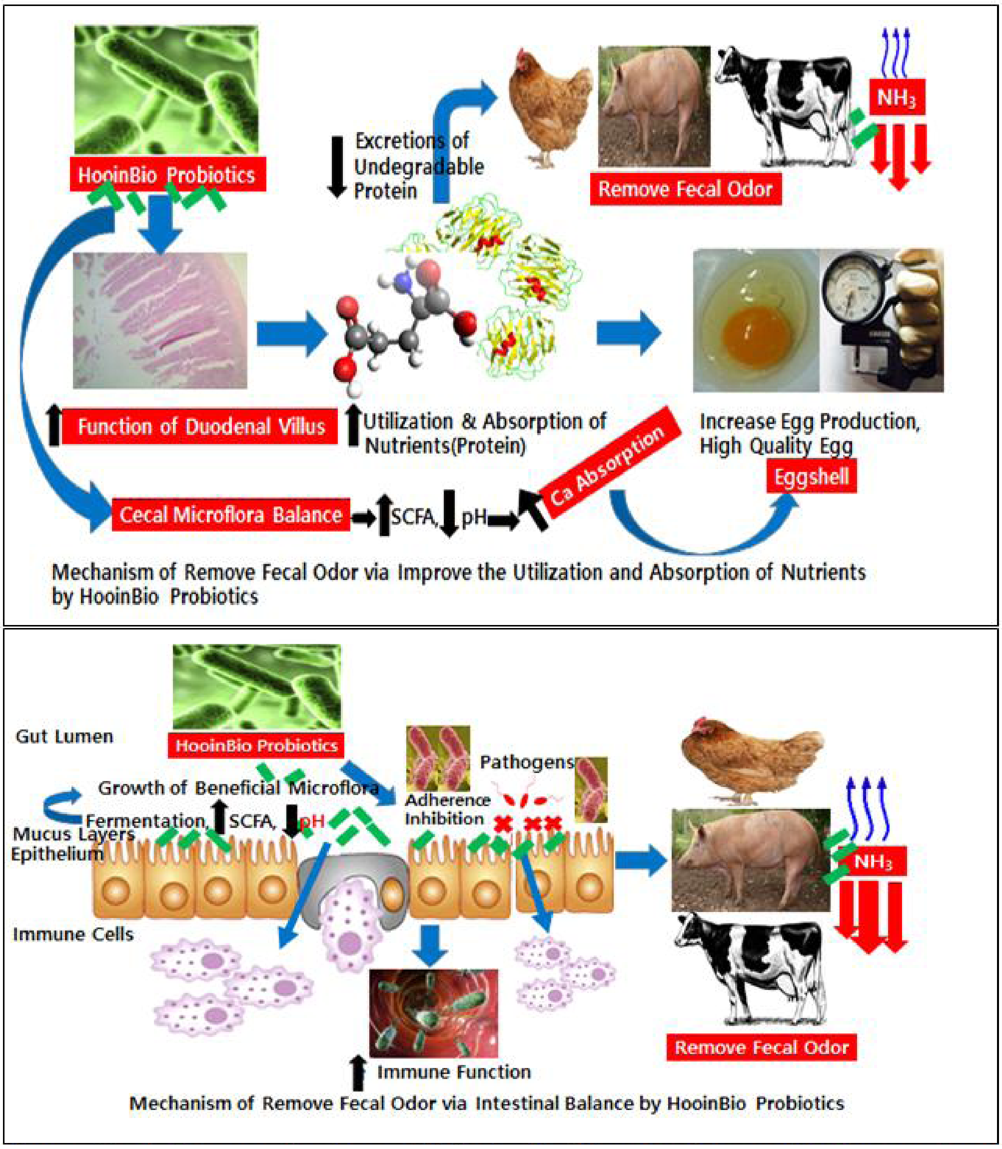

Figure 3. Action mechanism of HooinEcobio-complex probiotics on improving the poultry production and reduction of malodours in livestock

(Source: Park et al. 2019; Park 2021)

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of reducing GHG emissions to achieve a carbon neutral status by 2050 has become clear (Havlik et al. 2014; Fawzy et al. 2020; Moran and Blair 2021; FAO 2022; Portner et al. 2022). The time has also come to convert the carbon neutral livestock to an environmentally friendly industry. Various civil complaints targeting the livestock industry have been raised due to the GHG emissions and livestock malodours. The removal of heat stress and methane generation and a climate response smart livestock system are being realised as nutrition and feeding strategies to achieve carbon neutral in the livestock industry (Lionch et al. 2017; Rendon-Huerta et al. 2018; Fawzy et al. 2020; Moran and Blair 2021).

The goal of reducing GHG emissions and obtaining carbon neutral livestock requires technological solutions jointly created by livestock farmers and companies that can help mitigate the environmental footprint (Horrillo et al. 2020; Toro-Mujica and Gonzalez-Ronquillo 2021; Portner et al. 2022). Currently, the global food loss and waste generate approximately 8% of the annual GHG emissions (FAO 2021). Livestock farming is an important future food industry that can provide humans with valuable protein and solve hunger and food security issues. At the same time, livestock farming significantly contributes to global warming through GHG emissions. Livestock farming accounts for 12–24% of the anthropogenic GHG emissions worldwide, with beef and dairy cattle accounting for 41% and 21%, respectively (de Haan 2006; Gerber et al. 2013; Rao et al. 2013; FAO 2015; Herrero et al. 2015; Wilson 2019; Freeman and Mungai 2021; FAO 2022).

In terms of the GHG emitted from livestock animals, 50% is methane (CH_4) from rumen fermentation, 24% is nitrous oxide (N_2O), and 26% is carbon dioxide (CO_2) from manure. Cattle are major contributors, producing approximately 5.0 giga-tonnes of CO_2-equivalent that accounts for approximately 62% of livestock GHG emissions. In cattle, most (95%) of the methane is released into the atmosphere through cattle belching, while 5% is emitted via flatulence. Swine, poultry, and small ruminants account for 7–11% of the GHG emissions, a much lower amount. The contribution of methane to the global warming potential (GWP) after 20 years of GHG emissions (GWP20) is significantly greater than that after 100 years (GWP100) (de Haan 2006; Gerber et al. 2013; FAO 2019; Wilson 2019) (Figure 4).

The Food and Agriculture Organization (FAO 2021) estimated that the potential to reduce emissions from livestock farming, particularly methane, was about 30% of the baseline emissions. If GHG emissions continue to grow, they will reach 139 giga-tonnes by 2100, and global temperatures will be 4.5 °C higher than pre-industrial levels. As various countries around the world recognised the threat of global warming, an agreement to reduce GHG emissions was reached (Deloitte 2017; Fawzy et al. 2020; Moran and Blair 2021). The total GHG emissions from agriculture, including livestock animals, have been predicted to be 25–32% of the emissions depending on the emission source and land conversion ratio for livestock animal activities (EPA 2006; Deloitte 2017). The amount of carbon added to the atmosphere per year is between 4.5 and 6.5 billion tonnes. Methane has a positive radiative forcing effect on the climate, just like CO_2. A reduction in the methane emissions is environmentally necessary because CH_4 has strong GHG effects. An increase in CH_4 emissions can be considered as a loss of animal nutritional feed energy (Huhtanen et al. 2015). Projected intestinal methane emissions by 2050 are 120 kg × 109 kg, with an average growth rate of 0.90% (Knapp et al. 2014). The European Union (EU) currently promotes voluntary compliance with methane emission levels on farms, but a movement to include livestock animals in the industrial emission directives is underway. Approximately 90 million cattle are in the EU, accounting for approximately 41% of total ammonia emissions and 2% of total methane emissions in the EU. Many factors influence the CH_4 production in ruminants, including the feed intake level, feed composition, feed quality, energy consumption, animal size, growth rate, production level, and environmental parameters (Grady and Hare 2017). It should be noted that even when cows are fed the same feed at the same intake level, the CH_4 emissions vary significantly between cows. Efforts to model the methane production on farms have begun (Bell et al. 2014; Broucek 2014). Animal manure releases more N_2O proportionally, because it does not spread out, but remains on the pasture where the nitrogen leaches out. N_2O emissions from animal manure are much higher than other N_2O emissions from the livestock farming sector, and these emissions are dominated by mixed crop-livestock farming systems. Agricultural N_2O emissions will increase by 35–60% by 2030 due to the increased use of nitrogen fertilisers and increased livestock manure production. Livestock animals account for 15% of the anthropogenic CO_2 emissions worldwide, and the CO_2 emissions will increase

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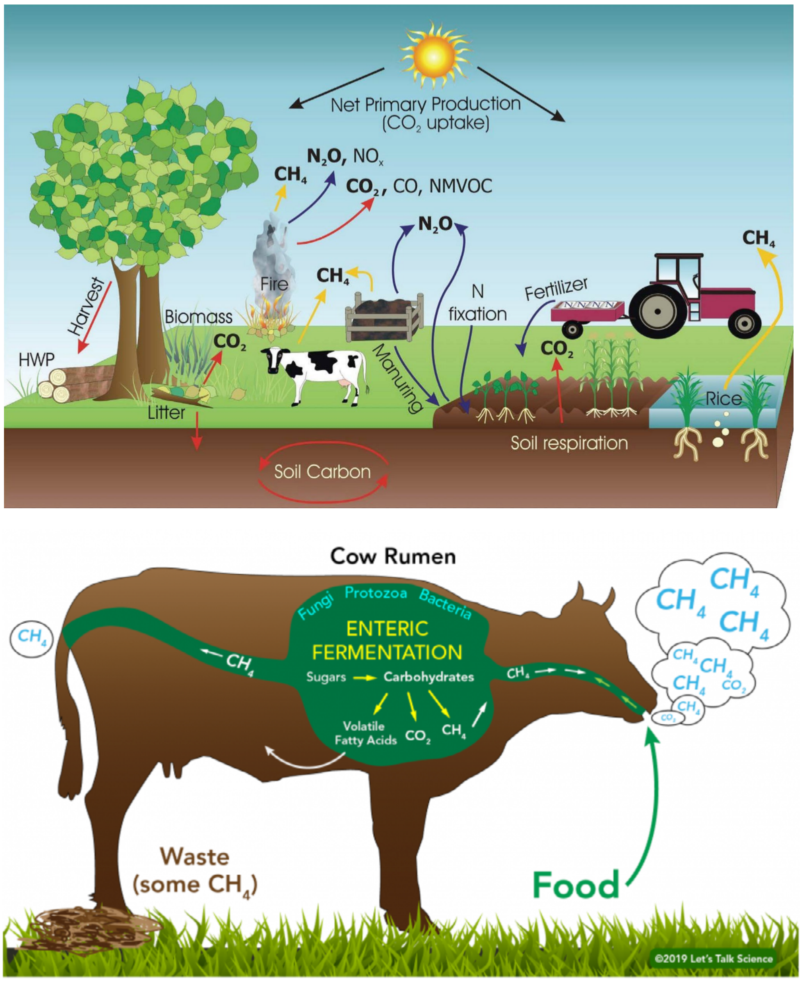

Figure 4. Livestock farming emissions come from a variety of sources that differ depending on the type of farm (Source: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_01_Ch1_Introduction.pdf; https://letstalkscience.ca/educational-resources/stem-in-context/cows-methane-and-climate-change)

as agricultural systems become more intensive and industrialised. The maintenance and enhancement of sustainable livestock production systems can be the core technologies for climate response (Gerber et al. 2013; Havlik et al. 2014; Fawzy et al. 2020; Moran and Blair 2021). Various strategies are needed to reduce livestock GHG emissions, including innovative feed supplements, nutrition and feed management systems, and grazing management using regenerative farming techniques (Havlik et al. 2014; Lionch et al. 2017; FAO 2022).

Heat stress, animal behaviour, and welfare

HS due to heat waves in the summer leads to various physiological reactions including a rapid increase in the body temperature of animals, changes to the animal's behaviour and welfare, and a decrease in the feed intake (Padgett and Glaser 2003; Nardone et al. 2010; Rojas-Downing et al. 2017; Lionch et al. 2018; Park 2021; Zammit and Park 2021) (Figure 5). Under HS, water drinking, lying, claw, gait, and keel bone deformation and plumage patterns, which are indicators of poultry's animal behaviour and welfare, are increased, while feather pecking, feeding, preening, standing, and walking are significantly lowered (Lay et al. 2011; Mack et al. 2013; Park and Zammit 2019; Park 2021; Zammit and Park 2021). For sustainable livestock farming, it is very important to prevent damage by HS to both humans and animals in order to adapt to and mitigate the HS (Polsky and Keyserlingk 2017; Park 2021; Ramon-Moragues et al. 2021; Zammit and Park 2021). To regulate the body temperature under HS, poultry lower their body temperature by altering their behavioural and

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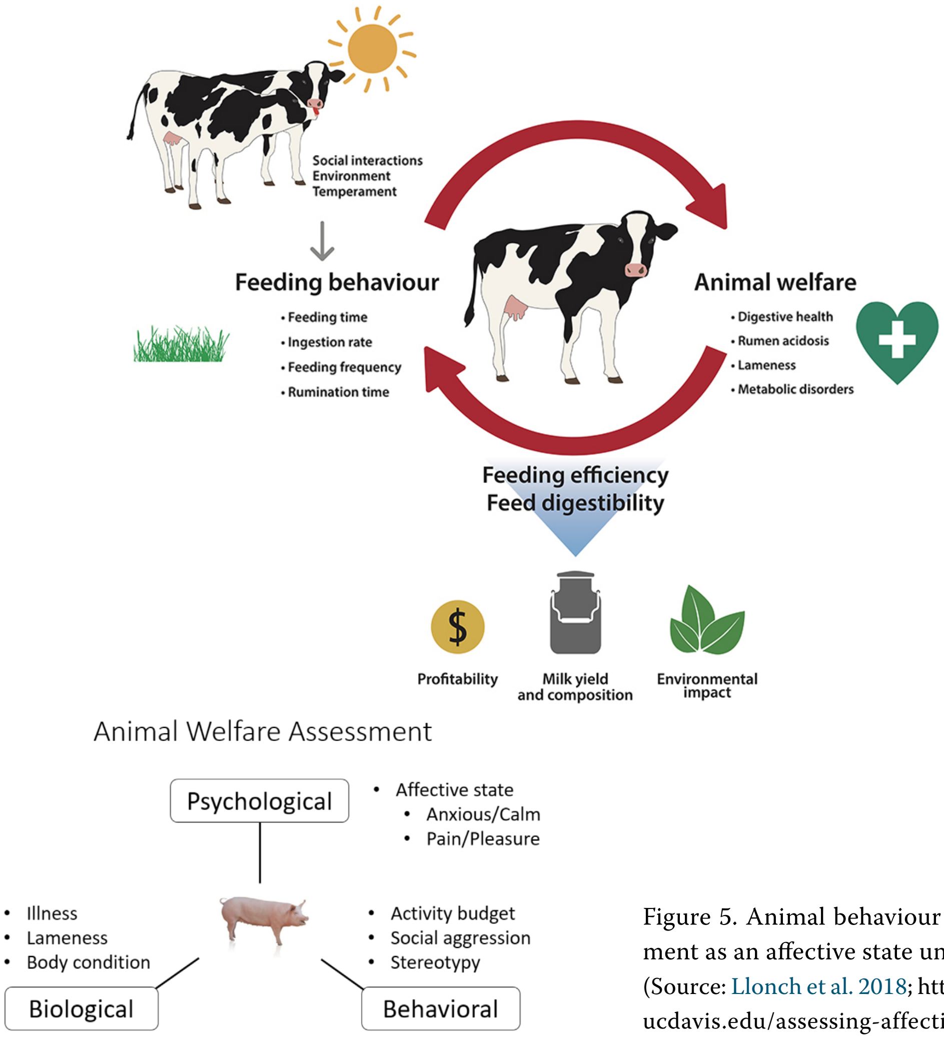

Figure 5. Animal behaviour and welfare assessment as an affective state under heat stress (Source: Llonch et al. 2018; https://horback.faculty.ucdavis.edu/assessing-affective-states/)

physiological homeostasis. Livestock production losses and health issues due to HS are important economic and animal welfare issues for poultry, including duck meat (Zeng et al. 2014). Poor environments surrounding farm animals adversely affect their physiological and behavioural responses. Global warming due to climate change is exposing both humans and animals to dangerous HS, causing immeasurable harm. HS can affect the immune systems of animals, animal behaviour and welfare, livestock farming, the quality of animal foods, livestock diseases, mortality, and biological diversity (Zhao et al. 2010; Renaudeau et al. 2012; Lara and Rostagno 2013; Caulfield et al. 2014; Rupesh et al. 2014; Park and Zammit 2019). Climate change poses numerous threats, including changes in the animal behaviour and welfare and loss of livestock farming due to HS in industrialised, factory-intensive livestock operations. HS caused by climate change reduces the feed intake, limits immune response, and body weight gain, and negatively affects the fertility and animal foods in cattle, poultry, and swine. HS also increases the mortality of farm animals (Bozakova et al. 2015; Admin 2019; Fawzy et al. 2020; Moran and Blair 2021; Park 2021; Zammit and Park 2021).

The *in ovo* injection, which injects various substances into eggs at the embryo's stage of development in poultry, as an animal nutrition model, can be a new technology for improving the hatchability, immune response, animal behavioural welfare, and growth performance of poultry exposed to HS (Feebles 2018; El-Sabrout et al. 2019; Alves et al. 2020; Park 2021; Zammit and Park 2021) (Figure 6).

Climate-smart livestock system

A climate-smart livestock system is a sustainable livestock farming system that perfectly supports climate change adaptation and mitigation activi-

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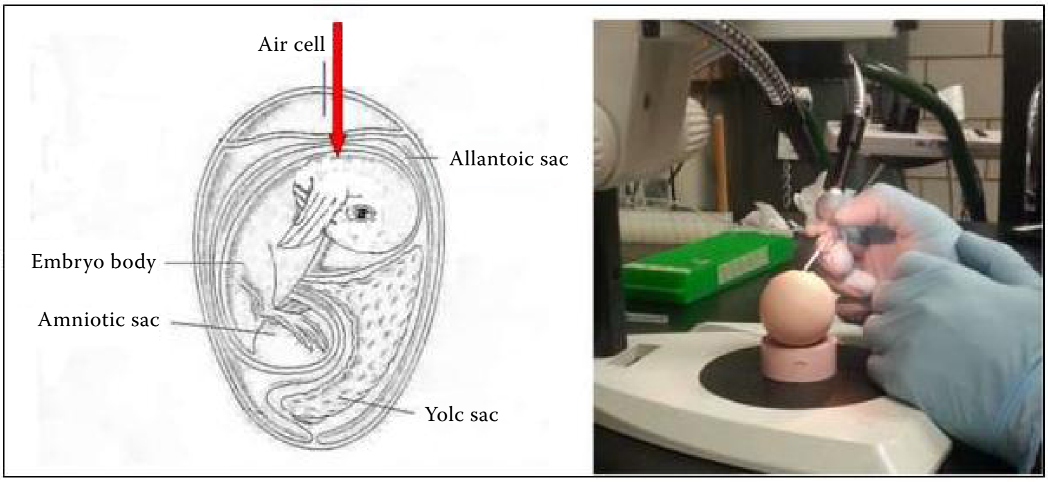

Figure 6. Site of *in ovo* injection in poultry as an animal model to climate response
Red arrow indicates the injection site of nutrients into the amnion of eggs
(Source: Park 2021; Zammit and Park 2021)

ties, food security, sustainable income, animal welfare, and the environmental impact (Kadzere 2018; FAO 2021). Animal life science approaches that use climate-smart livestock systems in the future can reduce the carbon footprint and realise a sustainable livestock production system by increasing the livestock production while realising social, economic, and environmental benefits (Moumen et al. 2016; FAO 2021; Neethirajan and Kemp 2021; Park 2021). Population growth, rapid urbanisation, and dietary changes have increased the global demand for animal foods and have negatively affected climate change. Increasing global temperatures, climate variability, and more frequent and severe weather events are all threatening livestock farming systems (Kadzere 2018; FAO 2021). A climate-smart livestock system can continuously improve the animal behavioural welfare, livestock production, and farm income, while reducing animal stress and suffering, animal health and disease issues, and environmental problems (Deloitte 2017; Kadzere 2018; Park 2021). A climate-smart livestock system can contribute to the reduction of GHG emissions through the efficient use of natural resources, carbon sequestration, and integration of livestock into a circular bio-economy. Livestock feeds that can lower GHG emissions are currently being developed (Kadzere 2018; FAO 2021; Moran and Blair 2021).

In an ICT-based smart livestock system, various sensors that are used for the external environment and feeding management inside animal farming houses enable excellent environment and feeding management processes through remote monitoring in real time using computers and mobile phones to alleviate animal stress and pain and increase the productivity. If the environment is poor, changes in the digestive system, respiratory system, animal behaviour and welfare patterns may cause animal stress and suffering, and the subsequent deterioration of the animal health, poultry production, and egg quality (Jones et al. 2005; Mahale and Sonavane 2016; Park 2021; Zammit and Park 2021). To operate a smart livestock system, biometric sensors are needed to connect the necessary equipment for the environmental management, feeding management, and business management to the internet. Environmental sensors, measuring items such as the temperature, humidity, carbon dioxide, and ammonia gas for environmental management monitoring, precisely monitor the internal and external environmental conditions and automatically control ventilation-related devices to maintain the appropriate animal housing environment (FAO 2017; Navarro et al. 2020; Park 2021). Next-generation smart livestock systems are being realised through automatic robots (manure robots, robotic milkers) and cattle tracking drones to monitor the feeding management (Park 2021; Zammit and Park 2021; www.zenadrone.com/livestock-management/). In the poultry industry, smart livestock systems can significantly improve the poultry production compared to a conventional poultry system, which can cause more damage and

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stress to the animal's behaviour and welfare under the same environmental conditions related to climate change (FAO 2021).

In previous research, Zammit and Park (2021) revealed that a smart livestock system improves animal behaviour and welfare by reducing animal stress and suffering through excellent environmental and feeding management, and also increases livestock production by maintaining the nutrient digestibility, immune response, and homeostasis (Park 2021). An intelligent precision livestock farming (PLF) and ICT-based smart poultry system using big data and the internet of things (IoT) maintained a good environment for broiler chickens and laying hens, and improved the livestock productivity through excellent feeding management (Park 2021; Zammit and Park 2021). Compared with a conventional poultry system, the smart poultry system had a very excellent feeding management system with real-time remote monitoring using a mobile phone with environment and feeding management sensors, so the indicators of animal behaviour and welfare were significantly improved (Park 2021; Zammit and Park 2021). Environments unfavourable to the growth of broilers can lead to reduced productivity, such as leg damage, an increased feed to conversion ratio, increased animal stress and suffering, and increased mortality. Conventional poultry systems may have insufficient control over the farm since this system cannot handle the environment and feeding management properly compared to a smart poultry system. Ultimately, environments unfavourable to the growth of broilers that have increased animal stress and suffering reduce the production due to the decreased animal behaviour and welfare (Mahale and Sonavane 2016; Choukidar and Dawande 2017; Park 2021; Zammit and Park 2021).

With regard to animal stress and suffering that affect human health, consumers today are more aware of animal welfare. Brand owners are focusing more on sensor monitoring and quality assurance to reduce animal stress and suffering. They can track the farm animals, as well as their stress and suffering on their farms better through connected data solutions, so transparency in the supply chain can be improved (Deloitte 2017; Halachmi et al. 2019; Astill et al. 2020). The impacts of a smart livestock system on the animal behaviour and welfare is a relatively new area of study that has not yet been clearly covered. Ethical judgments about a smart livestock system depend on how technologies are developed and on how animal welfare will be prioritised in the future (Werkheiser 2020; Dawkins 2021). With climate change and the livestock crisis, sustainable livestock production is one of the major global challenges of today. Population growth, increased consumption of animal foods, and public pressure related to animal welfare and animal bioethics along with a decrease in the available farmland and labour force are leading to the realisation of the need for a smart livestock system (Jankoski and Fischer 2019; Neethirajan and Kemp 2021; Park 2021; Zammit and Park 2021).

In the digital age, the smart livestock system, which is referred to as PLF combining ICT, the core of the 4th industrial revolution, and animal agriculture is known as the third green revolution. The smart livestock system is a technology that monitors and remotely controls the health of all the animals in livestock herds by using IoT, sensors, big data, cloud computing, block chains, artificial intelligence (AI), machine learning (ML), robotics, and drones (Botta et al. 2016; Bernstein 2019; Adamides et al. 2020; Garcia et al. 2020; Dawkins 2021; Neethirajan and Kemp 2021; Park 2021; Bao and Xie 2022) (Figure 7). Through ICT, more data related to the growth ability can be collected from animals. For example, such data can be collected through cameras, image recognition software, wearables, and weight or sound monitoring. Such data can also help improve animal health through the monitoring of climate, air quality, ventilation, and the use of drones to collect livestock animal facility data (Deloitte 2017; FAO 2017; Halachmi et al. 2019; Navarro et al. 2020). A smart livestock system using the potential of digitisation actually utilises intelligent precision livestock feeding (PLF) technologies as an approach of data-based operating models, such as IoT, big data, and predictive analytics, sensor monitoring and remote control, are the basic principles (Laca 2009; Neethirajan and Kemp 2021; Park 2021; Zammit and Park 2021). PLF is a method to remotely manage livestock animals by using continuous real-time information obtained through the monitoring, control, and tracking of animals. PLF is an ICT-based smart livestock system using big data and IoT to monitor livestock animals from a distance to increase productivity (Neethirajan and Kemp 2021; Park 2021; Zammit and Park 2021).

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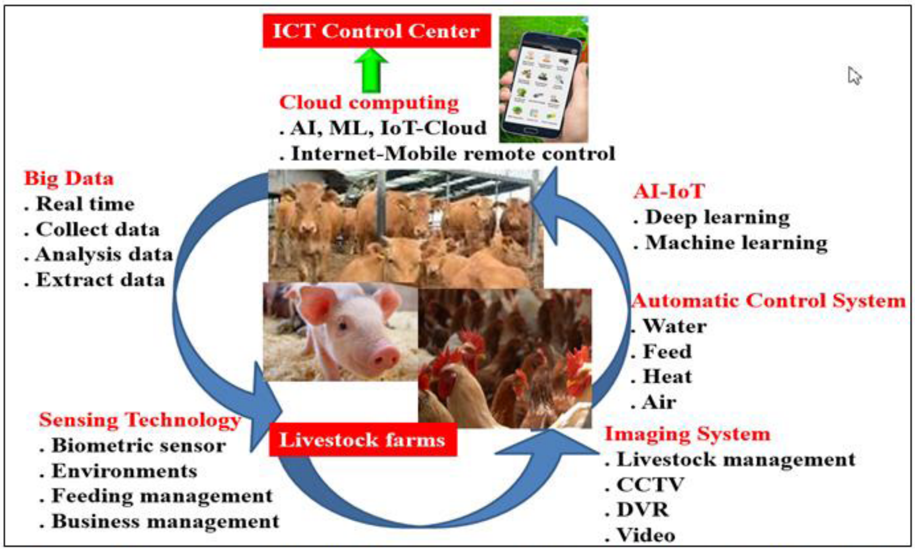

Figure 7. Climate-smart livestock system as a digital model (Source: Park 2021; Zammit and Park 2021)

In PLF, AI applications are mainly aimed at animal welfare and livestock farming. A previous study reviewed the use of AI algorithms to improve animal behaviour and welfare (Debauche et al. 2021). PLF aims to continuously and automatically monitor and improve the animal health, animal behaviour and welfare, productivity, and environmental impacts using sensing technologies, big data, image analysis, and global positioning signals (GPS). PLF uses smart engineering and computer technologies to control the environment and feeding management of regularly fed livestock animals. Tools and sensors in PLF continuously and automatically monitor key growth performance indicators of livestock animals in the areas of animal health, productivity, and environmental load. Operations can be further improved as farmers share information gathered across the supply chain with relevant stakeholders, such as veterinarians, slaughterhouses, meat processors, and animal feed producers (Gaire et al. 2013; Berckmans 2017; Astill et al. 2020).

The smart livestock system is an IoT system consisting of a smart analysis solution and smart control processes in a smart sensing, monitoring, and management information system that collects data using various types of cloud-based sensors (Madakam et al. 2015; Deloitte 2017; Adamides et al. 2020; Navarro et al. 2020; Neethirajan 2020). The IoT, consisting of systems connecting between the internet and devices through wireless connection, cloud computing, AI, and big data, helps establish a network of devices that can share data and information and also act based on network inputs (Zhao et al. 2010; Navarro et al. 2020). It is expected that the IoT technology will bring a breakthrough in livestock animal management by connecting the biological information of farm animals and the environmental information obtained through IoT sensors to farms that are far away through the cloud. This can help increase the efficiency of livestock farming and reduce the manual labour and labour costs (Madakam et al. 2015; Iwasaki et al. 2019; Navarro et al. 2020). The IoT is the promise of a framework that can collect and manage various data on farms using a network of sensors, which can never be processed separately from the Internet (Ma et al. 2011; Ilapakurti and Vuppalapati 2015; Jayaraman et al. 2015). The IoT is an indispensable technology for the smart livestock system, but when used with the internet in the future, it will provide the basis for the next generation animal housing management information system that will make the smart livestock system become an active node in business solutions and agricultural value chains (Kaloxylos et al. 2012; Caria et al. 2017; Terence and Purushothaman 2020). In the utilisation of big data, digital data from the animals' wearable sensors and livestock husbandry sensing platforms help create digital fingerprints that can be utilised in predictive and adaptive decision-making models (Neethirajan and Kemp 2021) (Figure 8). Big data plays a key role in the application of advanced

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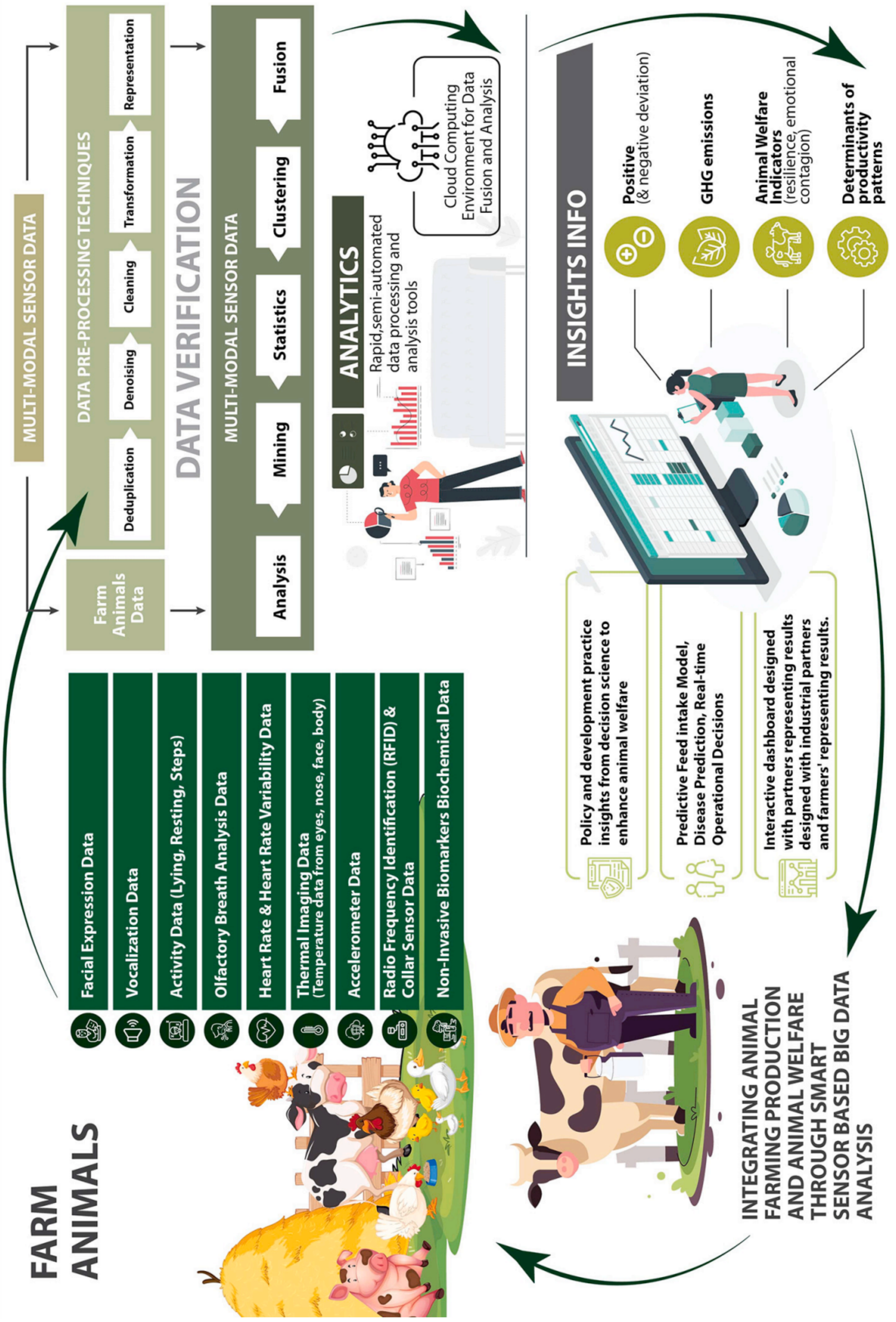

Figure 8. Application of a chain of sensor-based big data in a climate-livestock smart system
(Source: Neethirajan and Kemp 2021)

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technologies to animals. It provides an expandable solution for storing massive amounts of data on remote servers. AI and ML algorithms can utilise such massive amounts of data to analyse, predict, and alert farmers when an abnormal situation occurs (Grady and Hare 2017; Astill et al. 2020; Neethirajan 2020; Kim et al. 2021).

Conclusion

By 2050, the world population will increase to 9.9 billion and the consumption of foods, especially animal proteins, will increase by more than 60% due to the increased population growth. Global warming caused by climate change has led to a crisis in farm animal production due to the need to solve food issues for a continuously growing population. Thus, a solution for such issues is urgently needed. Climate change poses problems for food production and to ensure sustainable livestock production. Heat stress in animals due to global warming may result in livestock farming and water shortages, changes to the livestock feed resources, livestock malodours, GHG emissions, a deterioration in the animal behaviour and welfare, and quality of animal-based foods. Heat stress in livestock animals due to global warming in industrialised, factory intensive livestock operations occurs when homeostasis thermoregulation mechanisms of animals are challenged under heat waves during the summer period. HS reduces livestock farming outputs due to nutrient metabolic disorders, the immunity, and animal stress while increasing the occurrence of livestock malodours at the same time. The action mechanism of HooinEcobiocomplex probiotics related to farm animals, in high quality animal food production, in the removal of livestock malodours, and in the reduction in GHG emissions is known as a climate response livestock nutrition strategy. Carbon neutral (net zero), which is the GHG reduction goal by 2050 for food security and a sustainable society under the climate crisis and global warming, has become an important issue. Livestock farming accounts for 12–24% of the anthropogenic GHG emissions worldwide. Fifty percent of emitted GHGs from livestock farming are in the form of methane (CH_4) through cattle belching due to rumen fermentation. Various strategies are needed to reduce livestock GHG emissions, including innovative feed supplements and grazing management systems using regenerative farming techniques. To understand the response to climate change, an *in ovo* injection could be a new technology for improving the hatchability, immune response, animal behavioural welfare, and growth performance of poultry as an animal nutrition model after exposure to heat stress. Maintenance and enhancement of sustainable climate-smart livestock systems can be a core climate response technology. In a smart livestock system, a mechanism for improving the quality of livestock production and animal foods through nutrient digestibility, immune response, *in vivo* homeostasis, and animal welfare enhancement has been newly identified. It is predicted that this will make an important contribution to the mitigation of heat stress damage caused by climate change, the removal of livestock malodours, and the realisation of carbon neutral livestock for sustainable livestock production. More studies in this area are needed in the future.

Conflict of interest

The author declare no conflict of interest.

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