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*Review*

# Smart Pig Farming—A Journey Ahead of Vietnam

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**Abstract:** Vietnam heavily relies on pork as its primary source of animal protein. Traditional farming methods, characterized by small-scale operations, dominate the industry. However, challenges such as rising feed costs, disease outbreaks, and market volatility are prompting many farmers to abandon their businesses. Recognizing the pivotal role of the swine sector in both economic development and nutrition, authorities must intervene to prevent its collapse. In developed nations, smart pig farming, utilizing technologies like sensors and cameras for data collection and real-time decision-making, has significantly improved health and productivity. These technologies can detect subtle indicators of animal well-being, enabling prompt intervention. This review aims to analyze the drivers of Vietnam's swine farming, identify existing production system flaws, and explore innovative precision farming methods worldwide. Embracing precision farming promises to enhance Vietnam's competitiveness in export markets and bolster consumer confidence. However, reliance solely on expensive foreign technologies may benefit large-scale farms, leaving smaller ones behind. Therefore, fostering local innovation and validating cost-effective solutions will be crucial for the sustainable growth of small- and medium-scale pig farming in Vietnam.

**Keywords:** precision pig farming; sustainability; technical efficiency; sensors



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## 1. Introduction

The gross domestic product (GDP) growth rate in Vietnam was as high as 8.02% in 2022 [1]. Compared to 2021, the agricultural (crop, livestock, forestry, and fishery) growth rate increased by 3.36%, which hastened the overall progress [2]. A total of 12.56% of the national GDP (1065.08 trillion Vietnamese dongs) in 2021 [3] and 11.88% (1129.91 trillion Vietnamese dongs) in 2022 [2] has been the contribution of this sector. Livestock makes up a significant portion of the agriculture sector's output [4,5] in which swine contributes the most from both economic and nutritional standpoints [6–8]. In Asia, Vietnam ranks as the third highest meat-consuming country, worth USD 18 billion [4], and more than 70% of consumption is pork [9–11]. Such is the contribution that no other meat can be thought of as a substitute for it [9]. Per capita pork consumption in 2021 was 25.93 kg/year which is expected to rise to 32.72 kg/year in 2029 [12]. Vietnam produces a lot of pork as well. According to the GSO (General Statistics Office of Vietnam), the country raised 23.2 million

pigs in 2021 [13]. In the year 2022, Vietnam ranked second (within Asia) [14] and sixth (worldwide) [10,14] in pork production. This advancement has been contributed by both household and commercial pig farms that increase earnings and produce goods that appeal to the country's users [15–18]. The household level of production is the source of income for above four million pig farmers [9] accounting for about 80% of the total farms [6,19,20]. This conventional farming contributes largely to the economic development of rural and suburban areas. Still, at the same time, scattered production at this large scale causes challenges for sustainable development. The government of Vietnam, with limited capacity, cannot regularly monitor and control the unregistered farms, wet markets (a marketplace where products are sold raw and fresh), and veterinary services. Moreover, reliance on traditional farming and wet markets presents health risks from inadequate hygiene, limits market access caused by lower product quality and compliance issues, and results in income instability [21,22]. Conversely, modern farming enhances efficiency, reduces costs, and improves animal welfare and health monitoring, thereby optimizing resource utilization and overall farm management practices [23–27]. The Ministry of Agriculture and Rural Development (MARD) of Vietnam has expressed interest and provided policies to upgrade swine farming from traditional smallholder to smart medium and commercial scale farms. To do so, Vietnam will need a lot of infrastructural development, technical support, technological exposure, financial investment, and implementation of precision farming devices. All these changes look quite difficult right now, but with the ongoing trend worldwide, the signs of obvious changes are there.

This document seeks to examine the factors influencing and obstacles faced in the advancement of pig farming in Vietnam by conducting a comprehensive review of the literature. It aims to provide insights for ensuring the sustainable growth of swine production in the coming days. The first part of the manuscript presents the current scenario of Vietnamese swine farming in terms of the production status, technological advancements, disease condition, product marketing, policies, and challenges. The next section provides a review of invented technologies and methods worldwide for smart and sustainable swine farming. The later sections discuss prospects, future trading, and environmental sustainability related to Vietnam's swine farming. Finally, recommendations are set up proposing possible strategies for strengthening the industry, keeping sustainable development in mind.

## 2. Review Methodology

### *2.1. Search Strategy and Article Selection Process*

A thorough search was performed to find the pertinent literature about the state of pig farming in Vietnam today and in the future. Keywords and search terms related to Vietnam, swine production, pig farming, environmental impact, sustainability, smart pig farming, technical efficiency, and sensors were used in the Google Scholar, ScienceDirect, and Web of Science databases, given their comprehensive coverage of academic articles in the areas of animal husbandry and future farming. Additionally, to gather a wide range of perspectives and the most recent events, online sources were also incorporated, such as official government papers, policy documents, reports of international projects, and reliable news sources. For a more efficient search and to guarantee inclusivity, Boolean operators like "AND" and "OR" were employed. The period of 2016 to 2023 was analyzed. From the search results, studies that satisfied the following requirements were included in the review: (a) abstracts that concentrated on pig farming challenges and prospects in Vietnam; (b) offered quantitative data on pig and/or pork production, marketing, and consumption; (c) offered automation for precision livestock farming; and (d) published in peer-reviewed journals, credible websites, government reports or other official publications, and conference proceedings. All inclusions were limited to English, except for some online news sources in the Vietnamese language. A bibliographic manager program (Zotero) was used for processing citations in compliance with citation style requirements.

### *2.2. Data Extraction*

In order to ease the identification of trends, problems, opportunities, and emerging patterns in the Vietnamese pig farming sector, pertinent information was retrieved from the chosen literature sources (both from tables and text) and organized in a spreadsheet for tabular and graphical presentation in the manuscript.

## 3. Current Status of Swine Farming in Vietnam

### *3.1. Livestock Production Scenario and Pig Distribution*

Vietnam had a pig population of 29.08 million in 2016, but the outbreak of foot-and-mouth disease (FMD) reduced the population to 27.41 million in 2017 [5,11,28]. Recovery was initiated in the following year with an increase of 1.4 million heads in 2018 [29], but due to the spread of African swine fever (ASF), pig numbers dramatically decreased to 20.21 million in 2019 [13]. Since then, as the situation improved, the pig population has gradually increased. In June 2021, the swine herd expanded by 11.6% compared with June 2020 [30]. Some studies and reports claimed the pig population has increased by 2.8% to 6.9% at different time points in 2023 against the same period in 2022 [31–33]. According to several sources, 70–78% of Vietnam's total meat production is pork [34–36]. Improved slaughter weight (110 kg to 126.9 kg/pig from 2007 to 2020) has contributed to this figure, even at the time of fall in swine herds [37,38]. In the year 2017, 2.1 million metric tons (MMT) of pork were produced [39], which increased to 3.1 MMT in 2022 and was 2.75 MMT up to August 2023 [14]. Conversely, Vietnam produced only 1.07 MMT of chicken meat and 0.26 MMT of beef in 2022 [40]. Vietnam's livestock production scenario from 2018 to 2022 is presented in Table 1.

**Table 1.** Vietnam's livestock production scenario from 2018 to 2022.

| Year. | Registered Livestock Farm | Population (Millions) | | | | Meat Production (Million Metric Tons) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pig | Cattle | Buffalo | Goat | Pork | Chicken | Beef | Buffalo | Goat |
| 2018 | 19,639 | 29.83 | 6.33 | 2.49 | 2.68 | 2.81 | 0.84 | 0.184 | 0.051 | 0.019 |
| 2019 | 20,310 | 20.21 | 6.28 | 2.39 | 2.61 | 2.43 | 1.00 | 0.195 | 0.052 | 0.021 |
| 2020 | 13,752 | 22.03 | 6.33 | 2.33 | 2.65 | 2.47 | 1.15 | 0.205 | 0.096 | 0.021 |
| 2021 | 13,748 | 23.20 | 6.39 | 2.26 | 2.72 | 2.93 | 1.28 | 0.256 | 0.066 | 0.021 |
| 2022 | 14,084 | 24.68 | 6.34 | 2.23 | - | 3.10 | 1.07 | 0.265 | 0.066 | 0.022 |
| Ref. | [13] | [13] | [13] | [13] | [41] | [40] | [40] | [40] | [40] | [40] |

GSO categorized Vietnam's swine population into six regions: Northern midlands and mountain areas, Red river delta, Northern central area and central coastal area, Central highlands, South east, and Mekong river delta. The government's initiatives to shift swine concentration from the densely populated Red river delta and Mekong river delta regions to the lightly populated Northern central area and central coastal area, and Central highlands can be understood from Figure 1.

Conventional/traditional small-scale household farms, medium-size farms, and industrial/large-size commercial farms are Vietnam's available swine farm types [5,42,43]. According to the results of the 2011 census, the smallest category of pig farms having only 1 to 5 heads occupied 77.50% of the farms nationwide [44]. Although the proportion of small farms is decreasing and medium and large farms are increasing gradually [44,45], Vietnam's pork sector will still be influenced by smallholder production for a few more decades [46]. Less than 20% of pork is contributed by industrial farms, according to a 2015 study [47]. In both conventional and industrial farming, one of two types of production systems, namely, "farrow-to-finish" and "fattening", is practiced [19]. Farrow-to-finish is a complete production cycle where breeding stocks are reproduced and offspring are sold at market age. This process usually takes 7.5–10.5 months to complete one cycle. Fattening

takes around 4 months in well-managed farms [18]. However, Vietnamese farmers spent around 5.8 months in fattening hogs [43], leading to more production costs. Another cost-boosting item is the increased floor space offered by Vietnamese farmers. The ideal floor area for fattening hogs is 1.27 to 1.47 $m^2$/head, whereas traditional Vietnamese farmers allow roughly 3.25 $m^2$ [48]. Therefore, increasing the number of pigs raised in the same facility could increase the profit [19,49]. One more crucial factor associated with performance and profitability is the source and quality of feed. Feeds for pigs vary greatly following the scale of operation. About 22.50%, 70.70%, and 6.80% of farmers in Vietnam feed their pigs solely homemade, a mixture of homemade and purchased, and solely purchased feeds, respectively [10]. As weight development and well-being are significantly affected by nutrition [50] and it is quite impossible to measure the quality of homemade diets [7], performance is often compromised. According to Galanopoulos et al. [50], commercial meals more closely meet the animal's dietary requirements. Another study strongly supports the statement that the nationwide feed conversion ratio (FCR) for pork is 4.4, whereas for the intensive commercial farms, it is only 2.8, and for the household pigs, the FCR is more than 5 [10]. Vietnam has a long history of importing exotic breeders like Landrace, Hampshire, Duroc, Yorkshire, and Pietrain [51–53]. More than 43,300 breeding pigs were brought from the USA, Canada, Thailand, and Denmark in 2020 alone [54]. In small-scale operations, farmers mostly rear local breeds like Mong Cai, Ban, Muong Khuong, Soc, Co, Meo, Tap Na, Ha Lang, Muong Te, Lung Pu, Lung, O Lam, Chu Prong, etc. [20,51–53,55–57]. Indigenous breeds mature early and are more adaptable but lack the productive and reproductive traits of exotic pigs [55]. In this regard, contract farming introduced recently by some large companies can be beneficial for all parties involved. There is less market risk for the farmer, and the company can earn a large profit share without directly managing the animals [58,59]. However, contract farming is now limited to large-scale industrial farms only [60].

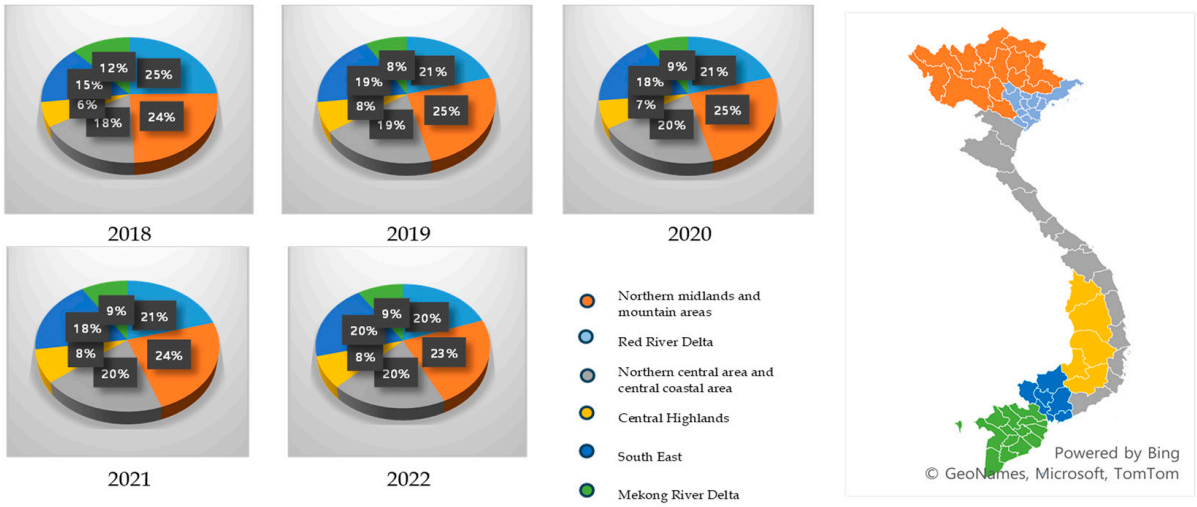


**Figure 1.** Gradual changes in the concentration of pigs in different regions. Generated from [13].

### *3.2. Technological Advancements in Vietnam's Swine Farms*

Innovation and technology are essential to the global food system's sustainable growth [61–63]. The success of Vietnam's agricultural production in recent years is thought to have been largely due to science and technology, especially advancements in plant types, inputs, and sophisticated farming instruments [64]. As for developed countries, the implementation of advanced tools and technologies are in place for the livestock sector as well. This has led to professional livestock production, mostly known as precision livestock farming (PLF) nowadays [4]. However, the same has not been the case for Vietnam and many other developing countries' livestock sectors. The official livestock farms classification in Vietnam emphasizes the number of livestock, while the degree of automation

and efficiency is often overlooked [18]. In conventional pig farming, there is no technical advancement, as the farmers have refrained from investing in advanced tools due to limited financial availability and lack of interest [6]. Moreover, just 18.2% of agricultural businesses have an internet connection [65], which is one of the major prerequisites of smart farming. A few major commercial producers are introducing foreign-invented sensors and models in their farms and other associated pork processing and marketing branches. Overall, very few farms are operated with automatic drinking, feeding, and cooling systems in the country [44]. Precise and advanced technologies shall be encouraged and incorporated for production to marketing automation [28]. For the production part, sensors capable of reading body and environmental temperatures, activity, respiration rate, heart rate, and postures can be implemented. Additionally, for marketing, stress-free automated weighing, robotic slaughter, and processing are options explored. Barcode, blockchain technologies, etc., can support the traceability of marketed products.

### *3.3. Disease Management and Biosecurity Measures*

Ideal health is essential for the well-being of swine and the profitability of farms [45]. To minimize risk, Vietnamese farmers vaccinate pigs against common diseases. Porcine reproductive and respiratory syndrome (PRRS), ASF, hog cholera, FMD, etc., are some of the most fatal and impactful diseases in Vietnam [19]. The average vaccination cost for fattening pigs ranges from USD 4.7–9, depending upon the number of vaccines applied [19]. Despite the vaccination program and other limited disease monitoring systems, the occurrence of new diseases and the recurrence of former diseases has always been the case. For example, between the years 2003 and 2015, the number of birds destroyed due to avian influenza infection exceeded 60 million [66]. In 2022 alone, up to November, Vietnam had to destroy around 55 thousand livestock (buffalo, cows, and pigs) and 96 thousand poultry [67]. Because of the nature of scattered small-scale farms, government authorities face a hard time minimizing swine diseases. In 2006 and 2016, FMD caused farmers to experience financial dropout [10,11]. Another fatal disease, PRRS, was first detected in 2007 [68] and spread to more than 13 thousand farms, killing about 30 thousand swine. By 2010, PRRS spread to 49 provinces [69] infecting more than 800 thousand and killing around 450 thousand [70]. Hog cholera forced many farmers to close their operations as well [7]. According to one report published in 2019, above 2300 cholera-infected pigs had to be culled, resulting in heavy losses [71].

The first case of ASF in Vietnam was reported on 19 February 2019 [5,72]. By October of the same year, the disease spread all over the country [72,73]. Nguyen-Thi et al. [74] reported that in 2019, nearly 6 million ASF affected pigs (above 20% of the overall swine population) had to be put to death. Authorities responsible for veterinary services made efforts to halt the outbreak. Therefore, a decreasing number of infections was observed over time. In the first year of the outbreak, more than 6 thousand outbreaks were recorded; in 2020, the number was reduced to 1737, followed by an increase to 3154 outbreaks in 2021 and again reduced to 1256 outbreaks in 2022 [75]. On 24 July 2023, Vietnam approved the world's first commercial vaccines (NAVET-ASFVAC and AVAC ASF LIVE) against ASF [76–78]. China has also been devoted to developing ASF vaccines since 2018 and has made marked progress [79]. Although the outbreak situation seems better than the previous year, because of the very highly infectious nature of the disease, the sector is still at risk, and if not handled properly, the situation may become worse in the coming days. According to one report published on 21 July 2023 by the Lak district media, culture, and sports center, the district's Animal Husbandry and Veterinary Station destroyed 261 infected pigs weighing 8.7 thousand kg [80]. Another 6402 infected pigs were eliminated in Ninh Binh province between mid-March and late July [81]. Lang Son province had to cull more than 2000 animals from an ASF outbreak in 10 districts in 2023 again [82]. Between 24 July and September of 2023, 12 provinces experienced new outbreaks [31]. Bac Kan province authority has also confirmed further infections in new districts [83]. The new infection is also prevalent in central Vietnam districts [84,85]. As of 20 October 2023, the

Dien Chau district of Central Vietnam had destroyed 291 infected animals [84]. Yen Thanh district also culled over 500 pigs to control the further spread of the infection [86]. All these reports indicate ASF has a high probability of recurrence, and so farmers must take proactive steps to control and prevent epidemics to lower the likelihood of widespread outbreaks again [87]. One way that ASF and other illnesses spread is through the marketing of live piglets and finished pigs through middlemen [5,10]. Piglets obtained from markets or dealers cannot be tested or verified for quality by farmers [6]. Low-quality veterinary medications and ineffective treatments put pig production at more risk and human health in danger [88]. Recent cases of *Streptococcus suis* bacterial infection in humans have caused the authorities to strengthen the supervision of biosecurity awareness programs [89]. Since most pig homes are open style with low levels of biosecurity, illnesses can spread quickly to other locations when they arise.

### *3.4. Market Dynamics*

Lower marketing strength is a major problem faced by traditional farmers. The most normal practice is to sell live pigs to intermediaries who gather and resell them to slaughterhouses. Slaughterhouses market their products in the following three ways: (i) sell the meat to both retail and wholesale businessmen (70%), (ii) sell to wholesalers only (24%), and (iii) sell to consumers directly (6%) [10]. Usually, retailers collect pork from wholesalers and sell it to final consumers. Approximately 75% of pork in Vietnam follows the conventional value chain, including farmers, butchers, retailers, and end users [22]. This is how swine products in Vietnam must go through undesired middlemen before they reach the end user. Repeated handovers increase the transaction costs, and the market becomes unstable, where both the actual producer and consumer must pay for the middlemen.

People of Vietnam prefer fresh pork, and 93.3% of consumers buy from a traditional or wet market in the countryside, where the origin and quality of meat are not traceable. Only 13.2% of pork comes with a quality-check stamp [10]. About 97% of customers do not believe the meat supply chain, indicating serious problems with trust [9]. There are growing numbers of supermarkets in Vietnam, but they are still limited to large cities and most consumers are not accustomed to buying frozen pork yet [9,90]. The frozen pork in supermarkets is sometimes from imported sources. Around 4 percent of pork in Vietnam is imported [64]. The occurrence of ASF inside the country has increased the amount of pork imported [54]. In the first six months of 2021, 70 thousand tons of pork were imported [64], which rose to 89 thousand tons in the next four months, costing nearly 190 million USD, according to Vietnam's department of customs [91]. Frozen pork and pork products are mostly imported from the USA, Canada, Brazil, Germany, Russia, and the Netherlands [91,92]. Overflow of pork may force the market to reduce prices. This has been the case in Vietnam several times, where smallholders become the major victims and many of them cannot run their businesses anymore. According to a GSO-conducted investigation engaging 26,500 swine-producing households all over the country in 2022, household-level pig production cost is close to market value, where only 38.64% of producers made a profit and 8.51% of producers had a loss [67]. Another earlier study observed that 24% of smallholder farmers yielded a negative benefit from their business [93]. However, many other studies have found it profitable even for smallholder operations [56,94–96]. Loss in business is not always related to supply overflow though. Some research has shown farms are not operated at their maximum capacity. One study in Hanoi showed that optimal technical efficiency (efficiency of resource utilization) can reduce the input costs of Vietnam's traditional and industrial pig production by 26.2% and 34.3%, respectively, with no effect on output [19]. A separate investigation carried out in North Vietnam revealed that home pig farming had a technical efficiency of 80.40% [18], meaning it had a scope of reducing input cost by 19.60%. Vietnam's pig production system is not competitive enough for the international market yet [92]. According to the development strategy towards 2045, the expected share of exports will be 15–20% of total pork in 2030 [97]. To go somewhere

near the target, Vietnam must prove its capability to produce quality pork at reasonable costs. This is where large-scale precision farming can help.

### *3.5. Government Policies and Initiatives*

The production of pigs and other animals is regulated by national policy [98]. Through policy implementations, MARD aims to resolve the limiting issues of pig farming they currently have, like decreased land, limited choices for breeding, and pollution of the environment [5]. A World Bank-funded livestock competitiveness and food safety project (LIFSAP) was implemented in 2006, engaging small-scale producers to improve food safety and reduce environmental risks in the production process and supply chains [99]. To support farmers and the environment, MARD, along with international organizations, support household biogas development [100]. Another supportive program, livestock insurance was also introduced experimentally for cattle and buffalo in 2011–2013 [6,101–103] but never evolved [104]. Focusing on the sustainable development of swine farming, MARD approved a livestock sector reshaping plan on 9 May 2014 intended to increase non-native high-producing stock from 19.8% (2013) to 33% and to boost large-scale farms with intensified biosecurity by 2020 [6]. In 2019, MARD established the livestock task force to accelerate public–private partnerships (PPPs) to efficiently sort out the constraints involved in the livestock business and resolve them accordingly. The missions of the task force were to develop training materials, examine inventive proposals, create collaborative business models, establish livestock information systems, and form programs for sectoral experience sharing [4]. The Vietnam National Assembly approved the animal husbandry law in 2019 [105]. The government has decided to create epidemic biosafety zones for livestock out of the cities and highly populated areas (minimum of 1 km away) [19,42]. They are looking forward to establishing modernized processing plants and secure marketing facilities to serve sustainable development. MARD has proposed to aid in the establishment of well-equipped modernized livestock production systems at both individual and organizational levels to control illness and enhance food safety [6]. They expect that more than 70% of pigs will be raised in intensive large-scale farms by 2030 [97]. To facilitate this expectation, the minimum required annual turnover to establish a livestock business was set to 2.0 billion Vietnamese Dong (VND) or more in 2020, which was previously limited to 1 billion VND [2].

Vietnam joined the World Trade Organization (WTO) in 2007 [106], and since then, it has reduced import tariffs on feed ingredients [107]. The import tax was reduced to 2% and 0% from 5% in maize and wheat, respectively [6]. However, only a few large companies and importers received most of the benefits, leaving others at a disadvantage. This is a lesson to learn that a long-term master plan to reduce the dependency on imported feed ingredients and the establishment of an accomplishable policy is inevitable. The agreement of free trade with the EU in 2019 has opened a corridor for Vietnam to export pork [108]. One guideline, namely, "development strategy of livestock production sector for the period of 2021–2030, prospect towards 2045" was issued in 2020 to stimulate livestock development at the rate of four to five percent per year during 2021–2025, and three to four percent per year during 2026–2030, focusing both local consumption and the export market [97].

The government also takes strategies like genetic development, price control, product safety inspection, and welcoming large high-tech companies to satisfy domestic demand and promote exports. A 50% reduction in interest over the loan sanction for improving animal genetics [6] and supportive programs to encourage artificial insemination for genetic enrichment [109] are on the priority list of MARD. A national livestock breeding policy is also in place; however, the application is not ensured due to a lack of monitoring capacity and a highly scattered production system countrywide [110]. The government of Vietnam has been fighting with ASF for the last four and a half years. Numerous infected pigs have been destroyed over the period [74,111–113]. At the same time, the government is taking care of other diseases as well through vaccination and awareness-building programs. A subsidy for PRRS and classical swine fever vaccinations was announced for both small- and large-scale farmers. In addition, very little to zero rent on government-owned land is

available for farmers and other agricultural investors. Furthermore, the government also assists with up to 50% of the land cost for the first 5 years of business when renting land from other sources, up to 100% in training labor, up to 50% of consultancy fees, and up to 50% for the research towards the invention of new technologies [6]. Despite the supportive programs and policies taken by MARD to strengthen pig production and the value chain, many loopholes have yet to be fixed. Issues that policymakers should focus on can be identified when the current problems are detected. The following section aims to discuss the challenges in place.

### *3.6. Major Challenges and Constraints*

#### 3.6.1. Environmental Impacts

Animal farming all over the world has to face obstacles like soil and water pollution, contagious disease risks, antibiotic resistance, smell issues, product quality deterioration, animal waste processing, global warming, and many more [4,11,114–116]. Vietnam is not an exception, and sustainable livestock development is questioned there too [11]. The expansion of livestock contributes to substantial waste, posing a significant threat of greenhouse gas emissions that can adversely affect climate change, jeopardizing soil quality, surface water, groundwater, and human health if not appropriately addressed [7]. According to one study in Ha Hoa district, Phu Tho province in 2018, no waste treatment systems were implemented by 3% of farms having more than 30 pigs and by 38% of farms having less than 30 pigs [117]. Farmers possess a limited understanding of manure composition [118]. While farmyard manure was historically a crucial nutrient source in crop production, its significance has diminished due to the widespread adoption of chemical fertilizers [119], attributed to their lower cost and greater convenience [120]. The hauling of manure is regarded as the most unpleasant and physically demanding task [118,121]. Tropical livestock farming discharges significant volumes of wastewater, leading to the pollution of both surface and groundwater [43,122–124]. Water utilization efficiency stands at a mere 52% in large-scale industrial farms, and it is even less favorable for the other two categories [43]. In Vietnam, each pig requires an average of 40 L of water per day for washing and cleaning purposes [120], which is 12 L in Malaysia and 50 L in Singapore [125]. Industrial farms frequently treat their pig excrement in liquid form [60], which lowers the grow-to-finish farms' technical efficiency [126]. A survey in the northern region of Vietnam highlighting a lack of expertise among farmers in managing liquid manure revealed that approximately 19% of the total manure generated is released into public waterbodies [120]. Another study conducted in Ha Nam province in 2020 showed that 11% of farmers discharge their animal waste directly to drains and ponds [127]. Emissions to receivers transfer harmful bacteria into waterways and pollute water [128]. Greater animal numbers without advanced waste treatment reduce technical efficiency as handling animal waste occupies a large area of land [19], which is opposite to crop cultivation [129]. To offset the adverse environmental effects, South Korea, Italy, the UK, and Japan have decided to import pork, while some other countries have tightly regulated swine farming and waste treatment rather than ceasing production [130]. Vietnam has also pledged to handle all non-household waste by the year 2025 [131].

#### 3.6.2. Feed Price

COVID-19, followed by the combat of Ukraine and Russia, has greatly disturbed the animal feed market's stability [132]. Rice bran, soybean meal, corn meal, fish meal, etc., are commonly used ingredients [133,134], and the majority (70–80%) of the feed ingredients are imported [10,11,29,135–137]. Due to heavy reliance on premixes, soybean, and maize imports, feed markets are volatile, and small farmers are exposed to risks. Another feed issue is that the feed industry is dominated by a select group of big producers like CP and Cargill, who hold substantial market shares. Very few farmers purchase feeds directly from industries; the majority purchase them from agents at 8–12% higher prices [10]. As feed

accounts for more than 70% of total costs [138–140], pig farming costs are increasing every year following the feed costs.

#### 3.6.3. Pork Price

The price of pork fluctuates highly throughout the year. For example, live hogs' price in March 2022 was 2000–3000 VND/kg, down from January 2022; July's price was 8000–15,000 VND/kg, up from June of the same year [87,132]. In recent years, the price issue has forced 30% of small farmers to wrap up farming [141]. Vietnam has substantially more small farms than other nations; nearly all of the country's swine herds consist of under 100 animals [142]. Sometimes the supply exceeds the demand, as information sharing is not practical on this scale. Diseases like ASF and PRRS have also impacted the market significantly [143,144]. Moreover, China's policy to stop importing live pigs from Vietnam led to a swine price crisis in 2017 [5,145]. China, the EU, and the USA greatly impact pork prices worldwide since they contribute 78% of global production [146]. Cut-off tariffs among WTO and AFTA (ASEAN free trade area) nations undoubtedly subjected Vietnamese pig farmers to fierce market competition, which has significant ramifications for the country's pork markets. In the immediate and distant future, prices are probably going to be impacted by inexpensive meat and edible offal imports. This imposes a great threat that small farmers may not be able to cover their production costs in the future. Vietnamese customers largely prefer raw, non-frozen pork [147]. However, if there is a significant difference in the price of meat imported and domestically produced, and if consumers' preference converts due to increased spending capacity, ease, and diversity offered, Vietnam may have to import more pork. Timely action for sustainable swine farming integrated with modern processing plants is the possible way out for the country in the coming days.

#### 3.6.4. Genetic Resources

One of the major issues that pig growers deal with is a lack of understanding of optimal techniques for operations and breeding [5]. Vietnam's pig breeding expenses surpass the global average, thus making the nation's pork less competitive [91,92]. Only nucleus herds and breeding farms in Vietnam engage in planned reproduction [20], unlike numerous small-scale farms where reproduction aims to prioritize a short-term improvement in quantity over features related to resistance to illness and lifelong output. Indiscriminate crossbreeding with exotic breeds has led to a loss of genetic diversity of local breeds [148]. Consequently, Vietnam's sow efficiency is significantly less than many other countries. The mean annual production of completed pigs is 12.3 per sow, but modern pig farms produce 20.5 pigs per sow [10,149]. The government has been advocating for the use and spread of alien breeds [54]. If it is conducted haphazardly like before, there is greater fear over the decline of native genetic resources [54,148].

#### 3.6.5. Pathogens, Harmful Agents, and Veterinary Services

Numerous bacteria, viruses, and protozoa found in livestock manure may be harmful to both human and animal health [120]. Animal discharges in rivers and streams can spread highly transmissible and deadly viral diseases like Aujeszky's disease, hog cholera, and FMD to other farms [150]. According to reports from 2010, as much as 61% of animal and poultry products were infested with Salmonella, *E. Coli*, and Coliform, making them unsanitary [151]. Thai et al. [152] observed that about 39.6% of pork samples collected from North Vietnam were Salmonella-positive. Dang-Xuan et al. [153] and Ngo et al. [154] found 44.7% and 58.1% Salmonella-positive meat in pork shops. Another study in 2022 claimed high levels of Salmonella-contaminated pork, even in supermarkets and modern outlets [35]. According to Nguyen-Viet et al. [155], 90% of marketed pork was found not to meet standards for bacterial contamination, and 98% did not meet standards for coliforms. Pork samples tested positive for harmful residue of beta-agonists [156] and tetracycline [157] in Hanoi and sulfamethazine in Ho Chi Minh city [158]. Nhung et al. [159] noted a 9.6%

occurrence of antimicrobial residues in the Vietnamese pork sample. Uncovering multiple pig farms utilizing illegal substances like salbutamol and clenbuterol in animal feed, the number of pigs fell by 1.1 million between 2010 and 2013 [11]. Veterinary items and services are not sufficiently governed to ensure that they adhere to the necessary standards. A sizable portion of veterinarians do not have registration either [160].

#### 3.6.6. Insufficient Technological Involvement

Vietnam's farming system is conventional with very few exceptions. With the growing number of young populations and extended income, a rise in meat demand is expected. On the other hand, because of the nature of in-farm operations and the business model of other successful pork-producing countries, the farm number seems to decrease in the future. Therefore, the establishment of a well-equipped ICT-based large-scale farming system is a must. So far, some farms have implemented a few sensors and monitoring tools. Extension of the use of these automated real-time data collection tools is required to facilitate precision pig farming for the sake of achieving sustainable development with reduced environmental effects [26,161]. It is quite challenging to invest a substantial amount of money into this developing industry [162].

The root cause of most of these issues is the policies' weaknesses, which lack a solid foundation in the nation's relevance and context. Policies have always been challenging to implement because there is a significant mismatch between goals and available resources.

## 4. Research Progress and Innovation Worldwide in Precision Swine Farming

### *4.1. In Animal Identification, Behavior Recognition, and Other Productive Trait Detection*

With the positive intent of sustainable development of the pork industry, Vietnam should move the farming system towards precision farming. In addition to offering a means of individualized care and surveillance, digital transformation proves to be a practical means of supplying the growing need for food for the world's population in the future [163]. A variety of innovations have been developed that are intended to enhance production [164,165]. Monitoring the indoor farm environment using the Internet of Things (IoT) and sensors is highly convenient because there are relatively few expenses associated with maintaining and installing this equipment [166,167]. Studies and commercial applications of sensors in the field of animal identification [27], temperature measurement [168], etc., are in place. Radiofrequency identification (RFID) has proven effective in identifying and tracking individual animals [169–173]. Camera systems equipped with sensors can also be used for identification and body temperature measurements [174–177]. Cameras are found effective in determining the body weight, lameness, and injury of animals too [164,178–190]. Alongside fixed round-the-clock monitoring cameras, portable infrared cameras are now well-known in advanced farming systems. They are effectively used in estrus detection [191,192] and fertility checks [193–195]. Some of the other innovative ICT tools, like the use of accelerometers [196,197] and GPS [198] for tracking, RFID for computing the feeding time [169], flow meters for measuring water intake [199], sound analyzers for detecting respiratory health [200–203], and stress [204], etc., are being explored by researchers and industries. These tools enable instantaneous information acquisition, which is then analyzed with statistical software or automatically by artificial intelligence [205]. Several studies used deep learning methods for animal recognition [206], posture and locomotion recognition [185,207,208], disease symptom or unusual behavior detection [209], feeding behavior determination [207], body weight determination [179,210,211], water consumption measurement [212], etc. The integral use of sensor-driven data, artificial intelligence, and other cutting-edge technologies can facilitate more reliable prediction and real-time decision-making [45,213]. Predictive analytics help farmers anticipate potential issues, manage risks, and make informed decisions to enhance productivity and profitability. Producers can be more positioned by knowing the time their livestock will be prepared for shipment to the butcher store [213]. Therefore, contemporary hog growers may need to employ automated models to keep an eye on the condition, well-being, and

behavior of their pigs, and the farm's overall environment [185,214]. The profitability of large farms increases when the automation of management practices is applied, according to Otsuka et al. [215]. The employment of robotic systems for washing and cleaning farms and processing carcasses has proven to be profitable by saving time, labor, and money [45]. Though many technologies exist, only a few have received complete validation [165]. Vietnam can go for well-validated products as a beginner on the path of precision farming, but developing its own products is crucial to facilitate the improvement and maintenance of developed tools in the long run.

### *4.2. In Veterinary Monitoring and Disease Control*

Welfare risks are present in the traditional agricultural system [216], and often diseases cannot be identified at their early stages [45], resulting in more expensive medical care [217]. Precision pig farming integrates advanced veterinary monitoring and disease control measures to ensure the early detection of health issues and the implementation of timely interventions [27,162,218–222]. According to Racewicz et al. [220], the best and most practical method for managing the good health of a big herd of pigs would be to monitor the health parameters of animals automatically. Some researchers have successfully employed sensors to detect foodborne infections in animals [223–226]. Microfluidics has become more popular recently for its quick disease detection capabilities [227–229], and it has been shown to be a dependable and successful method of diagnosing ketosis [230]. Ahmed et al. [231] concluded that early detection of *Escherichia coli* and *Salmonella enteritidis* infections in piglets is possible using a ZigBee-based network.

Variations in an animal's feeding or drinking habits can be used as markers of health, since illnesses, physiological abnormalities, and adverse environmental conditions interfere with regular feeding schedules [172,232]. Monitoring of feeding and drinking habits, including the amount of time spent consuming feed or water, and the number of visits to feeding area—either for nutritional or non-nutritive purposes—can be detected using an RFID system [169,233,234] and deep learning techniques [169,235–238]. Animal sounds can also be used to identify respiratory conditions, stress, and other illnesses [200–204,239–241]. Coughing sounds may serve as a useful marker for respiratory illnesses like pneumonia [202]. An approach based on the AlexNet model was developed by Yin et al. [242], who reported a 96.8% accuracy rate in cough recognition. Using sound analysis, Exadaktylos et al. [241] found 85% accuracy in real-time pig disease diagnosis. Furthermore, sound can be employed as a biomarker for farm indoor air pollution [243]. However, the primary limitation of audio-based health evaluations of farm animals is the cacophonous atmosphere within the farm [45]. As the occurrence and recurrence of diseases are quite common in pig herds in Vietnam, some early detection methods need to be implemented. Early detection and interventions do not necessarily serve economic benefits only but also help improve animal welfare, an important pillar of sustainability [244] and one of the major criteria for entering the international market [245]. A summary of Vietnam's pig farming influencing factors, obstacles, and possible way-out proposals is shown in Figure 2.

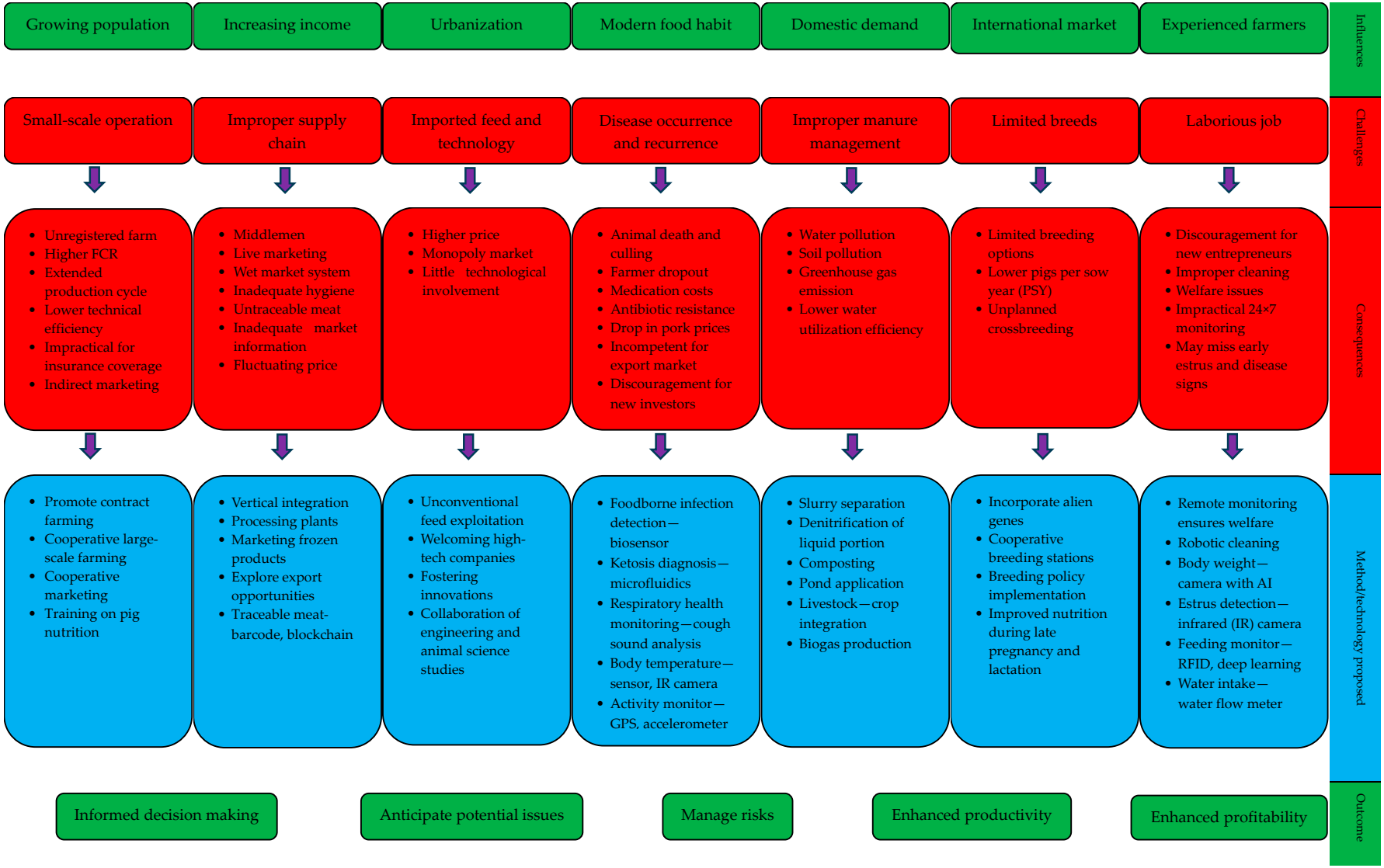


**Figure 2.** Influencing factors, obstacles, and proposed methods and technologies to overcome obstacles in Vietnam pig farming system.

## 5. Opportunities and Prospects

Vietnam was formerly among the nations with the lowest incomes worldwide, and today it is among the fastest-developing nations [246–248]. The country has an enormous population of approximately 99 million [249], which is expected to reach 105.9 million by 2040 [250]. The median age of the current population is 32.8 years [251]. This is a major factor for the sharp increase in the overall intake of food and drink items [11]. Between 2010 and 2018, the average monthly intake of meat per person rose from 1.8 kg to 2.2 kg [252]. Demand for animal products increases linearly with income [253,254]. The income of Vietnamese people has consistently increased [255]. The mean monthly earnings per person climbed from 2.64 million dongs in 2014 to 4.67 million dongs in 2022 [256]. Vietnamese consumers spent around 43.96 billion USD on food in 2018, which rose to 53 billion USD in 2021 [257]. An increase in the choice of ready-to-cook products and the changes in food habits are attributed to urbanization too [11,258]. According to one study in 2023, 62% of Vietnamese people live in rural areas, making it a largely rural country [259]. However, by 2040, the percentage of people living in cities is predicted to rise quickly to 48.4% [250]. An increase in the number of city dwellers will lead more consumers to shift their preferences towards animal proteins [260]. The desired increase in demand in the coming days is an opportunity that can be achieved through large-scale commercial farming equipped with precise data-providing tools. In addition to domestic demand, pork is globally recognized as one of the primary protein sources [19,261–263]. It is the second most eaten meat globally, constituting around 33–34% of consumption [19,264,265]. Some studies between 2019 and 2022 claimed pork to be the most consumed meat as well [266,267]. Being a member of ASEAN and WTO, Vietnam has easier export chances if quality products at reasonable prices following standard animal welfare are ensured. Moreover, several sustainable development objectives, such as women empowerment and poverty eradication can be achieved through the development of agricultural practices [213].

## 6. Future Trading

In the year 2021, annual pork consumption worldwide was 102.15 MMT, which is predicted to be 116.93 MMT in 2031 [268]. Pork imports throughout the world are increasing linearly. In 2017, the total importation of pork was 7.88 MMT, which lifted to 10.16 MMT in 2021 [269]. Although Vietnamese people do not traditionally favor chilled meat, Vietnam imported 0.16 MMT of pork up to April 2023 [270]. The frozen meat market was projected to generate USD 1.14 billion in 2023, with a 6.88% annual growth forecast [271]. These days, urban dwellers are more concerned with food hygiene and pork grades for their well-being. They are far more likely to buy meat from contemporary retail establishments, leaving old-fashioned markets [272,273], as more consciousness is growing about the food origins and processing lines [274]. The food sector is heading on the same path to satisfy the demands of its increasingly informed customers [275]. Consumers are even prepared to spend more for higher-quality and safer meat [6,9,276–279]. Moreover, an increase in Vietnamese people's meat expenditures is evident, climbing from USD 14.14 billion in 2016 to USD 18.36 billion in 2021 [280]. The pork industry can take the opportunity by producing safer meat with sufficient traceability. Traceability is a criterion for export as well. Traditionally, Vietnam exported meat to several Asian and Western European nations [91,281]. The export value totaled 48.6 million USD in 2011 and 60 million USD in 2012 [10], with the majority of chilled pork and suckling pig shipments going to China, Hong Kong, and Singapore [282,283]. The country's meat export business has recently shrunk and mostly produces for the native market, with little thought given to exports. Disease outbreaks and increased production expenses caused significant fluctuations in the production of exportable meat [19,282]. The Ministry of Industry and Trade claims that owing to issues with processing, market projections, and infection avoidance and management, the quantity of exported pork made up just a tiny fraction of the nation's supply [91]. Despite the financial crisis due to COVID-19 worldwide, in Asian nations, there is yet a significant desire for pork [284]. Many more countries, like China, Japan, South

Korea, France, Russia, United States, Australia, Poland, Sweden, England, etc., import pork [285–289], and Vietnam can take the chance by improving pork standards.

Overflow of products and improper timing of marketing may cause heavy losses in the pork business. Contract farming, being more informed of national and international markets, may ensure demand-based production [290]. It connects small-scale livestock farmers to mainstream markets. The contract provides producers with high-quality genetic resources, balanced feed, vaccination, biosecurity tools, and technical support. This policy may protect farmers from market shocks, like the sudden fall in prices that occurred in 2017 and 2018, for instance. In addition to contract farming, vertical integration, and the establishment of large-scale farms aiming at bulk marketing are expected to rise [209] to lower market risks [36] and better tackle disease outbreaks [45]. By all means, the marketing channel is supposed to develop in such a way that it will skip middlemen as much as possible. Another approach would be the implementation of an integrated livestock–crop production system that will optimize resource utilization, improve soil fertility, enhance overall farm sustainability, and reduce dependency on a single output.

## 7. Environmental Sustainability

Amidst escalating environmental apprehensions, the prospective trajectory of smart swine farming in Vietnam necessitates a steadfast focus on sustainable methodologies to mitigate the environmental ramifications. Traditional livestock farming methods generally impose significant environmental burdens on both rural and urban environments [291,292]. Given the current unsustainable nature of livestock production systems, a comprehensive reform aimed at enhancing sustainability is urged, thereby mitigating adverse effects on animals, health and well-being, and the environment [293].

Waste management and the extent of pollution are significantly affected by the location of a farm [60,124]. Although MARD has advocated for the relocation of animals away from residential zones [42], the effective implementation of this policy has been hindered by constraints related to land availability and farmer reluctance to transfer pig production operations to locations distant from their residences. However, water pollution caused by traditional pig farms can be minimized by reducing the fattening period and increasing the stocking density [43]. The reasons are that the grower–finisher period requires around 64% of the total water requirement [294], and conventional pig farmers give animals more space than is advised [94]. Some experiments suggested that an increased farm size positively minimized emissions into water, air, and soil [19,49,50,295–298], while others concluded adverse effects [299,300]. However, it is necessary to address and control environmental challenges stemming from pig farming. The Deputy Minister of MARD emphasizes Vietnam's dedication to transforming its food and agriculture system into a "green," low-emission, and sustainable model [64]. Promoting feasible technologies, fostering agricultural innovation, and adopting collaborative models will all help to ease this transition. Advanced manure treatment technology offers more value-added products, including nutrient-rich bio-solids, fiber, and recycled water [301] and improves treatment efficiency by cutting down emissions into the atmosphere [302]. Kunz et al. [303] used a method called swine manure treatment systems (SMTS) and found positive impacts on the environment. Dróżdż et al. [304] stated composting, anaerobic digestion, and pyrolysis of manure into biochar are effective ways for energy recovery. Overapplication of animal dung on soil results in environmental emissions of nitrogen, phosphorus, and potassium. According to Burton [305], a decanter centrifuge can remove phosphorous, but to remove potassium, membrane separation is needed, which is rarely suitable in farm conditions. The most promising methods for treating manure are slurry separation and anaerobic digestion, according to Hou et al. [306]. Riaño et al. [307] also suggested that on-farm manure separation and denitrification of the liquid part are alternatives for treating manure sustainably. Many other studies supported slurry separation as a means of reducing greenhouse gases [308,309] and producing environmentally friendly fertilizer [305,310–312]. Integrated livestock–crop production is an essential resilience

approach that aims to maximize household resource usage and reduce risks resulting from the ever-changing physical and economic environment [313]. Rather than being released into the environment, animal waste and agricultural leftovers are frequently recycled and reused extensively on the farm, which makes efficient use of available resources and lowers production costs. As pig dung has a higher nitrogen concentration than ruminant manure [314], it is a better fertilizer source for crop fields and ponds [120]. Hence, integrated crop–livestock systems can improve farms' and communities' environmental sustainability and profitability [315,316].

## 8. Recommendations

1. Promote seminars and training sessions to encourage the use of proven PLF tools for information sharing. Prioritize automated systems that do not require dedicated data analysts or complex software handling.
2. Use advanced disease monitoring and early detection systems. Support robust biosecurity measures through incentives and knowledge sharing programs.
3. Extensive validation of sensors, IoTs, and methods before commercial use of the service.
4. Create a scientific governing structure that supports innovation in agriculture. Provide support and incentives for companies involved in automation of farm business.
5. To promote export, invite technologically advanced producers, support vertical integration, and establish connections to international markets.
6. Set up automated systems for collecting production, health, environment, processing, marketing, value addition, and consumption data.
7. Given how crucial shared data are in machine learning for decision-making, precompetitive collaborations between businesses should be promoted for data sharing. In doing so, the government ought to handle the data security issues.
8. Conventional small-scale pig farms should also have access to technical assistance and other supportive policies to support growth.
9. Capacity building is needed to accumulate and analyze market information for more accurate pork supply and demand forecasting, improving cost competitiveness in pig value chains.
10. Application of good agricultural practices and collaborative marketing of small farms is required to make the products traceable and safe for health and the environment. The expansion of contract farming and the creation of a quality inspection system may help in this regard.
11. For better efficiency and profitability, we suggest increasing herd size, reducing floor space per fattening hog to 1.27–1.47 $m^2$ in conventional production systems, taking care of pregnant sows' nutrition, and practicing early weaning.
12. Cooperative breeding programs and preservation of native genotypes should be emphasized in the national livestock breeding policy.
13. Implement existing policies regarding the farm location away from waterways, densely populated areas, public facilities, and other high-risk areas.
14. Implement an integrated agricultural system that improves cropland and ponds by utilizing animal dung as a nutrient source. Manure treatment before soil application is important.
15. Explore and encourage local feed ingredients to reduce the reliance on imported raw resources.
16. Develop manure treatment processes that allow for maximum use of manure nutrients without large land occupation. On-farm manure separation can be encouraged.
17. For the industry to thrive sustainably, integrated research on nutrition, swine growth, disease, marketing, waste management, pollution, and food safety is crucial.

## 9. Conclusions

In recent years, Vietnam's livestock farming has undergone significant changes, marked by a gradual increase in livestock numbers despite a decline in the number of households raising animals. The growing demand for animal-derived food, both domestically and internationally, presents opportunities for the continued expansion of livestock production. With younger generations embracing new technologies, there is an expectation that sensors, IoT, robotics, etc., will modernize and automate swine production, enhancing productivity and quality for export markets. However, challenges such as disease transmission, market volatility, and environmental pollution from farm waste must be addressed through sustainable practices and evidence-based decision-making. The application of sensor driven data for predictive analysis and decision-making is expected to increase the technical efficiency of Vietnamese swine farms in the future. To achieve that, Vietnam must embrace technological innovations for livestock farms. Additionally, a comprehensive swine development policy is crucial, focusing on integrated production systems, good agricultural practices, biosecurity measures, environmental sustainability, contract farming, and cooperative breeding facilities. The Vietnamese government is anticipated to provide support through incentives and policies promoting the adoption of smart farming tools and sustainable practices.

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