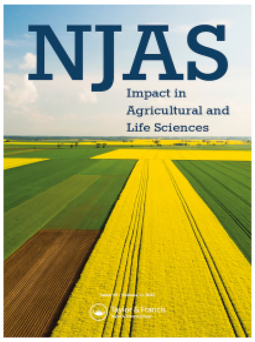


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# Socio-environmental systems in technology adoption in animal husbandry in South-East Asia: A framework synthesis approach

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**ABSTRACT**
In agriculture innovation adoption research, socio-institutional and environmental factors are often not addressed. This study employed a framework synthesis approach to identified factors affecting the smallholders' decision-making in innovation adoption in animal husbandry in South-East Asia (SEA) and unravelled the interactions between these factors. First, we composed an initial framework based on worldwide reviews on (agriculture) innovation adoption. Next, we conducted a systematic review and identified 19 adoption factors: 7 individual, 6 socio-institutional, and 6 environmental factors. These factors were subdivided into 58 subfactors and scored both absolutely and relatively on their influence on farmers' decision-making processes. At the individual farmers' level, human and social capital subfactors with high importance were skills and knowledge, education, access to training, and being a member of a farmer group. At the socio-institutional level, learning platforms (extension services and training) were moderately important. These subfactors were interrelated and influenced by other factors, like age and culture. Important innovation characteristics affecting farmers' motivation for innovation adoption were benefits, price, and compatibility. Highly important (sub) factors that contributed to the financial capital of farmers at the socio-institutional level, are the provision of grants, incentives, and loans. Water, soil condition, and climate risk were highly important environmental pressures affecting farmers' innovation adoption. Finally, we synthesized the factors with (high) importance into the Framework for Innovation Adoption of Animal Husbandry Farmers in SEA (FIFSEA[1]). The FIFSEA can help stakeholders to understand the complexity of innovation (dis)adoption and to guide actions and develop strategies for technology transfer.

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[1]The Framework for Innovation Adoption of Animal Husbandry Farmers in SEA.

**KEYWORD** Animal husbandry; socio-institutional factors; socio-environmental system; South-East Asia; innovation adoption factors

## 1. Introduction

The demand for animal protein from products such as dairy, meat, and fish is increasing in the global south (Michalk et al., 2019), including South-East Asia (SEA[2]), defined here as the region including Vietnam, Thailand, Laos, Cambodia, Indonesia, and the Philippines. As a consequence, animal production is rapidly increasing and shifting to more intensive systems, which have been causing acute environmental degradation (Goldstein et al., 2022). In recent years, animal husbandry has been linked to emerging diseases, global warming, environmental pollution, and continuing food insecurity and deprivation due to the competition for resources between human food and animal feed (Ahuja, 2013). Animal husbandry at larger scales can also lead to deforestation and encroachment into wildlife habitats, increasing contact rates between humans, domesticated animals, and wildlife that may carry infectious disease (Goldstein et al., 2022). SEA's livestock sector is also relatively less efficient than other regions because smallholders who account for more than a quarter of total livestock production in the region – have higher emissions per unit livestock holdings (ACIAR, 2022; Salmon et al., 2020). Conventional animal farming in SEA often led to eutrophication, acidification, and deforestation (Higgins et al., 2019). The manure produced by livestock is reaching millions of tons a year and this often leads to negative environmental effects by increasing nitrogen loads and GHG emissions, excess fertilization (especially in agricultural areas), and pollution of water bodies (Mouri & Aisaki, 2015). Animal farming is therefore aiming to increase its production sustainably (Khoiriyah et al., 2020; Muller et al., 2017; Scholten et al., 2013).

Smart farming is currently being promoted to animal farmers in rural areas, because it supports sustainability (Köksal & Tekinerdogan, 2019). Smart farming technology aims for plants and/or animals to receive the treatment that they need, determined with great accuracy by utilizing a collection of technologies including the Internet of Things (IoT), sensors, robotics, management information systems, and cloud computing. This is used to support operational decision-making on farms (Köksal & Tekinerdogan, 2019). Examples are technologies such as automatic oestrus detection systems, inline milk metres, electronic cow identification systems, and herd management software. These technologies are currently used in developed countries to monitor parameters at an individual cow level, to increase production efficiency and performance of dairy farms (Gargiulo et al., 2018), and

[2]South-East Asia.

contribute to the efficient production of animal protein. This reduces the environmental impact of animal production, especially concerning GHG emissions and nitrogen and phosphorus levels in manure and subsequent release to the environment, thus supporting climate-smart practices (Blok & Gremmen, 2018; Mutune & Nunow, 2018; Sadeghi et al., 2023). Beyond the farm level, the use of smart farming can support more sustainable land use and prevent disease outbreaks in animal farming, e.g. using sensor data to improve animal health management (Hogeveen et al., 2021; Tesfa & Mekuriaw, 2014). Meanwhile, in developing countries, such technology is less utilized. So far most of the agriculture-related mobile services available in the developing world are only offering simple functionalities due to limitations in available delivery technologies such as web and platform apps. Yet, rapidly evolving mobile technologies may soon change that situation (Baumüller, 2017; Budiman & Alta, 2022)

The introduction of smart farming needs engagement with local stakeholders in SEA (Zheng et al., 2016). This technology transfer is dependent on stakeholders' (especially farmers') acceptance of innovations (Ronaghi & Ronaghi, 2021). Factors influencing the acceptance decision include individual factors and socio-institutional factors. Individual factors are aspects related to technology users (farmers), such as farmers' knowledge and attitudes towards technology (Adnan et al., 2019). Socio-institutional factors refer to broader aspects outside the individual control of users. This includes technology promotion, such as the provision of training, policy support, institutional contexts (local groups, etc.) (Scholten et al., 2013) and social system and contexts (religion, cultural practice, risk attitudes), which affects farmers' perception of innovation (Lisson et al., 2010). The social system is the patterned network of relationships constituting a coherent whole of activities, individuals, groups, and institutions (Parsons, 1991; Rice & Aydin, 1991).

Socio-institutional factors in innovation adoption in SEA animal farming are not well studied (Houben, 2014; Thapa & Gaiha, 2011). Reviews about the adoption of technologies related to animal farming are mainly focused on regions outside SEA (Guerin & Guerin, 1994; Kebebe, 2019; Klerkx et al., 2019; Niles et al., 2019; Njisane et al., 2020; Pathak et al., 2019; Pierpaoli et al., 2013; Teno et al., 2018; Tey & Brindal, 2012; Ugochukwu & Phillips, 2018). Pathak et al. (2019). and Pierpaoli et al. (2013). reviewed case studies from Western countries, Nigeria, Iran, and Brazil. Tey & Brindal (2012) reviewed case studies from Australia and the USA, and Ugochukwu & Phillips (2018) and Klerkx et al. (2019). combined different case studies from multiple countries outside SEA. In these reviews, there was not much attention to the diversity in the socio-cultural context in different regions, where local networks and institutions play a much larger role (Pathak et al., 2019; Tey &

Brindal, 2012; Ugochukwu & Phillips, 2018). For example, in Indonesia, the average number of cattle managed by small farmers is only 2–3 cows, while in developed countries such as (West) Europe, small farmers manage around 100 cows (Hemme & Otte, 2010). Compared to commercial farmers, smallholders in SEA also often have more complex constraints, such as a lack of access to knowledge, lack of capital, and lack of incentive for technology adoption (Pathak et al., 2019; Thapa, 2010). Also, most studies on technology adoption in animal farming do not consider the impact of the social system as a whole (Klerkx et al., 2019), and often concentrate on individual adoption factors (Caffaro et al., 2019; Pierpaoli et al., 2013). For example, Pierpaoli, et al. (2013). and Tey & Brindal (2012) analysed adoption factors as separate factors, i.e. they did not consider a systemic perspective. As a result, little is known about social system factors, such as the role of (rural) stakeholders' networks, cooperation/conflict among them (Pathak et al., 2019), and interaction between different adoption factors that have various possible effects on different adoption decisions (Ayele et al., 2012; Fisher et al., 2000).

Therefore, the aim of this study was to identify and synthesize factors that affect the decision-making process of smallholders in innovation adoption in animal husbandry in SEA, and to unravel the interactions between these factors.

## 2. Materials and methods

This study applied the framework synthesis approach (Brunton et al., 2020; Carroll et al., 2013; Ritchie et al., 2014) to critically appraise relevant frameworks and concepts, to identify key factors that affect the decision-making process of farmers in adopting (technological) innovation. The framework synthesis approach consisted of three parts: 1) composing an initial framework, 2) performing a systematic literature review on adoption factors in SEA and 3) synthesizing factors into a new framework specific for animal husbandry in SEA.

### *2.1. Composing the initial framework*

First, we composed the initial framework by integrating the decision-making processes on innovation adoption from Rogers 2010), (Ugochukwu & Phillips (2018), and Pathak et al. (2019). (Figure 1). In the previous reviews (Klerkx et al., 2019; Pathak et al., 2019; Pierpaoli et al., 2013; Shang et al., 2021; Tey & Brindal, 2012; Ugochukwu & Phillips, 2018) on innovation adoption processes and adoption factors in (animal) agriculture, we found that most of the concepts were built on the theory

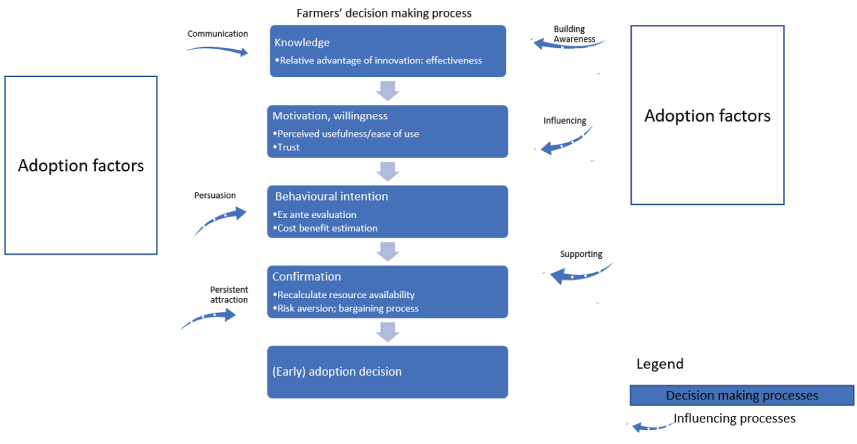


**Figure 1.** The initial framework on innovation adoption decision (making) process as adapted from Ugochukwu and Phillips (Pierpaoli et al., 2013), Rogers (Fisher et al., 2000), and Pathak et al. (2019).

of diffusion of innovation and decision-making processes in innovation adoption by Rogers (2010).

For Rogers (Rogers, 2010), the innovation-decision process involves five steps: (1) knowledge transfer, (2) persuasion, (3) decision, (4) implementation, and (5) confirmation (of adoption). These stages typically follow each other in a time-ordered manner. Ugochukwu and Phillips (Ugochukwu & Phillips, 2018) further developed Rogers' framework by elaborating the decision-making processes. They argue farmers' intention is influenced by their evaluation of *ex-ante* benefits and costs of innovation, and farmers' motivation is influenced by adoption factors such as characteristics of new technologies. Then, we added additional features from Pathak, et al (Pathak et al., 2019). to the framework by Rogers and Ugochukwu and Phillips (Ugochukwu & Phillips, 2018). Pathak, et al (Pathak et al., 2019). adapted the Model of Determinants of Diffusion, Dissemination, and Implementation of Innovations (MDDDII[3]). MDDDII includes features such as communication, influence (information availability and communication pathways), and linkage (connections between the parties associated with the innovation) which are likely to influence adoption.

## 2.2. Systematic literature review

Second, we systematically examined the literature to identify and classify factors influencing farmers' decision-making processes in SEA. We scored the identified adoption factors using absolute and relative scoring systems to determine the importance degree (level) of the factors. Then, we

[3]The Model of Determinants of Diffusion, Dissemination, and Implementation of Innovations.

**Table 1.** PICO-based inclusion criterion in screening search results.

| |
|---|
| Included if |
| Population: Animal farmers, smallholders, rural/livestock stakeholders |
| Intervention: The topic is technology adoption in animal farming (e.g. dairy, inland fishery) and mixed farming system[4] |
| Comparison: To compare different factors and (social) aspects that affect technology adoption<br>• Adoption factors by farmers (not adoption impact)<br>• Social theories, stakeholders/farmers' behaviour/behaviour change, systemic approach, etc. |
| Empirical papers with case studies located in South-East Asia (SEA) |
| Year of publication after 2000 |

connected the innovation adoption factors from SEA with the initial framework and synthesized them in a framework specific for innovation adoption in SEA.

### 2.2.1. Study selection

The systematic literature review (Dewey & Drahota, 2016) started with determining search terms based on the research question and in consultation with two librarians. The search terms were: 1. Animal farming, 2. Technology adoption, and 3. Social system; and synonyms or similar related topics. We used Boolean operators, the wildcard technique, and the Proximity operator in formulating the search queries:

(″animal farm*′ OR ′inland fisher*″ OR "dairy farm*" OR "livestock agricult*" OR "livestock product*" OR "animal product*") AND ("technology W/3 adopt*" OR "technology W/3 uptak*" OR "technology W/3 diffus*" OR "technology W/3 transf*" OR "technolog* W/3 disseminat*" OR "adoption W/3 barrier" OR "adoption W/3 fact*" OR "uptake W/3 barrier" OR "innovation W/3 adopt*" OR "uptake W/3 fact*") AND ("institution" OR "mechanis*" OR "organizat*" OR "act" OR "stakehold*" OR "farmer" OR "peasan*" OR "socio-technical system" OR "socio-technical transition*" OR "farmer behavio*")

The query was used in May 2022, in Scopus and Web of Science to guarantee quality records and adequate and efficient coverage for the topic (Bramer et al., 2017). The flow scheme of the search and screening process is as follows:

The titles and abstracts of the 1,673 records identified in Scopus and Web of Science were screened by the first author (IB), based on inclusion criteria adapting the PICO (Population, Intervention, Comparison) system (Eriksen & Frandsen, 2018) (Table 1). This resulted in 25 articles on animal husbandry in SEA. Next, the full text of the 25 articles was assessed on compatibility with our research objective. We evaluated whether the articles contained relevant data and information for answering our research question. This resulted in 20 relevant articles, consisting of 11 quantitative

[4]Mixed crop livestock is included because 60–75% of animal products in developing countries come from this farming system. All the 20 selected papers include animals in their case studies of farming systems.

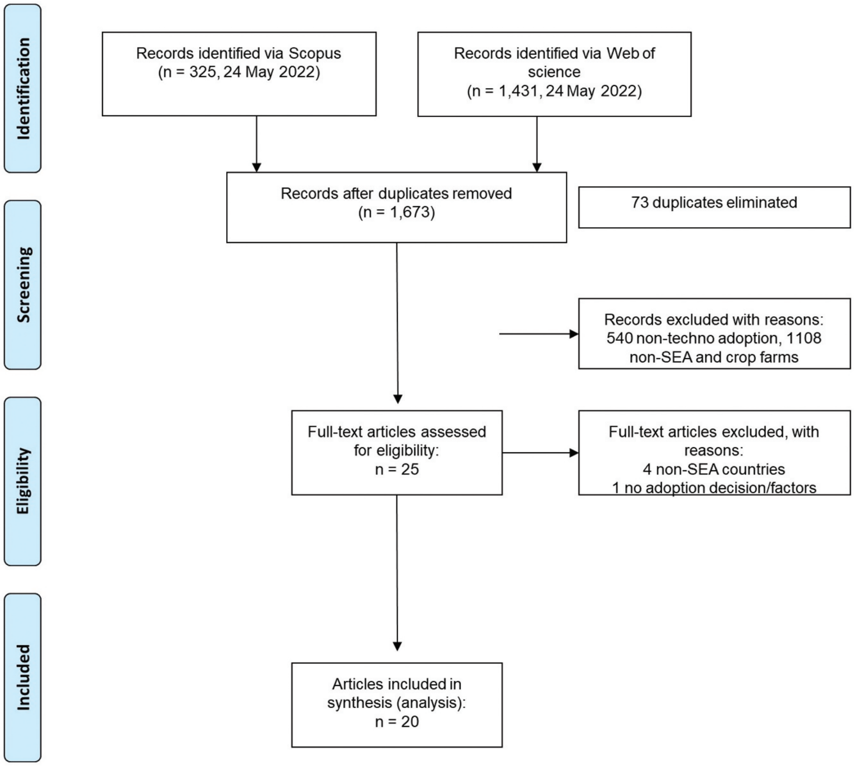


**Figure 2.** Screening process of search results.

studies, 7 mixed-method studies, and 2 qualitative studies. Five articles were excluded because they mixed the analysis with case studies from outside SEA and focused on impact of innovation adoption, not adoption itself (Figure 2).

To ensure the 20 articles are trustworthy, valid and reliable, three authors (IB, MD, AW) conducted a quality assessment, using the appraisal tools from Hong, et al (Hong et al., 2018). The tools focus on methodological criteria and include five core quality criteria for different study designs: (a) qualitative, (b) quantitative and (c) mixed methods. Each author scored the articles on a scale from 0–15. The final score was based on consensus by all three authors. Articles required a minimum score of 11 (Hong et al., 2018). As all 20 papers scored 11 or higher, all papers were included (Appendix).

#### *2.2.2. Data analysis*

Analysis of included articles was based on 4 steps: 1) the identification of adoption factors, 2) defining and categorising factors and sub-factors, 3) scoring the sub-factors, and 4) identifying relationships among factors and

**Table 2.** Scoring systems (absolute and relative) for adoption factors identified in 11 quantitative, 7 mixed methods,[5] and 2 qualitative studies.

| | Type of articles | |
|---|---|---|
| | Quantitative studies | Qualitative studies |
| Absolute scoring | • Score 1 for factors with a significant statistical correlation (p-value ≤0.05)<br>• Score 0.5 for factors with lower correlation (p-value 0.06–0.1). | • Score 1 for factors that were most emphasized in the result and discussion section<br>• Score 0.5 for other mentioned factors |
| Relative scoring | Dividing the total absolute score (of a factor) with the number of papers that mention the factor | |

with the decision-making process. Each paper was analysed by three authors (IB, MD, AW) and discussed until consensus was reached.

The first step was the identification of adoption factors by extensive reading of the 20 articles. Adoption factors were defined as activities or aspects influencing the decision-making process of farmers in adopting innovation or technology. Content analysis (Gaur & Kumar, 2018) was used to 1) Identify the adoption factors and 2) Identify relationships among factors and how those factors influence decision-making processes (explained in the last step).[5]

The second step was redefining and categorising factors, based on comparing the names and definitions of factors. Since several factors overlapped, we (re)defined and renamed factors. In case factors were related – based on the definitions – we grouped them as sub-factor under one factor. For example, customs and religion were merged into local knowledge/practices. Local knowledge, language, and norms are sub factors to the factor culture. Next, we categorized the factors and subfactors into three categories: individual, socio-institutional, and environmental. The categorisation was based on an iterative process comprising reading, interpreting, and summarising the data, and on reflecting on categorisation in previous reviews (Klerkx et al., 2019; Pathak et al., 2019; Pierpaoli et al., 2013; Shang et al., 2021; Tey & Brindal, 2012; Ugochukwu & Phillips, 2018).

The third step was quantifying the identified (sub) factors by scoring them with absolute and relative scoring systems (Table 2). The absolute score was calculated by accumulating the scores of factors in the 20 articles. The absolute scoring system was applied differently for quantitative and qualitative studies. In quantitative studies, it was based on the strength of the statistical correlation between factors and farmers' technology adoption decisions. In qualitative studies, it was based on the emphasis on the factors in the result/discussion sections. This assessment was done by three authors

[5]For mixed method studies, the scoring system followed the approach for quantitative studies because the adoption factors were found in the quantitative part of the articles.

(IB, AW, MD). Differences between scores were discussed among authors until consensus was reached.

Relative scoring was calculated using the formula:

$$\text{Relative score} = \text{Absolute score} \div \text{Number of papers mentioning the factor}$$

For example, the absolute score of factor technology benefit is 8, then 8 is divided by the number of papers that mention the factor. The number of papers is 9, then the relative score of factor A is $8 \div 9 = 0.88$.

The absolute and relative scores were used to determine the importance of each factor: high importance, moderate importance, arguably low importance, and very low importance. We combined the absolute and relative scoring systems to strengthen the analysis. The use of absolute scores only might result into bias as important factors were potentially ignored or omitted because subsequent studies repeatedly examined a similar set of variables in line with pioneering studies. The use of only relative scores might not an accurate reflection of the importance of the factor.

Factors were classified using the quartile (Q) approach, where the score distribution of each scoring system is divided into quartiles (absolute score 0.5–8; relative score 0.5–1). The quartile approach was used to ensure that the importance classification was not affected by extreme values/highest scores (Langford, 2006). Next, the relative and absolute scores were combined as follows:

(1) Factors with high importance: factors that were found very significant or important in many articles. The relative score is in $4^{th}$ quarter (1) and the absolute score in $3^{rd}$ and $4^{th}$ quarter (3-8)
(2) Factors with moderate importance: factors that were found significant or important in several articles. The relative score is in $3^{rd}$ quarter (0.9-0.99) and the absolute score in $3^{rd}$ and $4^{th}$ quarter (3-8).
(3) Factors with arguably low importance. The relative score is in $2^{nd}$ quarter (0.6-0.89) and the absolute score is in $3^{rd}$ and $4^{th}$ quarter (3-8)
(4) Factors with very low importance. Both scores in the 1st quarter (absolute score 0.5-2 and relative score 0.5-0.59)

## 2.3. A new framework

To synthesize the new framework, we identified relationships among (sub) factors and how factors influence decision-making processes in technology adoption. Based on empirical evidence and the discussion sections of the papers, we studied for each (sub)factor its relation with other factors and with decision-making processes.

We adapted the socio-ecological model in understanding the relationships. Bronfenbrenner's Development Ecology model provides a tool for understanding the encounter between societal, organisational and individual dimensions, a continual meeting point where phenomena and actors occur on different levels, including those of the organisation and society at large (Christensen, 2016). This theory has been developed further in the context of (digital) technologies (Navarro & Tudge, 2022). In this study, we adapt it to the context of agriculture technology.

We visualised the relationships among factors and with decision-making processes in simple maps, using Vensim software (García, 2020). These simple maps were compared and interpreted based on similarities and differences in relationships between factors, and reviewed several times by all authors until consensus was reached. The factors and the relationships were unified with the initial framework, resulting in a final framework, the Framework for Innovation adoption of animal husbandry Farmers in SEA or FIFSEA (Figure 3).

## 3. Results

Our review identified 20 articles: six articles from Indonesia, six from Vietnam, three from Lao, two from Thailand, two from the Philippines, and two from Cambodia. The articles include innovations and technologies such as biosecurity measures (Lestari et al., 2012), forage improvement (Lapar & Ehui, 2003; Lisson et al., 2010; Monjardino et al., 2020), cleaning and disinfection (C&D), vaccination (Pramuwidyatama et al., 2020), biogas (Ly et al., 2015; Putra et al., 2019), artificial insemination (Sirajuddin et al., 2018), stock enhancement (Garaway et al., 2006), ultraviolet light C system (Makarapong et al., 2020), good agriculture/animal husbandry practices (H. G. Hoang, 2020; Nguyen et al., 2020), mixed crop and animal (circular) productions (Mak, 2001; Moglia et al., 2020; Nhan et al., 2007; Phuong et al., 2019; Sambodo & Nuthall, 2010; Simelton et al., 2017), and semi-intensive ponds/nurseries (Baticados et al., 2014; Richardson & Suvedi, 2018) (Appendix).

From those articles, we found 19 factors and 58 sub-factors affecting technology adoption in animal husbandry in SEA. We grouped the factors into three broad categories: individual, socio-institutional, and environmental (Table 3).

In the following sections, we discuss the (sub)factors with high and moderate importance and their interaction with other (sub)factors in affecting farmers' decision-making processes. The effects can be as drivers or barriers to innovation adoption, depend on (local) context. The key factors and their interactions are visualised in the Framework for Innovation adoption of animal husbandry Farmers in SEA (FIFSEA) (Figure 3). The Figure shows the (interaction between) factors affect the four stages of the decision-making process of innovation adoption: 1) formation of knowledge, 2) motivation building, 3) having intention, and 4) confirmation before adoption. For readability, we structure this section into four sub-sections: human and social capital, financial capital, innovation characteristics, and environmental pressures.

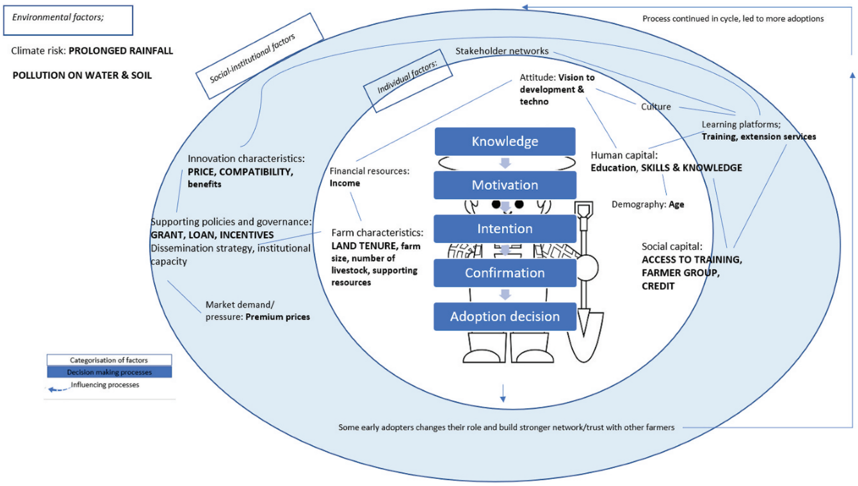


**Figure 3.** Socio-environmental system affecting farmers' innovation adoption in South-East Asia, factors on the right side are related more to human capital and social capital; factors on the left side are related more to financial capital. (bold and CAPITAL = highly important factor; bold is the moderately important factors).

### *3.1. Human and social capital*

At the individual or farmers' level, the key human and social capital subfactors are skills and knowledge, education, access to training, being a member of a farmer group and vision for development. At the socio-institutional level, learning platforms such as extension services and training stand out for their importance. These subfactors are interrelated and are influenced by the demographic subfactor age and by the factor culture.

Farmers with more education, skills, and knowledge about innovation and technology have higher innovation adoption rates as they show information-seeking behaviour: they actively look for learning platforms, and technologies that can advance their farms (Putra et al., 2019). This is illustrated by research in Indonesia, where higher-educated farmers more often adopted measures against highly pathogenic avian influenza in broiler farms (Pramuwidyatama et al., 2020) and artificial insemination programmes in cattle farms (Sirajuddin et al., 2018). In Vietnam, higher educated farmers more often adopted good agricultural practices in cattle farms (H. G. Hoang, 2020). More skilled and knowledgeable farmers are often younger than those with less skills and knowledge (G. H. Hoang, 2020). Also, having education, knowledge and skills influences farmers' attitudes, i.e. vision to development, perception of innovation (Lapar & Ehui, 2003) and intention to adopt new technologies (Nguyen et al., 2020). Hoang (G. H. Hoang, 2020), who conducted research among farmers in Vietnam, concludes that "*the farmers with the vision for development and innovation showed more information-seeking behaviour, willingness*

**Table 3.** Adoption factors affecting innovation adoption in animal husbandry in South-East Asia, (bold and CAPITAL = highly important factor; bold is the moderately important factors).

| Individual factors | | Score | | Socio-Institutional factors | | Score | | Environmental factors | | Score | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Factor | Sub factor | Absolute | Relative | Factor | Sub Factor | Absolute | Relative | Factor | Sub factor | Absolute | Relative |
| Human Capital | **Education** | 7.5 | 0.93 | Innovation characteristics | **PRICE** | 4 | 1 | **CLIMATE RISK** | **HEAVY AND PROLONGED RAINFALL** | 3<br>1 | 1<br>1 |
| | **SKILLS, KNOWLEDGE** | 3 | 1 | | Availability observability | 2.5 | 0.83 | | Drought | | |
| | (Farming) experience | 1.5 | 0.75 | | Practicality/Usability | 1 | 1 | | | | |
| | | | | | **Benefits** | 8 | 0.88 | | | | |
| | | | | | **COMPATIBILITY, TRIALABILITY, CREDIBILITY** | 4 | 1 | | | | |
| Demography | **Age** | 5.5 | 0.91 | Learning platforms | **Training offered** | 5.5 | 0.91 | **LAND/SOIL DEGRADATION** | **SOIL DEGRADATION** | 4<br>1 | 1<br>1 |
| | Women Support | 2 | 1 | | **Extension services, peer learning** | 8 | 0.96 | | Land scarcity | | |
| | Gender | 2 | 0.66 | | Social care/ counselling | 1 | 1 | | | | |
| | Family size, support | 2.5 | 0.83 | | | | | | | | |
| | Household needs, future orientation: income, food | 3.5 | 0.875 | | | | | | | | |
| Culture | Norms | 1 | 1 | Providing (consultancy) services | Facilities for maintenance (M&E) | 0.5 | 1 | Pollution | **WATER POLLUTION** | 5<br>0.5 | 1<br>1 |
| | Local knowledge/practices | 4 | 0.75 | | Veterinary services | 2 | 1 | | Air pollution | | |
| | Language | 1 | | | | | | | | | |

(*Continued*)

**Table 3.** (Continued).

| Individual factors | | Score | | Socio-Institutional factors | | Score | | Environmental factors | | Score | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Factor | Sub factor | Absolute | Relative | Factor | Sub Factor | Absolute | Relative | Factor | Sub factor | Absolute | Relative |
| (Financial) capital | **Income** | 7.5 | 0.93 | Policies and governance of technology transfer | Mandates, regulations (food, health, environment) | 2.5 | 0.83 | Species scarcity | | 2 | 1 |
| | Assets/ownership (including ICT tools) | 1.5 | 0.5 | | **FINANCIAL INCENTIVES, GRANT** | 3 | 1 | | | | |
| | | | | | Dissemination strategy: marketing, experimentation | 3 | 0.75 | | | | |
| | | | | | Politics | 0.5 | 1 | | | | |
| | | | | | **PROVISION OF LOAN/ INVESTMENT** | 4 | 1 | | | | |
| | | | | | Building capacity of local/institution, institutional arrangements | 8 | 0.8 | | | | |
| Social capital (access to networks) | **ACCESS TO FINANCIAL SUPPORT** | 3 | 1 | Creating market demand/ pressure (local/ international) | **Premium price for animal products** | 5.5 | 0.91 | Vegetation issues | Pest | 1 | 1 |
| | **ACCESS TO TRAINING**, experimentation, experts | 7 | 1 | | Market orientation | 0.5 | 0.5 | | Diseases | 1 | 1 |
| | **BEING MEMBER OF FARMERS' GROUPS**, other households | 7 | 1 | | | | | | | | |

(*Continued*)

**Table 3.** (Continued).

| Individual factors | | Score | | Socio-Institutional factors | | Score | | Environmental factors | | Score | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Factor | Sub factor | Absolute | Relative | Factor | Sub Factor | Absolute | Relative | Factor | Sub factor | Absolute | Relative |
| Farm(ing) characteristics (management, technical, cost) | Farm income | 2 | 1 | Stakeholder network/ dynamics | Cooperation | 8 | 0.83 | Ecosystems | Landscape | 1 | 1 |
| | Time availability/concern | 1 | | | Partnership (with successors) | 2 | 1 | | Elevation | 1 | 1 |
| | **Farm size, number of livestock** | 8 | 0.9 | | | | | | | | |
| | **LAND TENURE** | 3 | 1 | | | | | | | | |
| | Farm system/types (diversity); layout; business/marketing management; confinement | 0.5 | 0.5 | | | | | | | | |
| | Farm location, distance from home/dealer/buyer | 4 | 0.7 | | | | | | | | |
| | **OTHER SUPPORTING RESOURCES (FACILITIES, TECHNOLOGY, LABOUR)** | 4 | 1 | | | | | | | | |
| Attitude | **Vision for development** | 7.5 | 0.93 | | | | | | | | |
| | Perception to sustainability | 2.5 | 0.83 | | | | | | | | |
| | **Perception of technology advantage** | 7.5 | 0.93 | | | | | | | | |

*to expand their farms and adopt new technologies. As a result, they put more effort into having a high number of animals, possessing a large farm, and gaining a higher income*" (p. 158).

Having skills and knowledge and having access to farmers' groups and extension services are mutually reinforcing factors. Farmers benefit from farmer groups and extension services as these networks provide them with access to knowledge and training about innovation (Bantilan & Padmaja, 2008; H. G. Hoang, 2020; Nguyen et al., 2020; Nhan et al., 2007). Participation in farmers' groups and training creates positive attitudes and confidence to adopt technologies (Baticados et al., 2014; Ly et al., 2015; Makarapong et al., 2020; Moglia et al., 2020). In SEA, extension services are usually supplied by the government. They are important for the uptake of innovation, not only as they provide skills and knowledge (Bantilan & Padmaja, 2008; H. G. Hoang, 2020; Lapar & Ehui, 2003; Nguyen et al., 2020; Nhan et al., 2007), but also because they provide the opportunity to experiment with new technologies (Lisson et al., 2010; Mak, 2001), to learn from successors (farmers who have already adopted the innovation) (Makarapong et al., 2020; Nguyen et al., 2020), to strengthen the network among farmers, government officials, entrepreneurs, and experts (Budiman & Smits, 2020; Garaway et al., 2006; Putra & Pedersen, 2018; Putra et al., 2019) and to gain access to financial support, such as grants, incentives and loans (H. G. Hoang, 2020; L. T. H. Phuong, G. R. Biesbroek, L. T. H. Sen, & A. E. J. Wals, 2018; Phuong et al., 2019).

Experimentation provides farmers with an option to test innovation on their farms. In the literature, there are multiple examples, including Indonesia, where two years of experimentation with forage improvement technologies provided farmers the opportunity to evaluate the technologies' performance and to demonstrate and communicate how to use the technology. To gain local farmers' trust, the experimentation was a cooperation of technology promotors, NGOs, and local organisations (Ismail et al., 2019; Lisson et al., 2010). Likewise, in Cambodia, the experimentation process with a mixed crop-livestock system, was a joint learning process to continuously match the technology to the farm(ers) social circumstances (Mak, 2001). Experimentation helped to select the right timing and the proper language for technology promotion (Mak, 2001) and supported a change in farmers' perceptions about innovation (Phuong et al., 2019).

Successors are crucial in the transfer of innovations. They have real-life experience with innovation (Makarapong et al., 2020) and therefore motivate other farmers to trust and adopt new technology. This was demonstrated among household pig production farmers in Vietnam (Nguyen et al., 2020): the presence of successors – who were well-trained in Good Animal Husbandry practices (GAHP) – enhanced GAHP adoption rates significantly. A younger age of successors facilitated communication and feedback loops between extension services and farmers (H. G. Hoang, 2020). Feedback loops occurred when farmers (adopters) took part in activities to promote innovation, for example that farmers became intermediaries or trainers (Nguyen et al., 2020; Shimahata et al., 2020) and/or started working for extension services. Farmers who fulfilled the role of intermediary had a positive influence on other farmers to adopt innovation (Pathak et al., 2019). The feedback loop is visualised in Figure 3 as it strengthens the system for (future) technology adoption.

For extension services to be successful, stakeholder engagement is required (Budiman & Smits, 2020; Garaway et al., 2006; Makarapong et al., 2020; Putra & Pedersen, 2018; Putra et al., 2019). In Lao, the villages that had a partnership with the government fisheries department had access to extension services, including skilful leaders, entrepreneurs, and district government staff (Lestari et al., 2012). As a result, farmers adopted stock enhancement initiatives. Similarly, in Thailand, the cooperation between technology providers and (local) dairy experts resulted in better information about the benefits of Ultraviolet-C technology (Makarapong et al., 2020).

Culture, i.e. norms, local knowledge, and language, also affect farmers' innovation uptake, especially related to extension services (Razavi, 2009). Information from extension services was not always well accepted. For example, in Vietnam, farmers with conservative people in their network did not adopt innovation technology (L. T. H. Phuong, G. R. Biesbroek, L. T. H. Sen, & A. E. J. Wals, 2018; Phuong et al., 2019). The inclusion of local knowledge and local people in designing extension services can be valuable (Moglia et al., 2020; Sambodo & Nuthall, 2010; Sirajuddin et al., 2018), as shown in Lao, where the local perspective on gendered roles resulted in teaching women about non-farming practices such as financial management, while men were taught about farming practices (Moglia et al., 2020; Sambodo & Nuthall, 2010).

### *3.2. Financial capital*

Important (sub)factors that contribute to the financial capital of farmers at the individual level are land tenure, other supporting resources (facilities and labour), farmers' income, and family size. At the socio-institutional level, key factors include the provision of grants, incentives, and loans.

Land tenure relates to the relationship that farmers hold with respect to land, e.g. land rights. In general, farmers who have land ownership more often adopt new technologies and have other supporting resources – like facilities, technologies and labour – compared to farmers who do not own land (Nhan et al., 2007). This is shown in the Philippines, where land ownership helped farmers to utilise mangroves for aquaculture of their mud crab ponds (Baticados et al., 2014). Moreover, farmers with land ownership often have larger farms and livestock and more often are high-income farmers, who can take the risk of failure of innovation (Moglia et al., 2020). This is shown in cattle farming in Vietnam, where farmers with land holdings and high number of livestock have a more stable income, own information communication technology tools, and adopted good agriculture practices.

Family size and (future) household needs relate to farmer's (financial) preparedness to invest in innovation, either positively or negatively. Lestari, et al (Lestari et al., 2012). found that farmers in Indonesia with smaller families were more willing to adopt biosecurity in laying hen husbandry as they had less expenses for their families. On the other hand, Ly, et al (Ly et al., 2015). and IndoDairy (IndoDairy, 2020) found the opposite: Vietnamese and Indonesian farmers with large families had a higher probability of technology adoption, as it saves time. In Cambodia, the need for a higher income among farmers with larger families, facilitated the adoption of a mixed crop-livestock system (Mak, 2001).

Financial support, either provided by the government or market, influences the uptake of innovation. The general assumption is that farmers with access to grants, incentives or loans have increased financial capability to adopt technologies (Phuong et al., 2019). However, farmers' adoption-decisions related to financial support differ and is not uniformly positive, as explained below.

Grants provide free or highly subsidised technologies to farmers (Budiman & Smits, 2020) and usually are provided by governments in collaboration with NGOs, research institutions, universities, and farmer's cooperatives (Putra & Pedersen, 2018). It is argued that grants sometimes lead to temporary or pseudo-adoption behaviour. Farmers adopt the technology while it is free or provides benefits like credit, prestige, or training. They dis-adopt the innovation later on, since farmers are not really motivated to develop their farms (IndoDairy, 2020; Kiptot et al., 2007). This was the case in an aquaculture technology project in Cambodia, where start-up materials such as fingerlings, fish feed and lime were subsidized. When the subsidies were ended, 20% of farmers dis-adopted those technologies (Richardson & Suvedi, 2018).

Market incentives include bonuses on performance and premium prices on products, provided by collaboration between farmers' enterprises, agricultural extension associations, businesses, and technology providers (H. G. Hoang, 2020; Richardson & Suvedi, 2018). In most cases, the provision of a bonus and premium prices had positive impacts on adoption behaviour. In Indonesian broiler farms, the bonuses (rewards) on performance in improving productivity, resulted in an increased motivation and intention of smallholders to adopt vaccination and Cleaning and Disinfection (Komaladara et al., 2018; Pramuwidyatama et al., 2020). In Vietnam, the application of premium prices to beef had a positive impact on farm income and encouraged farmers to adopt good agriculture practices and mixed crop-livestock systems

(H. G. Hoang, 2020). In the Philippines, premium prices on livestock products were given to farmers who adopt dual-purpose forages (Lapar & Ehui, 2003) and smallholders who adopt mud crab nurseries (Baticados et al., 2014). The dual-purpose forages increased the quality of livestock products thus making them eligible for premium prices (Lapar & Ehui, 2003).

Farmers who participated in loan programmes are in a better position to adopt innovation than those who did not take part in these programmes. In Vietnam, participation in (government) loan programmes was positively associated with beef cattle farmers' adoption of good agriculture practices (G. H. Hoang, 2020; Makarapong et al., 2020). In the Philippines, the provision of loans together with training and marketing assistance by the local governments supported adoption of mud crab nursery among smallholders (Baticados et al., 2014).

### *3.3. Innovation characteristics and dissemination*

Important innovation characteristics affecting farmers' motivation for innovation adoption are benefits, price, and compatibility. These factors attract farmers to the innovation, but only in case these innovation characteristics are known by farmers and thus, are delivered to farmers through dissemination strategies.

Benefits or relative advantages (of technology) – especially its effectiveness and its value for money – are crucial in the uptake of innovation. Garaway, et al (Garaway et al., 2006). lists the benefits experienced by farmers in Lao: "*farmers adopted fish stock enhancement due to its multiple benefits; a cheap source of good quality fish, increased community income, improved community services, a catalyst for institutional change, and payment (in fish or cash) for communal harvesting and marketing*" (p.40). Another example comes from Thailand, where dairy farmers adopted ultraviolet light C systems as it helped farmers to control microorganism growth in raw milk after milking (Makarapong et al., 2020). In Indonesia, broiler farmers adopted routine cleaning and disinfection, and vaccination due to their time-saving prevention and control scenarios (Pramuwidyatama et al., 2020) and the ICT tools of cattle farmers in Vietnam helped them to find information easily and to communicate with technology promotors, extension services, and other stakeholders (Baticados et al., 2014).

The price of technology is an important consideration for farmers' intention to adopt technology. In Lao, Moglia, et al (Moglia et al., 2020). found that access to a fair price for innovation had a strong association with farmers' motivation to adopt a mixed crop-livestock system. Farmers consider not only the technology costs, but also the cost of after-sale services such as maintenance and veterinarian service. In Indonesia (Pramuwidyatama et al., 2020) and Vietnam (Nguyen et al., 2020), the cost of technology and after-sale services were combined in one price and it triggered farmers' interest in the waste treatment system (Nguyen et al., 2020) and vaccination (Pramuwidyatama et al., 2020) as they saw them as important warranties. Also, farmers evaluate the costs of the innovation in relation to other factors, such as the benefits of the technology, their (future) household needs, and their financial resources, like for example income and other resources (Richardson & Suvedi, 2018).

Good technology compatibility, i.e. the ability of the technology to perform or be compatible in the user (farmers') environment, affects farmers' perception on usefulness of the technology (Pathak et al., 2019). This was demonstrated in the adoption of multiple technologies in dairy farms in Thailand (Makarapong et al., 2020; Panmethis & Islam, 2016). Farmers adopted alternative protein sources and artificial insemination (AI) due to their good compatibility; both technologies matched their needs and were safe and easy to use (Panmethis & Islam, 2016).

Farmers receive information about innovation characteristics (price, compatibility, benefits) through dissemination strategies. As such, dissemination strategies and stakeholders involved, e.g. technology providers, government, extension services, and farmers groups, are important for innovation uptake (Richardson & Suvedi, 2018) and are related to other factors such as the capacity of (local) institutions (L. T. H. Phuong, Biesbroek, Sen, & Wals, 2018) and institutional arrangements (Budiman & Smits, 2020). In particular, the importance of well-educated extension personnel with skills related to animal farming (Richardson & Suvedi, 2018) was stressed in several papers. In Indonesia, educated workers were employed to promote forage improvement technologies in cattle farms. The workers were committed to working with the households and providing technical assistance and feedback. It strengthened farmers' belief that forage improvement is important and beneficial to them (Lisson et al., 2010). In the promotion of the VACB (V garden/orchard; A fishing farm; C livestock farm; B biogas) system in Vietnam, locals were involved as extension personnel for maintaining cohesion within the local network and to build better trust with farmers (Phuong et al., 2019).

### *3.4. Environmental pressures*

Farmers in agricultural regions with more environmental pressures tend to be more willing to adopt innovation to deal with those pressures (Eder et al., 2017). In SEA, we found water, soil condition, and climate risk as highly important environmental pressures affecting farmers' decisions to adopt innovation.

Water pollution affects the adoption of fish stock enhancement in Laos (Garaway et al., 2006) and Good Animal Husbandry Practices in Vietnam (H. G. Hoang, 2020). Water pollution in Lao rivers made inland fishers adopt stock enhancement by putting fish from a hatchery into a lake with better water conditions. Water pollution increased fishers' awareness of protecting resources such as reservoirs, small ponds, canals, irrigation canals, swamps, and small, seasonal, and inland floodplains (Garaway et al., 2006). In Vietnam, cattle farmers improved the provision of clean drinking water for cattle because of water pollution (H. G. Hoang, 2020). This practice is included in the Vietnamese Good Animal Husbandry Practices (H. G. Hoang, 2020).

Soil conditions affected innovation adoption in the Mekong delta of Vietnam, where farmers in less fertile soils in peri-urban rice-dominated areas were more prone to adopt medium-input fish farming integrated with less intensive fruit production. Soil and water pollution was hypothesized to be caused by the many fish- and feed-processing industries in the peri-urban area. Yet, the existence of the industries brought excellent market accessibility for farmers (Nhan et al., 2007). This shows a trade-off between the soil degradation factor and market accessibility.

Climate change increased the adoption of the VACB system in the Mekong Delta in Vietnam (Phuong et al., 2019). This system helps farmers to adapt their livelihood to prolonged rain and to shift towards sustainable agriculture. Likewise, in the Philippines, farmers moved from mud crab nurseries to ponds, to save their crabs from growth issues and increased mortality rates due to prolonged periods of rain (Baticados et al., 2014).

## 4. Discussion

This study has revealed the interrelated individual, socio-institutional and environmental factors that influence the decision-making process of smallholders in innovation adoption in animal husbandry in SEA. In total, 7 individual, 6 socio-institutional, 6 environmental factors, and 58 subfactors have been identified and scored on their degree of importance. Individual factors with high importance are farmers' skills and knowledge, being members of farmers' groups, and having access to training and financial support. At the socio-institutional level, the factors with high importance are innovation characteristics (compatibility and price) and government financial support (loans and grants). As for environmental aspects, factors with high importance are prolonged rainfall, soil degradation, and water pollution. As part of the framework synthesis approach (Brunton et al., 2020; Carroll et al., 2013; Ritchie et al., 2014), the factors with high and moderate importance were synthesized with the initial framework resulting in a new framework: the Framework for Innovation adoption of animal husbandry Farmers in SEA (FIFSEA).

### 4.1. The added value of FIFSEA

The FIFSEA is based on (sub)factors found in SEA, the relationship among factors and between factors at different levels, and the importance degrees of factors, resulting in a comprehensive framework that can help stakeholders, including farmers, professionals, policy-makers and researchers to understand the complexity of innovation (dis)adoption and the factors relevant for systems change, to guide actions and decisions, and to predict the adoption rate of innovation uptake. The added value of our framework lies in 1) the specific focus on animal husbandry in SEA, 2) the fact that we used a systems approach, 3) the use of a combined absolute and relative scoring system, and 4) the practical use for development practices.

The focus on animal husbandry in SEA adds to the novelty of this study, as previous studies focused on crop production outside SEA and did not include socio-institutional and environmental factors (Adnan et al., 2019; Brown et al., 2021; Shang et al., 2021). Animal farmers tend to have different characteristics and needs compared to crop farmers due to many different field operations (Adesehinwa et al., 2004; Monteiro et al., 2021). We found four subfactors that were not part of previous review studies (Klerkx et al., 2019; Pathak et al., 2019; Pierpaoli et al., 2013; Tey & Brindal, 2012; Ugochukwu & Phillips, 2018), and therefore might be unique for animal husbandry in SEA: farmers groups, dissemination strategy, provision of loans, and capacity of local institutions. In addition, we categorized environmental factors as a new group because these factors impact both individual and socio-institutional factors related to on-farm situations and off-farm situations (Baticados et al., 2014; Garaway et al., 2006; H. G. Hoang, 2020; Phuong et al., 2019). For example, climate risk affects soil degradation and forage production in dairy farming as well as milk quality in milk collection points (Indodairy, 2022). Also, climate change impacts other food production systems like arable farming, potentially increasing the need for dairy products. In previous reviews (Klerkx et al., 2019; Pathak et al., 2019; Pierpaoli et al., 2013; Tey & Brindal, 2012; Ugochukwu & Phillips, 2018), environmental factors were part of the farm characteristics factor. Environmental factors are important for SEA as the region is one of the most vulnerable regions with severe environmental impacts due to climate change and high emissions from animal husbandry (Eder et al., 2017; Otte et al., 2019). The impacts of climate change, such as increasing temperature, erratic rainfall patterns, and drought on smallholders are being increasingly reported in SEA countries (Ismail et al., 2019). Also, emissions from agricultural land, nitrogen, and phosphate from livestock are high in South-East Asia (Habib-Ur-Rahman et al., 2022; Otte et al., 2019).

The FIFSEA framework unravels the key factors and their relationships while taking the complexity of the system into account. This complex system is dynamic as factors (inter)relate and influence each other especially among and between the individual and socio-institutional levels (Ladyman et al., 2013; Schläpfer, 2016). For example, the human capital (skills and knowledge) of farmers was influenced by their social capital (access to learning platforms). Both human capital and social capital influenced their financial capital (income). These factors can individually or together impact farmers' adoption decisions, and often, factors influence multiple decision-making processes simultaneously. As such, farmers' decision-making processes are interactive and iterative, rather than linear. For example, information about innovation characteristics is delivered through learning platforms such as extension services and experimentation. This influences knowledge transfer and building motivation to attract farmers to the innovation. Yet, the same innovation characteristics are perceived differently by each farmer due to their various capacities in absorbing the information, and their (local) attitude about (technology) innovation and farm development. Also, each farmer has different levels of access to extension services. Likewise, before deciding to adopt, farmers consider the risk of adoption by reviewing the innovation characteristics, recalculating the availability of their (financial) resources, and looking at the market situation. This is often done through a bargaining process/discussion with their networks and family (Moglia et al., 2020; Phuong et al., 2019; Sambodo & Nuthall, 2010). Also, others point out that farmers have limited knowledge of the consequences of their actions; they act with limited rationality and intuitively – thus sometimes having a complex and iterative nature of decision-making (Notenbaert et al., 2017; Sambodo & Nuthall, 2010; Singh et al., 2016). The fact that our model identifies the relationships between factors, makes it a useful tool for those who aim to expand the use of smart technologies in SEA. By understanding the relationships between factors, multiple starting points for increasing innovation adoption become available. However, our study only focuses on the (relationships between) factors in the current situation. Many studies have shown that technology uptake can severely impact the relationships between people in the community, since it may change the power balance between stakeholders, and may favour some farmers more than others, increasing social inequity (Lioutas et al., 2021). Preferably, the changes in the system over time are known. With the current literature, this time dimension could not be taken into account.

We used a combined absolute and relative scoring system to determine the degree of importance of the factors. This scoring system allowed us to identify and select the (highly) important factors that significantly affect farmers' decision-making in innovation adoption. Our scoring system is different compared to previous studies (Klerkx et al., 2019; Pathak et al., 2019; Pierpaoli et al., 2013; Tey & Brindal, 2012; Ugochukwu & Phillips, 2018), as we used qualitative, quantitative, and mixed method papers to broadening the scope and include new evidence. For example, Tey and Brindal (Tey & Brindal, 2012) reviewed quantitative econometrics studies and captured factors with statistically significant correlations. Like Tey and Brindal (Tey & Brindal, 2012), Pierpaoli, et al (Pierpaoli et al., 2013). and Pathak, et al (Pathak et al., 2019). sorted adoption factors by counting absolute scores without considering the significant correlation of factors. The use of only absolute scores might result in bias as this tends to benefit the most frequently explored factors, such as age, education, and extension services, at the cost of relevant factors less often studied, like for example cultural norms and technology maintenance. The use of a combined scoring system also provides insight into different effects of factors on adoption decisions in different regions and countries. Based on our findings, the sub-factors local knowledge/practices and stakeholder cooperation had a high absolute score (4 and 8), but a low relative score (0.75 and 0.83). The low relative score was due to different degrees of this factors' importance in different countries. For example, the absolute score of local practices was high because there were several cases in Indonesia, Lao, and Vietnam. The relative score was low because the factor more significantly affected adoption decisions in Lao and Vietnam, and less significantly in Indonesia.

To manage the complex system in development practices, adoption factors in the FIFSEA were categorised based on decision-making levels; individual users/farmers, non-user or other (external) institutions, and environment (where individuals and institutions also interact). The categorisation of factors in the FIFSEA allows stakeholders such as the government, (development) practitioners, and technology promotors to build and explore options and scenarios on which factors and actors they can intervene to trigger change in the social system and evaluate their effects on shaping system behaviour and the overall system dynamics of technology transfer. Furthermore, the FIFSEA might guide policymakers and practitioners to select specific locations for promoting particular innovations such as smart farming and modelling the adoption rate. From the list of technology/innovations (see Appendix) reviewed in this study, the use of novel technologies was found in Indonesia, Vietnam, and Thailand. The framework can be used to investigate characteristics (adoption factors) of several potential areas suitable for smart farming in those countries. For example, the area must include farmers with good human, social, and financial capital, and good institutions with robust technology dissemination strategies (Mahindarathne & Min, 2018).

Finally, the framework can also be used for future research to model the dynamics of the social system or the domino effects of interaction (the synergies and trade-offs) in a particular case/region with a more detailed contextual explanation. Also, further research can calculate the sensitivity of users/farmers in responding to the changes in socio-institutional and environmental factors.

### 4.2. Strengths and limitations

The strength of this study is the use of a systems approach in synthesising the FIFSEA. Dynamics in complex systems do not exist on the level of the individual but only emerge on the level of the collective or institutions (Ladyman et al., 2013). This causes complex interdependencies between multi-level adoption factors (individual and socio-institutional levels) and the multidimensional nature of the decision-making process, inhibiting farmers to adopt new technology. Understanding and considering the complexity can help to account for trade-offs and guide the actual change through development and policy initiatives (European et al., 2019). Complex system approaches also help to include important societal factors such as (local) norms and perceptions (Lee et al., 2019). Moreover, compared to previous studies (Klerkx et al., 2019; Pathak et al., 2019; Pierpaoli et al., 2013; Shang et al., 2021; Tey & Brindal, 2012; Ugochukwu & Phillips, 2018) with a more reductionist approach, we took a more holistic approach. This is complementary to innovation adoption field. Reductionism can provide valuable insights into the underlying mechanisms and components of a complex system, while our study helps understand the system's collective dynamics and emergent properties (Ladyman et al., 2013).

The authors are aware of several limitations relating to the scope of the literature study, the categorisation of factors, the contextual relationships among factors, and the influence on farmers' decision-making processes.

For the literature study, we selected papers published in referred scientific journals, to ensure the scientific robustness of our results. However, this might exclude relevant information about factors that affect animal husbandry in SEA, as many studies are not published in (English) scientific journals.

The nature of the interaction between factors resulted in some overlap among the 19 factors into individual and socio-institutional categories. Some factors consist of sub-factors on multiple levels that simultaneously influence each other. For example, access to extension services is an individual sub-factor of social capital, and the provision of extension services is a socio-institutional sub-factor of learning platforms. Social capital and culture have individual and socio-institutional dimensions.

The system approach helps us to include the importance of environmental factors, however, we could not make the relationships between environmental factors and other factors, and with decision-making processes as the studies included in our review did not provide that information. Likewise, the interaction with environmental factors is more complex, as it is linked to natural and broader anthropogenic causes. More research about the impact of environmental factors on technology adoption is therefore needed.

Although we synthesized (sub)factors relevant to SEA, there are differences between countries and regions due to for example culture, stakeholders' network, and family size, causing the relationships between the different (sub)factors and their impact on adoption to vary (Pathak et al., 2019). In Vietnam, larger families were more willing to take up innovations to save time (Ly et al., 2015), while in Indonesia, farmers with smaller family sizes tended to be more willing to adopt innovations as they had less expenses for their families, thus having money to afford innovations (Lestari et al., 2012). Large families in Vietnam were in general better educated and had a more developed vision of their future development, partially due to Confucianism (Anh et al., 1998; Knodel et al., 2000; Ngo, 2020). In Indonesia, large families in rural areas more often had lower education levels, which is related to culture. Cultural roles are correlated with wealth flows between parents and children, whether the burden of child-rearing is limited to the nuclear family or extended across broader kin networks, and whether and how much school-aged children work inside and outside the home (Laksono & Wulandari, 2021; Maralani, 2008).

As we took a holistic approach, a limitation might be that we did not relate each adoption factor to one or more phases of the farmers' decision-making process. The interactions in a complex system are disordered, diverse, and iterated as there is feedback from previous interactions on a time scale relevant to the system's emergent dynamics (Ladyman et al., 2013). Nevertheless, this study shows the linkage of some adoption factors to some stages in the decision-making process. Financial resources, attitude/perception, social capital, farm characteristics, and learning platforms influenced a few stages in the decision-making process. Stakeholders' networks even affect all decision-making processes; knowledge transfer, building motivation and intention, and confirmation of adoption by farmers – because it supports the flow of information (Wiesner & Ladyman, 2021) in extension services, experimentation, and the creation of market-based incentives.

## 5. Conclusion

This study has revealed the interrelated individual, socio-institutional and environmental factors that influence the decision-making process of smallholders in innovation adoption in animal husbandry in Southeast Asia (SEA). In total, 7 individual, 6 socio-institutional, 6 environmental factors, and 58 subfactors have been identified and scored on their degree of importance. Key individual factors are farmers' skills and knowledge, being members of farmers' groups, and having access to training and financial support. At the socio-institutional level, the factors with high importance are innovation characteristics (compatibility and price) and government financial support (loans and grants). As for environmental aspects, key factors are prolonged rainfall, soil degradation, and water pollution. As part of the framework synthesis approach, the more prominent factors were synthesized with the initial framework resulting in a new framework: the Framework for Innovation adoption of animal husbandry Farmers in SEA (FIFSEA).

The FIFSEA is based on (sub)factors found in SEA, the relationship among factors and between factors at different levels, and the importance degrees of factors, resulting in a comprehensive framework that can help stakeholders, including farmers, professionals, policy-makers and researchers to understand the complexity of innovation adoption and the factors relevant for systems change, to guide actions and decisions, and to predict the adoption rate of innovation uptake. The added value of the framework lies in; the specific focus on animal husbandry in SEA, the use of a systems approach and a combined absolute and relative scoring system, and the practical use for development practices.

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# Appendix

**Table A1.** List of reviewed papers from South-East Asia.

| | Title | Authors and year | Countries case studies | Type of (technology) innovation |
|---|---|---|---|---|
| 1 | Continued innovation in a Cambodian rice-based farming system: farmer testing and recombination of new elements | S. Mak, 2001 | Cambodia | Mixed crop-livestock; incorporate rainfed lowland rice, dry season rice, animal production (cattle, pigs, chickens, and ducks), fishing (or fish culture), and other activities (such as palm sugar production, vegetable production, wild food collection, and trade |
| 2 | Assessing the Potential for Small-Scale Aquaculture in Cambodia | R. B. Richardson and M. Suvedi, 2018 | Cambodia | Semi-intensive pond management |
| 3 | Factors influencing biosecurity adoption on laying hen farmers | V. S. Lestari, A. Natsir, S. N. Sirajuddin, K. Kasim, H. M. Ali, Saadah, et al. 2012 | Indonesia | Biosecurity measures: farm inputs, traffic onto farms, distance from sources of pathogens to shed, exposure of farm, biosecurity at farm boundary, biosecurity between farm boundary and shed, biosecurity at the shed door, traffic into the shed, and susceptibility of the flock. |
| 4 | A participatory, farming systems approach to improving Bali cattle production in the smallholder crop-livestock systems of Eastern Indonesia | S. Lisson, N. MacLeod, C. McDonald, J. Corfield, B. Pengelly, L. Wirajaswadi, et al. 2010 | Indonesia | Cattle, forage improvement technologies; |
| 5 | Understanding the Motivation of Western Java Smallholder Broiler Farmers to Uptake Measures Against Highly Pathogenic Avian Influenza (HPAI). | M. G. Pramuwidyatama, H. Hogeveen and H. W. Saatkamp 2020 | Indonesia | Implementing cleaning and disinfection (C&D), vaccination, reporting, and stamping-out |
| 6 | Biogas diffusion among small scale farmers in Indonesia: An application of duration analysis | A. R. S. Putra, S. M. Pedersen and Z. Liu 2019 | Indonesia | Biogas |
| 7 | A behavioural approach to understanding semi-subsistence farmers' technology adoption decisions: The case of an improved paddy-prawn system in Indonesia | L. A. A. T. Sambodo and P. L. Nuthall 2010 | Indonesia | An improved paddy-prawn system |

(*Continued*)

**Table A1.** (Continued).

| | Title | Authors and year | Countries case studies | Type of (technology) innovation |
|---|---|---|---|---|
| 8 | Social-economic factors that affect cattle farmers' willingness to pay for artificial insemination programmes. | S. N. Sirajuddin, I. Sudirman, L. D. Bahar, A. R. Al Tawaha and A. R. Al-Tawaha 2018 | Indonesia | Artificial insemination |
| 9 | A social science perspective on stock enhancement outcomes: Lessons learned from inland fisheries in southern Lao PDR | C. J. Garaway, R. I. Arthur, B. Chamsingh, P. Homekingkeo, K. Lorenzen, B. Saengvilaikham, et al. 2006 | Lao | Stock enhancement |
| 10 | Gendered Roles in Agrarian Transition: A Study of Lowland Rice Farming in Lao PDR | M. Moglia, K. S. Alexander, S. Larson, A. Dray, G. Greenhalgh, P. Thammavong, et al. 2020 | Lao | Mixed crop-livestock system; non-rice crops, livestock husbandry, and forest |
| 11 | Quantifying the value of adopting a post-rice legume crop to intensify mixed smallholder farms in South-East Asia | M. Monjardino, J. N. M. Philp, G. Kuehne, V. Phimphachanhvongsod, V. Sihathep and M. D. Denton 2020 | Lao | Incorporating a legume crop into the traditional rice-cattle system |
| 12 | "Community-Based Technology Transfer in Rural Aquaculture: The Case of Mudcrab Scylla Serrata Nursery in Ponds in Northern Samar, Central Philippines | D. B. Baticados, R. F. Agbayani and E. T. Quinitio 2014 | Philippines | Mudcrab nursery in ponds |
| 13 | Adoption of dual-purpose forages: some policy implications | M. L. A. Lapar and S. Ehui 2003 | Philippines | Planted forages; Gliricidia sepium, Leucaena leucocephala, Setaria spp., Napier grass (Pennisetum purpureum), and vetiver grass (Vetiveria zizanioides) |
| 14 | Intention to adopt and diffuse innovative ultraviolet light C system to control the growth of microorganisms in raw milk among Thais Dairy Farmers. | D. Makarapong, S. Tantayanon, C. Gowanit and C. Inchaisri 2020 | Thailand | Ultraviolet light C system |

(*Continued*)

**Table A1.** (Continued).

| | Title | Authors and year | Countries case studies | Type of (technology) innovation |
|---|---|---|---|---|
| 15 | Adoption of Good Agricultural Practices by Cattle Farmers in the Binh Dinh Province of Vietnam | G. H. Hoang 2020 | Vietnam | The rules, orders, and procedures that guide farmers to produce, process, and market agricultural produce to meet several requirements relating to food safety and quality, product traceability, and environmental protection |
| 16 | Factors of Biogas Adoption in Manure Management of Vietnamese Household Pig Production: A Case Study in Tien Lu District, Hung Yen Province | N. T. Ly, T. Nanseki and Y. Chomei 2015 | Vietnam | Biogas |
| 17 | The impact of VietGAHP implementation on Vietnamese households' pig production | L. T. Nguyen, T. Nanseki and Y. Chomei 2020 | | The rules, orders, and procedures that guide farmers to produce, process, and market agricultural produce to meet several requirements relating to food safety and quality, product traceability, and environmental protection |
| 18 | Integrated freshwater aquaculture (IAA), crop and livestock production in the Mekong delta, Vietnam: Factors and the role of the pond. | D. K. Nhan, L. T. Phong, M. J. C. Verdegem, L. T. Duong, R. H. Bosma and D. C. Little 2007 | | Mixed crops and livestock (IAA-farming) |
| 19 | Transformative Social Learning for Agricultural Sustainability and Climate Change Adaptation in the Vietnam Mekong Delta. | L. T. H. Phuong, T. D. Tuan and N. T. N. Phuc 2019 | | The VACB (V garden/orchard; A fishing farm; C livestock farm; B biogas) model |
| 20 | Factors constraining and enabling agroforestry adoption in Viet Nam: a multi-level policy analysis. | E. S. Simelton, D. C. Catacutan, T. C. Dao, B. V. Dam and T. D. Le 2017 | | Agroforestry |