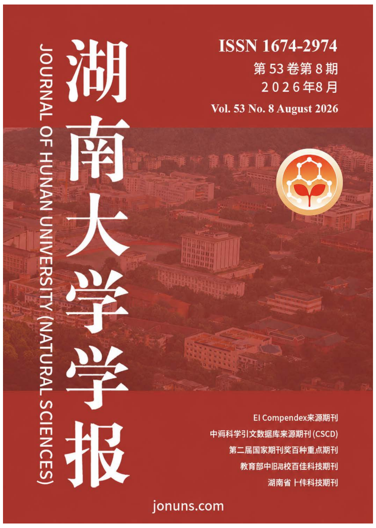

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SLIMFRESS: A Sustainable Livelihood and Flood-Resilience Model for Rice Farmers in South Sumatra, Indonesia

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Abstract: Climate change increasingly threatens farmers' livelihoods and heightens the vulnerability of smallholder farming communities in flood-prone areas. Integrated agricultural and livelihood strategies are therefore needed to strengthen resilience and ensure long-term environmental and socioeconomic sustainability. This study aimed to develop and validate the Sustainable Livelihood Model for Flood Resilience Strategies (SLIMFRESS) for smallholder rice farmers in South Sumatra Province, Indonesia. An explanatory sequential mixed-methods design was employed, in which quantitative data were analysed first and subsequently complemented by qualitative evidence obtained from relevant stakeholders. A system dynamics model was developed using STELLA Architect 9 through causal-loop diagrams, stock-and-flow diagrams, and model validation procedures. Thematic analysis of stakeholder perspectives was conducted alongside the system dynamics modelling process to interpret the quantitative findings and refine the structure of the model. The resulting SLIMFRESS model integrates farmers' sustainable livelihood assets with sustainable livelihood strategies to assess interventions aimed at reducing the economic and environmental risks associated with flooding in rice-farming areas. The simulation results indicate that livelihood resilience does not develop immediately but emerges gradually through sustained support, continuous knowledge development, and effective institutional collaboration. The model also highlights the importance of coordinated interventions addressing environmental conservation, household financial security, and market participation. Accordingly, policy measures should prioritise community-based conservation initiatives, financial mechanisms providing income support and agricultural insurance during flood events, and improved market access for products developed by smallholder enterprises. SLIMFRESS provides an integrated decision-support framework for designing and evaluating long-term flood-resilience strategies for smallholder rice-farming communities.

Keywords: sustainable livelihoods; flood resilience; system dynamics modelling; smallholder rice farmers; climate change adaptation.

SLIMFRESS：印度尼西亚南苏门答腊省稻农可持续生计与洪灾韧性模型

摘要： 气候变化日益威胁农民的生计，并加剧了洪灾易发地区小农社区的脆弱性。因此，有必要采取综合性的农业与生计策略，以增强其韧性，并保障环境与社会经济的长期可持续性。本研究旨在为印度尼西亚南苏门答腊省的小规模稻农构建并验证洪灾韧性策略可持续生计模型（Sustainable Livelihood Model for Flood Resilience Strategies，SLIMFRESS）。研究采用解释型序列混合研究设计，首先对定量数据进行分析，随后结合从相关利益主体获取的定性证据加以补充。研究运用STELLA Architect 9软件，通过构建因果回路图和存量流量图以及实施模型验证程序，建立系统动力学模型。在系统动力学建模过程中，同时对利益主体的观点进行主题分析，以解释定量研究结果并完善模型结构。最终形成的SLIMFRESS模型将农民的可持续生计资本与可持续生计策略相结合，用于评估旨在降低稻作区洪灾相关经济风险和环境风险的干预措施。模拟结果表明，生计韧性并非即时形成，而是在持续支持、知识不断积累以及有效的制度协作下逐步增强。该模型还强调了围绕环境保护、家庭经济保障和市场参与开展协同干预的重要性。因此，相关政策措施应优先支持社区主导的生态保护行动，建立在洪灾期间提供收入保障和农业保险的金融机制，并改善小农经营主体产品的市场准入条件。SLIMFRESS为小规模稻农社区长期洪灾韧性策略的设计与评估提供一个综合决策支持框架。

关键词： 可持续生计；洪灾韧性；系统动力学建模；小规模稻农；气候变化适应

1. Introduction

In agricultural countries, climate change impacts farmers' livelihoods, making them vulnerable, and undermines their food security and climate awareness. This situation certainly requires local visibility to mitigate the risks of vulnerable livelihoods through climate resilience knowledge [1]. Integration of various aspects is needed to address flood vulnerability and food insecurity in Indonesia. Other integrated agricultural practices needed to ensure sustainable livelihoods for farmers in flood-prone areas [2]. Another obstacle to sustainable agricultural livelihoods is the unstable rice supply and labor shortages. A key finding is the need for policies to support increased use of crops for floodplain areas, but farmers are currently unmotivated to change their farming practices [3].

The contribution of this research in line with several objective, this Livelihood resilience is related to the relevance of policies for groups and communities to cope with natural and human-made impacts. Efforts by affected communities to recover and adapt to shocks and stresses focus on changes in material or financial resources at the community level. Developing inclusive interventions and policymaking in ecologically vulnerable areas can anticipate transformative environmental changes and create sustainable livelihoods [4]. The region is highly vulnerable and faces a high level of food-related vulnerability, and that shifting from isolated hazard analysis to comprehensive assessment accounting for exposure and vulnerability can reveal the underlying root causes of risk. The concept of impact chains is essential to provide policymakers and researchers with an overview of potential food vulnerability risks, supporting recommendations for enhancing local capacity and fostering social transformation in flood-prone areas [5].

Local community empowerment integrated with traditional ecological knowledge serves as a modern innovation for building the adaptive capacity of smallholder farmers [6]. Study aims to identifies an agricultural system that protects against climate change, ensures environmental sustainability, through education on social needs, such as community efforts in dealing with floods. In this final modeling stage, the influencing factors analyzed are integrated into the resulting model to determine whether the inclusion of variable components can improve the effectiveness of efforts to address flooding in rice fields for small-scale farmers in South Sumatra Province, Indonesia.

The novelty of SLIMFRESS Model from existing livelihood resilience framework that the integration of Sustainable Livelihood Assets (SLA) and Strategy of Sustainable Livelihood (SSL) with system dynamics is potentially useful to give recommendation.

The name of "SLIMFRESS" reflects the novelty of this research in offering recommendations to address the flooding issues faced by rice farmers. “SLIMFRESS” stands for "Sustainability Livelihood Model to Face Flood with Resilience Strategy"; this model integrates an analysis of flood management factors with Sustainable Livelihood Assets (SLA) and Sustainable Livelihood Strategies (SSL), resulting in a comprehensive new model that is specifically implementable at both the farmer and local government levels. The SLIMFRESS Model has identifiable applied potential, particularly for flood-prone rice farming in South Sumatra, Indonesia.

2. Research Method

2.1. Study location

The study was conducted in South Sumatra, Indonesia. South Sumatra is an area in Indonesia that is prone to flooding in the rice fields. The agricultural area, taken as an example, is considered in each regency (purpose) criteria as the region's barns and paddy fields are affected by floods and water shortages. This research conducted in three regencies in South Sumatra that are mostly affected by floods, namely Ogan Ilir regency, Ogan Komering Ilir regency, and Banyuasin regency.

2.2. Sampling method

Type of sampling used in this research is purposive sampling. It aligns the sample directly with research goals, increasing data accuracy and credibility. Its four main concepts are credibility, transferability, dependability, and confirmability [6].[7].

The sample in this study will follow by purposive sampling at the research location, with divided by three districts in South Sumatra in different typological of farmland, there are tidal, swamp and rainfed. The sample must follow the sample criteria, consisting of:

1. Small scale rice farmers (having the cultivated area about 0.5-2 Ha)
2. Farmers have experience with flooding in the rice field at least once a year
3. Farmer have minimum 2 years experiences in rice farming

Table 1. Sample with Slovin formula

No	Small Scale Farmers	Population (N)	Slovin	Sample (n)
1	Ogan Ilir (OI)	13.959	99,2871	99
2	Banyuasin	12.593	99,2121	99
3	Ogan Komering Ilir (OKI)	26.606	99,6255	99
Total		53.158		298

Margin Error 0,10%

Table 1 shows, from the Slovin formula the total sample is 298, however only 202 farmers fulfilled the sampling criteria, as 98 potential respondents had not experienced annual flooding and were therefore excluded. Despite this reduction, the final sample size remains adequate for analysis. The minimum of 100–200 respondents are sufficient for the application of the maximum likelihood (ML) estimation technique, indicating that the retained sample of 202 farmers meets the recommended threshold for robust statistical modelling [8].

2.3. Research design

This study is a quantitative research project utilizing primary data collected with questionnaires from the respondents that meet the sampling criteria.

Quantitative research involves the collection and analysis of numerical data, while qualitative research considers narrative or experiential data [9].

2.4. The empirical basis of the SLIMFRESS model

2.4.1. Quantitative with Confirmatory Factor Analysis (CFA)

Confirmatory factor analysis (CFA) is employed to address the second objective of this study, which is to analyse the factors influencing the strategies adopted by small-scale rice farmers in responding to floods in South Sumatra, Indonesia. The analysis uses Mplus 8, which offers advanced capabilities for handling complex latent-variable models, accommodates non-normal data, and provides robust estimation procedures suited to social and environmental research. CFA performs using primary data collected directly from small-scale farmers whose rice fields are affected by recurrent flooding.

In this study, a questionnaire with a Likert scale was used. The Likert scale is used to measure a person's or a group of people's attitudes, opinions, and perceptions about social phenomena [10]. In this study, researchers used an even Likert scale, with even categories, such as 4, 6, or 8 choices [11]. The researcher used a six-option Likert scale, as this scale allowed respondents to avoid selecting the middle or neutral category, which could have prevented the researcher from obtaining accurate information. Therefore, the use of an even Likert scale is recommended for research purposes.

The software used in this study's confirmatory factor analysis (CFA), MPlus 8 is a latent variable modelling software, offers a broad range of analysis features. The software enables the study of complex survey data, Bayesian analysis, Monte Carlo simulations, mixture modelling (including latent class analysis), exploratory factor analysis, item response theory analysis, and multilevel data analysis.

2.4.2. Quantitative analysis with System Dynamic (SD) Model

System dynamics model with STELLA Architect software is used to formulate models through causal loop diagrams, stock flows, and system dynamics model validation testing. This produces reliable models for scenario analysis simulations. STELLA Software enables the creation of simulation models from causal loops or stock-flow diagrams [12]. System dynamics models describe complex dynamic feedback loops, nonlinear relationships, and simulate future trends. Systems dynamics generates scenario analysis, which is essential for policymaking. These models are flexible enough to simulate multiple scenarios simultaneously [13].

Conceptualization of the Dynamic System model was conducted to examine the relationships between variables. The Dynamic System simulation model was tested based on feedback information to generate forecasts. This was followed by the development and analysis of the Dynamic System model for various scenarios (the minimum-effort scenario, the partial-effort scenario, and the desired scenario) [14].

A sustainable livelihood model for flood prevention among small-scale farmers, a formula using the dynamic systems approach, structural thinking, and experiential learning laboratory with animation (STELLA). The constructed STELLA model comprises three subsystems: sustainable livelihood assets, sustainable livelihood strategies, and flood conditions affecting rice fields. STELLA Architect v9 (ISEE systems) employs a policy-oriented simulation model that generates recommendations to support the long-term sustainability of farmers' livelihoods in flood-prone environments.

The modelling process involves several stages: first, survey data are entered into Excel to produce Likert-scale scores; second, these indicator-level scores are incorporated into a STELLA modelling framework; third, stock-and-flow structures are created based on the specified indicators; and finally, converters containing ideal formulas are developed to ensure a calibrated and functional system model [15].

The final model is grounded in real-world experiences and reflects practical needs, thereby enhancing its relevance, credibility, and applicability in flood-affected agricultural settings [16]. The structured approach ensures consistency, replicability, and a clear linkage between the data, the interpretations generated, and the conclusion drawn [17][18].

In the model simulation using Stella Architect v9, equation validation reveals that if invalid values are entered or the predictive model inputs are incorrect, the model cannot be executed. Consequently, to achieve an executable model, the researcher must input valid variables that allow the model to run and the stock-and-flow structure to appear; if the entered equations are invalid, the stock-and-flow components fail to materialize, preventing the model from running. This demonstrates that the validation of equations as accepted by the system dynamics framework in Stella Architect v9 is achieved through digital system validation.

3. Result and Discussion

In this section, all influencing factors resulting from the analysis of the first and second objectives of this study are integrated, combined with indicators of sustainable livelihood assets (SLA) and strategy of sustainable livelihood (SSL), into a model built through dynamic systems using the STELLA Architech v9.

This modelling presents the analyse data and components to predict how SLA and SSL allocations will affect flood management over the next five years. The results demonstrate that implementing the modelled flood management efforts in rice fields can enhance farmers' sustainable livelihoods by utilizing asset allocation and strategies suggested by the STELLA dynamic system.

In dynamic systems, researchers will conduct in-depth observations of analysed indicators, grounded in theory and computer skills, to explore various recommended solutions to research problems that require critical and innovative thinking [19]. The vulnerability of farmers' livelihoods to climate change is influenced by topography, soil fertility, and available irrigation facilities, so that sustainable livelihood strategies and livelihood assets are needed that can be used to overcome various risks caused by flooding [20].

3.1. Integrated The Floods Influencing Factors for Sustainable Livelihood Model

3.1.1. Contruct variable of Confirmatory Factor Analysis (CFA)

The validity of the construct variables was established from the results of the CFA model analysis in the second stage, which was obtained by modifying the first-stage model to eliminate invalid variables identified in the first CFA simulation. The results of this model modification not only indicate that all factors in the second-stage model are valid but also provide practical recommendations for influencing efforts to address flooding in rice fields for small-scale farmers in South Sumatra province.

Table 2. CFA Construct variable

Code	Frequency of flood dissater	Loading Factor	Status
X1	*Frequency of flood disaster*		
B2	Depth of flood inundation	0.673	Valid
B3	Flood inundation area	0.882	Valid
C1	High rainfall	0.737	Valid
C2	Shift of rainy season	0.860	Valid
C3	Rainy period	0.609	Valid
D1	Types of rain	0.516	Valid
X2	*Responsibility for flood protection*		
F1	Water channel facilities	0.725	
F2	Water gate	0.505	Valid
G1	Extension workers	0.577	Valid
G3	Farmers group	0.728	Valid
H1	Suboptimal land adaptation strategy	0.509	Valid
H3	Planting calendar	0.673	Valid
X3	*Local flood knowledge and education*		
L1	Government assistant	0.571	Valid
L2	Knowlede Of Managing Rice Field	0.604	Valid
L3	Flood community establishment	0.669	Valid
X4	*Trust in the government in risk adaptation strategies*		
O1	Expert assistant	0.657	Valid
O2	Training to deal with floods	0.762	Valid
O3	Livelihood strategies	0.687	Valid
P1	Farming flood community	0.611	Valid
P2	Farmer group community	0.662	Valid
P3	Farmer business group	0.635	Valid

The results of the second stage of the CFA model in table 2 indicate that only a few of the four latent variables are valid. Overall, the highest loading factor values were observed in shifts during the rainy season, in flood-inundation areas, during high rainfall, at water channel facilities, and in indicators such as flood management training, livelihood strategies, and flood community establishment. Based on these valid construct variables, we recommend implementing an integrated program to address the most influential variables. This program has the potential to bring about significant positive changes, giving us hope and optimism for the future.

3.1.2. Model Equation

In the first stage of the model, a score is calculated based on the results of a survey with respondents regarding sustainable livelihood assets (SLA) and strategies of sustainable livelihood (SSL). This score is then entered into the dynamic system modelling in STELLA software to simulate and forecast the expected model.

The integration of SLA and SLL is carried out in a flood environment, the first stage of this modelling involves identifying an ideal model for flood management efforts in rice fields by small-scale rice farmers, aiming to improve sustainable livelihoods and reduce the risk of economic and environmental losses through the allocation of SLA and SSL.

In the next modelling stage, the second stage of modelling will be carried out in the form of integration of the first model, namely SLA, SSL and Farmers risk into the next integration with the influencing factors for flood management in rice fields that have been analyse with confirmatory factor analysis (CFA). The second stage of model integration is expected to present a more comprehensive modelling in this study which becomes a recommendation model for policy making in various stakeholders related to this research.

Table 3. Model equation for SLA and SLL

No	Variable	Equation
A	**Sustainable livelihood asset (SLA)**	
A.1	Natural capital	Score NC + depth of flood inundation+flood inundation area+ high rainfall+ shift of rainy season+ rainy period + types of rain + planting calendar +
A.2	Physical capital	Score PC + water channel facilities + water gate
A.3	Human capital	Score HC + famers group +

		suboptimal land adaptation strategy + knowledge of managing rice field + expert assistance + knowledge of managing rice field +training to deal with floods
A.4	Social capital	Score SC + farmers group + flood community establishment + farming flood community + farmer group community
A.5	Financial capital	Score FC + government assistant + livelihood strategies
B	**Strategy of sustainable livelihood (SSL)**	
B.1	Attractive to nature	Score AN +depth of flood inundation + flood inundation area + high rainfall + shift of rainy season + rainy period + types of rain
B.2	Crop	Score Cr + water channel facilities + water gate + suboptimal land adaptation strategy + planting calendar + knowledge of managing rice field
B.3	Wage of labor	Score WL+ extension workers + government assistant
B.4	Product and services	Score PS + expert assistant
B.5	Own business	Score OB + farmers group + flood community establishment + farming flood community + Farmer group community + armer business group

Table 3 above shows that the SLA and SSL variables in the integration model equation refer to the results of the combined CFA analysis, ensuring that the equation's fit is consistent with the previous CFA analysis. Each variable entered into the equation will make an equation that explains the integration model obtained. In this equation, the created cluster will be validated by STELLA Architech v9, ensuring the variable fit remains valid throughout the model run. However, if it cannot run, the equation is adjusted until a fit model is obtained, thereby improving farmers' sustainable livelihoods.

The equations were implemented and computationally verified within the STELLA Architecht v9, invalid mathematical formulations prevent the corresponding model structure from being successfully executed, whereas a model that can be compiled and run provides evidence of computational consistency of the formulated stock-and-flow relationships. This formulation enables the model to evaluate alternative livelihood and flood-resilience strategies through simulation over time.

3.2. SLIMFRESS: Sustainable livelihood model for flood resilience in rice fields

The modelling was conducted using the STELLA Architech v9 application, a dynamic system modelling tool, to obtain a fit model according to the scenario we hope can provide recommendations for adaptation efforts to flooding in rice fields faced by small-scale farmers. The modelling trials conducted have produced a suitable model for small-scale farmers' adaptation efforts to flooding in rice fields, thereby providing sustainable livelihoods.

The model was formulated by combining the input of sustainable livelihood assets with additional outputs in the form of sustainable livelihood strategies for farmers, resulting in outputs that reduce economic and environmental risks associated with flooding in rice fields. The outcome of this modelling output is an increase in the sustainable livelihood of small-scale rice farmers. Floods have a profound socioeconomic impact, particularly on small, coastal, and low-lying farming communities. However, understanding the perspectives of small-scale farmers on flood impacts and adaptation strategies is uncommon [21].

Flood control is a key strategy for preventing and minimize flood damage [22]. Flood management to support the livelihoods of farming households, enabling them to continue rice cultivation despite flood submersion in paddy fields.

Results suggest that focused effort on coordinated, strategic planning reduces the adverse effects of natural hazards in hazard-prone counties. These strategies involve long-term planning, land-use policies, structural mitigation, and non-structural mitigation measures to reduce community vulnerability to flood risk, thus advancing more sustainable rural livelihoods [23] The results indicate that farmers' flood response efforts are influenced by social, institutional, and economic factors. This suggests that the existence of farmer groups and farmer businesses is a crucial factor in economic resilience in the face of flood impacts [24].

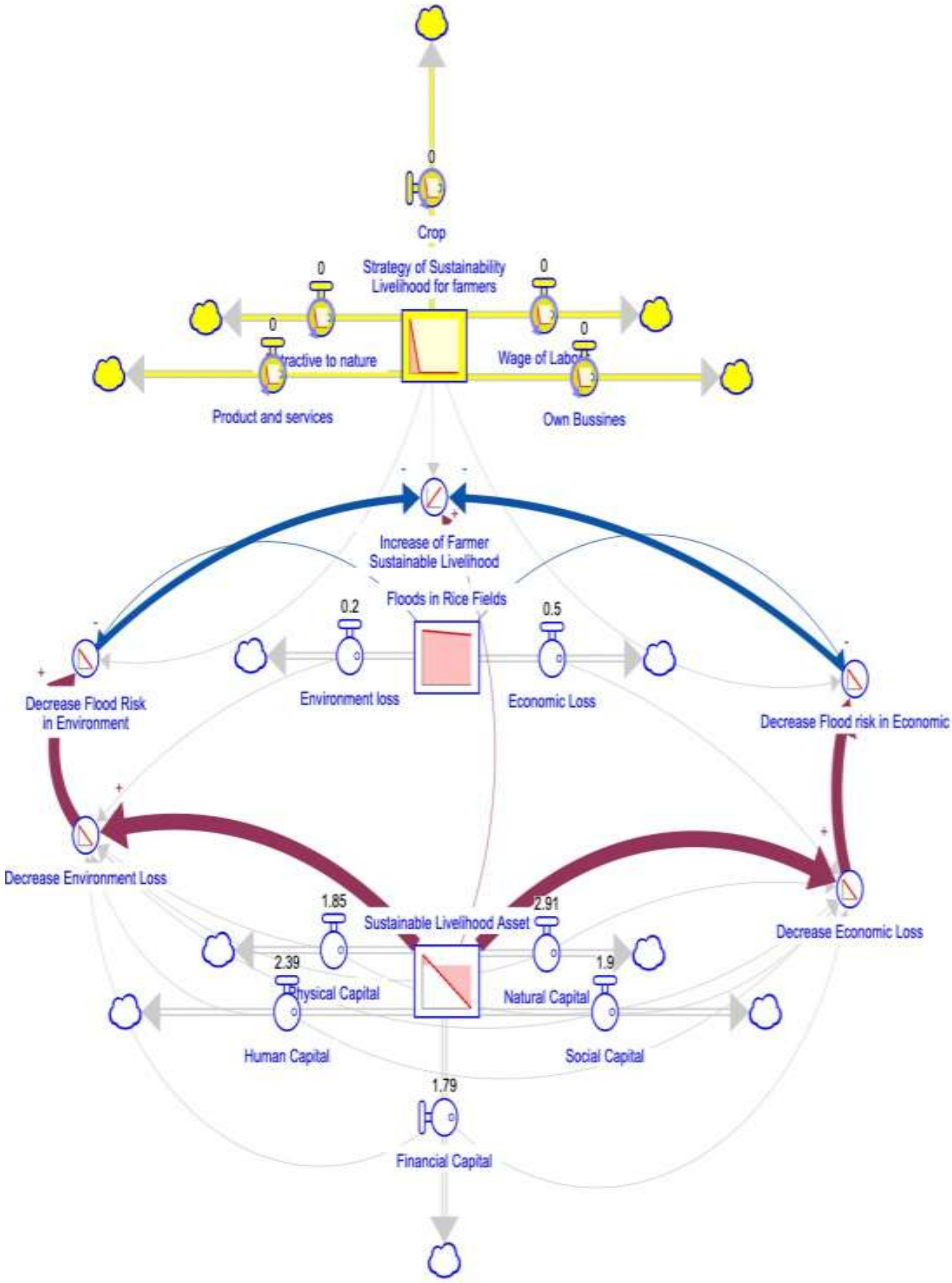

Figure 1. SLIMFRESS: Sustainable livelihood model for flood resilience in rice fields
Source: STELLA Analysis, 2025

According to figure 1, the results from STELLA Architech v9 provide a modelling scenario that simulates the achievement of the next 5 years towards efforts to improve the sustainable livelihoods of small-scale rice farmers, specifically in South Sumatra, Indonesia, the location of this study. The results of the simulation of the next five years on the output of the sustainability of the livelihoods of farmers affected by flooding in rice fields show that the fit model is obtained when farmers can allocate the use of livelihood assets optimally together with the five assets owned by farmers locally, in the form of five assets in sustainable livelihood, namely natural capital, physical capital, financial capital, human capital and social capital.

The map model demonstrates a simulation model that can enhance farmers' sustainable livelihoods by implementing a sustainable livelihood strategy to mitigate economic and environmental risks associated with flooding in rice fields. This model demonstrates that allocating livelihood strategies can improve farmers' livelihoods amid flooding in rice fields, supported by the maximum allocation of all livelihood assets. Maximize livelihood asset allocation by using all five livelihood assets together in the simulation model successfully resulted in a significant increase in farmer livelihoods over the next five years.

A reduction in flood frequency is also possible, although not as sharp. The number of flood events is predicted to decrease from 2025 to 2029, accompanied by a reduction in the risk of economic losses and environmental losses. The model successfully predicted that allocating livelihood assets to flood risk reduction efforts in rice fields could reduce economic losses by 21.2% and environmental losses by 21.5%. The model predicts that the decline in losses will continue, reaching -33 for economic losses and -32.7 for environmental losses due to flooding in rice fields for small-scale rice farmers. The prediction model is presented in the following table.

Formula validation in the STELLA model is performed automatically by the software during model construction and execution. Each equation is checked for consistency with the defined stocks, flows, and auxiliary variables**.** If a formula contains an invalid expression, undefined variable, or incompatible relationship, STELLA will identify the error and prevent the corresponding model structure from being successfully executed. Consequently, the stock and flow components cannot be properly generated or the model cannot be run until the formulation errors are corrected**.** This automated checking process provides an initial level of structural and formula validation before the model is subjected to further simulation and validation procedures.

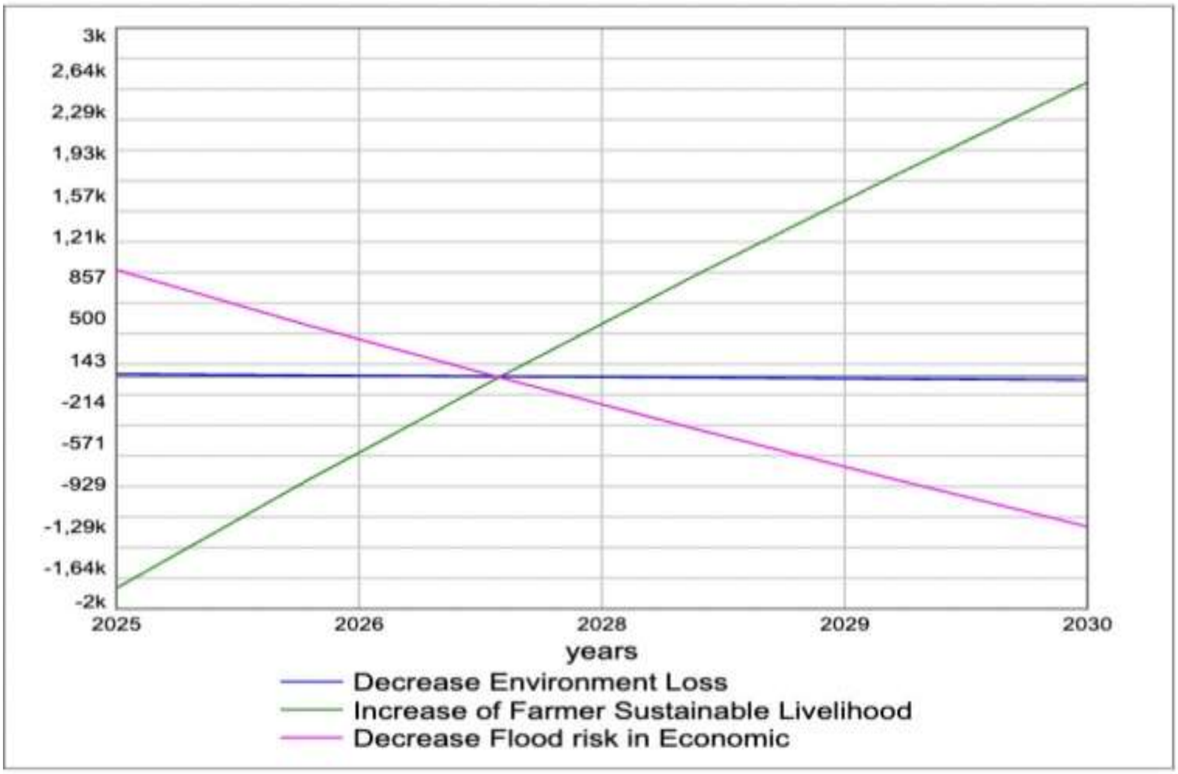

Figure 2. Model Prediction of SLIMFRESS: Sustainable livelihood model for flood resilience in rice fields
Source: STELLA Analysis, 2025

Figure 2, illustrates that maximize the allocation of subsystem variables can significantly improve farmers' sustainable livelihoods in flood-prone rice fields. Predictions from 2025 to 2030 indicate significant improvements in the subsystem aimed at enhancing farmers' sustainable livelihoods. Sustainable livelihood assets, including natural capital, physical capital, financial capital, human capital, and social capital, will yield significant positive changes if maximally allocated to flood mitigation efforts in rice fields.

The model also indicates that the forecast for reducing economic risk yields positive results, with the maximum allocation of the Livelihood asset subsystem expected to have a significant impact on reducing the risk of economic losses due to flooding in rice fields from 2025 to 2030. This condition also allows for a decrease in the frequency of flooding in rice fields, although it is not significant, resulting in only a slight decrease in frequency from year to year.

In the STELLA model simulation, various scenarios with minimum subsystem allocations have also been tested; however, the results obtained show no improvement in the sustainable livelihoods of small-scale farmers in flood conditions. Simulation experiments were conducted on the allocation of Sustainable Livelihood Assets (SLA) only at high scores, with the hope that the model could predict that the minimum allocation would overcome the flood problems faced by farmers. However, the resulting STELLA model shows that the minimum allocation of SLA does not provide an increase in the sustainable livelihoods of farmers in flood conditions in rice fields, this is because the scores generated from respondents on the SLA value are still relatively low, so that the minimum allocation has not been able to provide a significant impact on efforts to improve the livelihood conditions of farmers affected by flooding. Therefore, it is necessary to increase the SLA, which is the local potential owned by farmers, as the primary capital in sustainable livelihoods.

The results of the STELLA simulation on the allocation of SLA Strategy also show that the minimum allocation on the SLA strategy has not been able to provide a positive impact on the model, so that the simulation on the minimum model for the SLA strategy subsystem has not been successful and is not recommended, this is also because the interview scores with farmers obtained on the SLA strategy are relatively very low, this condition illustrates that both the SLA assets and the SLA strategy currently available to farmers still need to be improved so that farmers can face flood conditions according to model recommendations. A simulation image of the STELLA model scenario with the minimum subsystem allocation is shown in figure below.

Simulations were performed on the model five times until the desired recommendation model was obtained. In the first simulation, Model A allocated four Sustainable Livelihood Assets (SLAs) and three Sustainable Livelihood Strategies (SSLs). However, the results showed a decrease in these allocations, with no impact on the sustainable livelihoods of farmers.

3.2. Sustainability livelihood asset (SLA)

The Sustainability Livelihood Asset (SLA) is a crucial subsystem used in testing the STELLA model to generate recommendations for addressing flooding in rice fields for small-scale farmers. This subsystem represents the capital owned by farmers, so the influence of SLA capital allocation in the model is significant in producing a fit model.

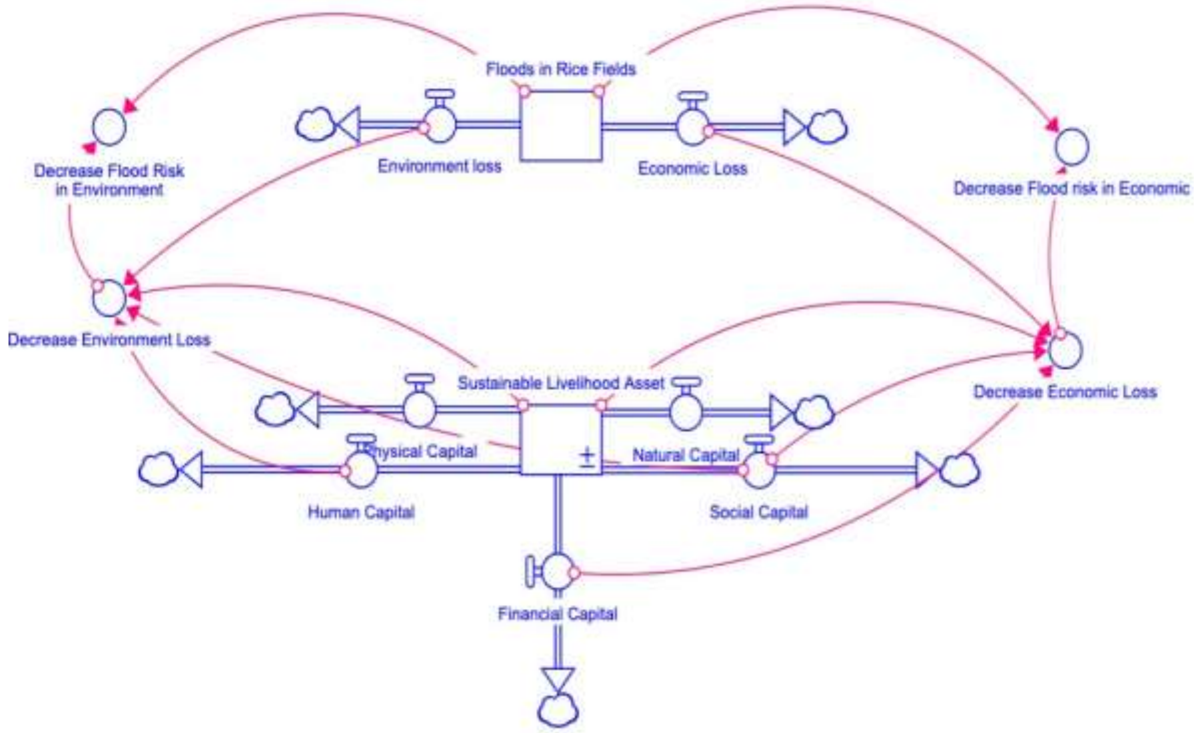

Figure 3. Sustainable livelihood asset (SLA) in system dynamics (SD) **Source: STELLA Analysis, 2025**

In figure 3, it is evident that the SLA capital allocated in this dynamic system modelling consists of

um allocation of SLA capital in the model has yielded positive results in addressing flooding problems in rice fields for small-scale rice farmers, demonstrating the practical implications of our study. However, the minimum allocation of SLA capital with a high score has not produced positive changes in the model. The SLA capital that obtained high scores was Human Capital and Social Capital. This aligns with the validation results from the CFA analysis, where variables with high validity include flood knowledge and education, indicating that the human capital factor plays a vital role in efforts to improve the sustainable livelihoods of rice farmers who face flooding.

In the STELLA simulation model, two capitals are applied that are considered capable of providing a maximum scenario, namely the allocation of sustainable livelihood assets in the form of natural capital, human capital, and social capital. Still, the model simulation natural capital, physical capital, financial capital, human capital, and social capital. The maxim

shows that the minimum allocation only on the dominant variable does not show positive changes in increasing the sustainable livelihood of small-scale farmers, so that it is still necessary to allocate the maximum of all sustainable livelihood assets owned by farmers together to obtain a model with a fit or ideal scenario, this is due to the still low level of ownership of SLA assets owned by farmers.

3.3. Strategy of sustainability livelihood (SSL) for farmers

The Strategy of Sustainable Livelihood (SSL) is a subsystem that also influences the dynamic system modelling process. This subsystem is very dominant in generating the desired changes in the model. The maximum allocation must still be applied to the SSL subsystem because the minimum allocation is insufficient to produce positive changes in the model.

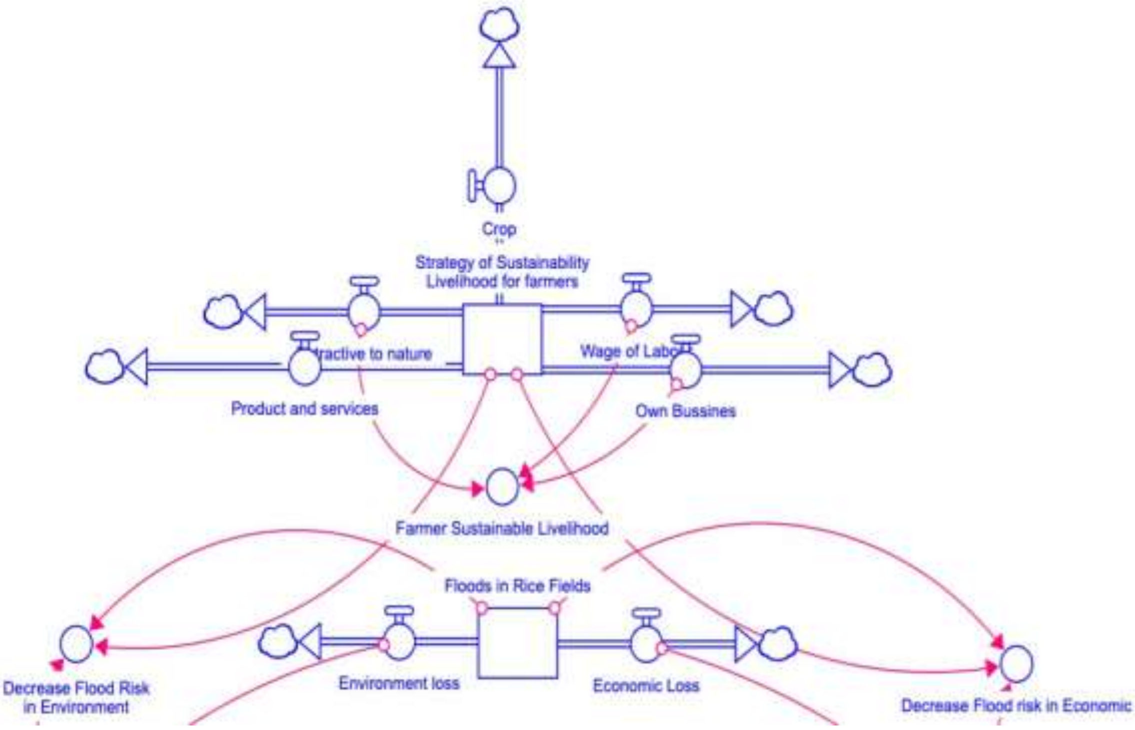

Figure 4. Strategy of sustainable livelihood (SSL) in system dynamics
Source: STELLA Analysis, 2025

According to figure 4, it can be seen that the SSL that gives the highest score is attractive to nature, wage of labor and own business, this is due to the current conditions of farmers as depicted in the subsystem, where small-scale farmers still rely on extractives on land which is the main livelihood of the household, and in addition to farming, farmer households also earn a living from working as laborers, both farm laborers and other daily laborers, in addition some have their own businesses such as opening stalls, selling vegetables. This condition is unable to provide the maximum contribution to efforts to improve the sustainability of farmers' livelihoods in flood conditions in rice fields, as their SSL strategy remains minimal. This condition renders the minimum allocation in the SLL subsystem incapable of yielding positive results in improving farmers' livelihoods; therefore, it is necessary to allocate the maximum amount to all SSL subsystem variables to produce a positive model. The allocation of SLL variables that can be given is Attractive to nature, crops, products, services, labor wages, and own businesses.

3.4. Integration Model of SLIMFRESS: Sustainable livelihood model for flood resilience in rice fields

This section presents the results of the second-stage model simulation, which integrates the first model, the SLA and SSL models, with the results of the CFA analysis. This results in a comprehensive model that reflects all the findings of this study. The resulting model will serve as recommendations for addressing flooding in rice fields faced by small-scale rice farmers in South Sumatra, Indonesia.

The flooding problem in rice fields, previously analyzed in the first and second objectives of this research, requires the integration of all factors into a single unit to obtain an equation that can be entered into the dynamic system modeling with STELLA Architech v9. Dynamic system modeling results predict the specific year when the allocation of influencing factors, as determined by the recommendation model, will achieve the optimal value.

To improve farmers' sustainable livelihoods, long-term technological interventions are needed. There is an agricultural system that protects against climate change, ensures environmental sustainability, through education on social needs, such as community efforts in dealing with floods. In this final modeling stage, the influencing factors analyzed in the CFA are integrated into the resulting model to determine whether the inclusion of variable components can improve the effectiveness of efforts to address flooding in rice fields for small-scale farmers in South Sumatra Province.

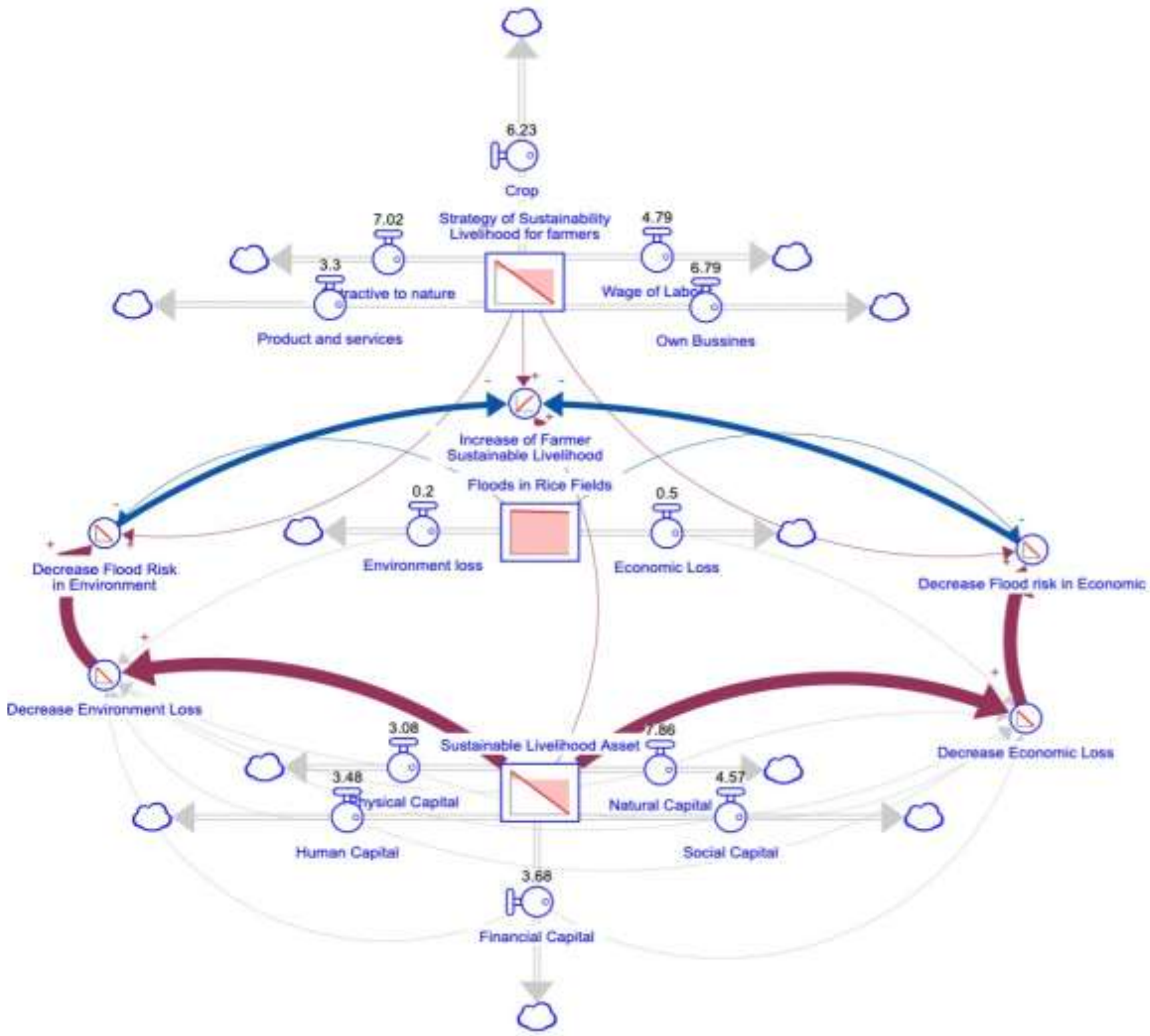

Figure 5. Integration Model of SLIMFRESS: Sustainable livelihood model for flood resilience in rice fields
Source: STELLA Analysis, 2025

The resulting integration model shows in figure 5, that the maximum allocation of all SSL and SLA variables, combined with factors influencing valid CFA results, yields a model consistent with the conditions for improving farmers' sustainable livelihoods. The results of the integration model show that scores increase after integrating sustainable livelihood assets (SLA) and sustainable livelihood strategies (SSL), thereby reducing economic and environmental losses and increasing the potential to reduce flooding in rice fields.

The results of the integration of Sustainable Livelihood Asset (SLA) show that the highest score is on the natural capital variable, which means that several influencing factors on flood management efforts in rice fields are still closely related to natural factors, where the influencing factors are still around the causes of flooding related to natural capital, so flood management need in the management of natural resources such as land, water and also types of plants that can reduce the risk of losses due to flooding in rice fields for small-scale farmers.

The score also increased after the integration of the social capital model, this condition shows that flood management efforts carried out through community action are more effective in reducing the risk of losses due to flooding in rice fields, in addition to the allocation of influencing factors in the form of flood community establishment and farmer flood community and farmer groups are considered adequate for flood management efforts carried out together.

In the sustainable livelihood strategy, influencing factors have also been integrated to improve farmers' sustainable livelihoods. This is done by intensifying agriculture, which leads to extractive practices on nature. In the SSL model, this variable shows the highest score after model integration. Activities that can be carried out include forest and swamp conservation and land rehabilitation. Strategies that are recommended by this integration model are own businesses, which means small-scale trade, MSME production (livestock farming, fisheries, food production), are necessary to provide additional income during floods. As development practitioners, policymakers, farmers, and local community leaders, play a crucial role in implementing these strategies.

The SLIMFRESS model introduces a novel concept to existing sustainable livelihood frameworks by integrating flood management factors with Sustainable Livelihood Approaches (SLA) and Sustainable Livelihood Frameworks (SLL). It offers recommendations for mitigating economic and environmental risks through optimal resource allocation on rice paddies during flood events. By further developing the existing sustainable livelihood framework into an integrated model, SLIMFRESS enables the proposal of alternative survival strategies for farmers in flood-prone areas.

3.5. Model Equation

In STELLA system dynamics modeling, an equation is needed to obtain a good fit. If the equation used is not suitable for the STELLA application, the model cannot run, so the equation needs to be adjusted until the correct one is found. The results of the equation used in the integration model, crucial for guiding the process, are shown in Table 1 below.

Table 4. Model equation in STELLA

No	Variable	Equation
1	Increase of farmer sustainable livelihood	Sustainable_Livelihood_Asset +Strategy_ of_Sustainability_ Livelihood_ or_farmers- Decrease_Flood_Risk_ in_Environment- Decrease_ Flood_risk_in_Economic
2	Decrease of flood risk in environment	Floods_in_Rice_Fields*Decrease_ Environment_Loss +Strategy_of_Sustainability_ Livelihood_for_farmers
3	Decrease flood risk in economy	Floods_in_Rice_Fields*Decrease_ Economic_Loss +Strategy_of_Sustainability_ Livelihood_for_farmers
4	Floods in rice fields	Decrease_Economic_Loss +Decrease _Environment_Loss
5	Sustainable livelihood Asset	Financial_Capital+Human _Capital+ Natural_Capital +Physical_Capital+Social _Capital
6	Natural capital	2.91+0.673+0.882+0.737 +0.860+0.609 +0.516+0.673
7	Physical capital	1.85+0.725+0.505
8	Human capital	2.39+0.577+0.509
9	Social capital	1.90+0.728+0.669+0.611 +0.662
10	Financial capital	1.79+0.571+0.687+0.635
11	Strategy of sustainable livelihood	Crop+Extractive_to_nature+Own_ Bussines +Product_and_services +Wage_of_Labour
12	Attractive to nature	2.74+0.673+0.882+0.737 +0.860 +0.609+0.516
13	Crop	2.45+0.725+0.505+0.509 +0.673 +0.604+0.762

14	Wage of labour	2.95+0.577+0.571+0.687
15	Product and services	2.64+0.657
16	Own Business	3.48+0.728+0.669+0.611 +0.662+0.635

Source: STELLA Analysis, 2025

In this equation model table 4, each variable to test is given an equation that forms it. The modeling objective is an equation that summarizes the constituent variables. Some of the model objectives are to improve farmers' sustainable livelihoods, reduce environmental flood risk, reduce economic flood risk, and reduce flooding in rice fields. These four model objectives are defined by the inclusion of variables in the equations for each objective.

Table 4 presents the mathematical equations implemented in the STELLA system dynamics model to represent the interactions between sustainable livelihood assets (SLA), strategies of sustainable livelihood (SSL), and flood risk reduction in rice-farming systems. The equations were formulated to capture the dynamic relationships between livelihood capacity and farmers' ability to reduce the environmental and economic loos of flooding.

The equations in Table 4 function as the mathematical representation of the causal relationships identified in the conceptual model. The model does not treat sustainable livelihood assets, livelihood strategies, and flood risk as independent variables. Instead, they are connected through feedback relationships.

In particular, livelihood assets provide the resource base for developing livelihood strategies**,** while diversified livelihood strategies can improve farmers' capacity to cope with flood impacts. At the same time, flood-related environmental and economic losses can reduce the effectiveness of livelihood systems. This creates a dynamic interaction in which strengthening livelihood assets and diversification strategies is expected to contribute to greater resilience of rice-farming households under recurrent flood conditions.

The equations are implemented directly within STELLA, where the mathematical consistency of the model is automatically checked during model construction and simulation. Variables that are incorrectly specified or contain invalid mathematical relationships cannot be properly incorporated into the executable model. Thus, the successful appearance of the stock-and-flow structure and the ability to run the simulation provide an initial technical verification that the equations have been correctly specified within the STELLA environment.

3.6. Model prediction in graph

The results from the STELLA modeling constitute a prediction model for the objective indicators. In this model, the predicted objective indicators are an increase in farmer sustainable livelihoods, a decrease in environmental loss, and a reduction of economic loss. The prediction model results in an integrated graph showing the expected changes resulting from the allocation of variables and factors that influence flood management efforts in rice fields for small-scale farmers in South Sumatra Province.

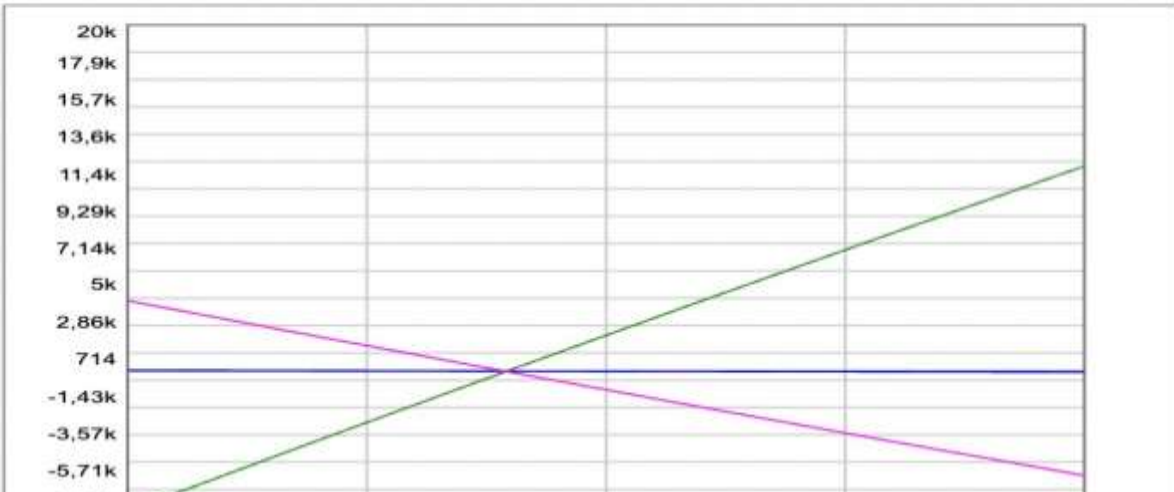

Figure 6. Model prediction 2025-2030
Source: STELLA Analysis, 2025

The results of this integrated modeling in figure 6, show that from 2025 to 2030, the model predicts a significant increase in farmers' sustainable livelihoods. It occurs by combining the previous SSL and SLA models with the CFA analysis results, thereby predicting an increase in farmers' sustainable livelihoods. This integrated model also predicts a decline in economic risk, with a relatively positive, stable downward trend. Environmental risk will also decline, but at a more gradual rate. However, the model's predictions indicate a positive change from the integrated model results

3.7. Model prediction in the table

The prediction model from the STELLA analysis, which integrates the SSL, SLA, and CFA models, yields a model that provides predictions from 2025 to 2030, consisting of four predicted indicators: an increase in farmer sustainable livelihoods, a decrease in economic loss, a decrease in environmental loss, and flooding in the rice fields. These four indicators were analysed using system dynamics, resulting in analytical recommendations as shown in the following Table.

The interpretation of simulation results, the values presented in Table 3 represent changes in each indicator over the simulation period. Positive values indicate an increase, while negative values indicate a reduction in the respective indicator. Therefore, increasingly negative values represent a greater reduction, particularly for indicators such as economic loss and flood impacts.

In the context of the model, negative values for economic loss and flood impacts should not necessarily be interpreted as unfavorable outcomes. Rather, they indicate a reduction in the corresponding indicators relative to the reference condition**,** meaning that increasingly negative values represent greater reductions in economic losses and flood impacts. This interpretation is applicable because these variables are defined in the STELLA model as changes or deviations from the reference condition**,** rather than as absolute measures of economic loss or the number of flood events.

Table 5. **Integrated Model prediction**

Year	Increase of farmer sustainable livelihood	Decrease economic loss	Decrease environment loss	Floods in rice fields
2025	-8.1k	44.8	90	45.1
2026	-3.99k	22.2	89.3	22.5
2027	67.4	-0.5	88.6	-0.2
2028	4.06k	-23.2	87.9	-22.9
2029	7.98k	-45.8	87.2	-45.5
2030	11.8 k	-68.5	86.5	-68.2

Source: STELLA Analysis, 2025

Table 5 presents the integrated model prediction generated using STELLA analysis for the period 2025–2030. The model illustrates the projected relationship between farmers' sustainable livelihoods, economic losses, environmental losses, and flooding in rice fields**.** Overall, the simulation indicates a gradual transition from a condition dominated by flood and economic impacts toward improved livelihood outcomes as the integrated intervention progresses.

In 2025**,** the model predicts a decline in farmers' sustainable livelihood of 8.1k**,** accompanied by an economic loss of 44.8 and an environmental loss of 90. Floods in rice fields are projected at 45.1**.** This initial condition indicates that farmers remain highly vulnerable to flooding, with substantial economic and environmental consequences. The negative livelihood value suggests that existing interventions and livelihood strategies have not yet generated sufficient resilience to offset the impacts of flooding.

In 2026**,** the predicted decline in sustainable livelihood is reduced to -3.99k, while economic loss decreases to 22.2. Environmental loss also declines slightly to 89.3, and flooding decreases to 22.5**.** This suggests an initial improvement in the system, particularly in terms of reducing flood exposure and associated economic losses. However, the livelihood system remains vulnerable because the sustainable livelihood indicator is still negative.

A significant transition occurs in 2027**,** when the sustainable livelihood indicator becomes positive at 67.4. At the same time, economic loss decreases substantially to -0.5**,** while flood occurrence reaches -0.2**.** This turning point indicates that the integrated intervention begins to generate a resilience effect, enabling farmers to move from vulnerability toward a more sustainable livelihood condition. The negative values for economic loss and flooding can be interpreted as a modeled reduction relative to the baseline or reference condition.

The improvement becomes more pronounced during 2028–2030. Sustainable livelihood increases from 4.06k in 2028 to **7**.98k in 2029 and reaches 11.8k in 2030. In contrast, economic loss continues to decline from -23.2 in 2028 **to** -45.8 in 2029 and -68.5 in 2030. Flooding in rice fields follows a similar declining pattern, from -22.9 in 2028 to -45.5 in 2029 and -68.2 in 2030**.** These results suggest that strengthening livelihood assets and strategies, combined with flood-management interventions, can progressively reduce farmers' vulnerability and the impacts of flooding.

However, environmental loss shows a different pattern. Although it gradually decreases from 90 in 2025 to 86.5 in 2030, the reduction is relatively small compared with the changes in economic loss and flooding. This indicates that environmental impacts may respond more slowly to intervention than economic and livelihood outcomes. Consequently, environmental management should remain an important component of the integrated model rather than assuming that reductions in flooding will automatically produce equivalent reductions in environmental loss.

The development of rural industry will have a significant impact on increasing human capital, social capital, and financial capital of farmers, thus becoming capital for the sustainable livelihoods of farmers [25]. Efforts to mitigate the impacts of flooding included providing education, agricultural technology training, transportation infrastructure, information accessibility, climate change awareness, perceptions of climate change, and shifting livelihood strategies away from agriculture.[26].

Table 2 provides strong evidence that the integrated model accurately reflects the behaviour of farmers' livelihood systems under flood pressure. The simulation demonstrates that resilience is not immediate but requires time, consistent support, and continuous improvement in knowledge and institutional cooperation. Overall, the simulation indicates that an integrated intervention combining flood management with livelihood strengthening can facilitate a shift from flood vulnerability toward resilience among rice farmers.

4. Conclusion

The dynamic system model, a significant outcome of our data processing using STELLA, indicates that the scenario with the maximum allocation of all livelihood asset capital is the most effective in reducing flood risk in rice fields for small-scale rice farmers.

The integrated STELLA model indicates a gradual shift from flood vulnerability toward greater livelihood resilience among rice farmers. The results show that combining livelihood-strengthening strategies with flood management can improve sustainable livelihoods while reducing economic losses and flood impacts. The negative values for economic loss and flood impacts represent reductions relative to the reference condition, rather than actual negative losses or flood events. Overall, the model highlights the importance of an integrated, resilience-oriented approach to strengthen farmers' livelihoods and reduce the impacts of flooding in rice-farming areas.

The recommendation policy to address these gaps, efforts should focus on: training and extension for climate-smart agriculture, access to flood-resilient seeds and technology, support for community-based conservation, financial schemes for flood-time wages and insurance then enhancing market access for small business products.

Declarations

Author Contributions

Conceptualization, N.E. and N.D.; methodology, K.E.; software, N.E.; validation, N.E., N.D. and K.E.; formal analysis, N.E.; investigation, K.E.; resources, N.E.; data curation, N.D.; writing—original draft preparation, N.E.; writing—review and editing, N.D.; visualization, K.E.; supervision, N.D.; project administration, N.E.; funding acquisition, N.D. All authors have read and agreed to the submitted version of the manuscript at the review stage.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The author declares that there is no conflict of interests regarding the publication of this manuscript.

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