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# Examining the Socio-Economic and Natural Resource Risks of Food Estate Development on Peatlands: A Strategy for Economic Recovery and Natural Resource Sustainability

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**Abstract:** Given the huge impact of the COVID-19 pandemic on the food and agriculture sectors, rapid measures are needed to reduce the risk of food crises, especially among the poor and the most vulnerable communities. The government of Indonesia planned to establish the Food Estate National Program to ensure food security. Most of the area will be on peatlands, and as such, the program still faces pros and cons as it might open up opportunities for deforestation, threats to biodiversity, and loss of community livelihoods. We conducted the present research in Central Kalimantan to formulate a food estate (FE) development strategy by taking into account the potential benefits and risks to ensure increases in the local community's welfare and the sustainability of biodiversity. Data were collected through field surveys, interviews, focus group discussion (FGD), and literature studies. The results show that the operation of a food estate on degraded peatlands has a moderate to high level of risk of negative impacts. Community activities and changes in farming methods through using more inputs and mechanical equipment are the most risky activities in FE development. The low substitutability of peatlands requires mitigation efforts as part of risk management. The operation of food systems on peatlands must be based on a strong sustainability perspective with a main principle of complementary resources. The main strategy is to protect natural resources and replace cultivated exotic plants with potential native peat plants with minimal risk. In addition, the policy and capacity building of farmers towards a business-oriented direction will maximize socioeconomic benefits. Utilization of biodiversity and low-impact cultivation techniques can ensure sustainability.

**Keywords:** food security; peatland ecosystem; socio-economic; sustainability

## 1. Introduction

The COVID-19 pandemic caused a multidimensional crisis on a global scale, impacting, among others, the food dimension, threatening people's access to food [1,2]. Disruptions occurred in the food supply chain triggered by the health crisis, and the global economic slowdown delayed the achievement of SDG-2 (zero hunger) [1]. The World Food and Agriculture Organization (FAO) identified 27 countries at risk of experiencing a food crisis due to the COVID-19 pandemic, including Indonesia [3]. FAO warned of a world food crisis due to the COVID-19 pandemic and asked all countries to prepare for it [1].

The COVID-19 pandemic also had a domino effect on Indonesia's social, economic, and financial aspects. The cessation of economic activity over one year during the COVID-19 pandemic caused an increase in unemployment of 2.56 million people, and the number of poor people rose by 0.97%, amounting to 27.55 million people [4]. Furthermore, it had an impact on food security indicators (availability, affordability, and price stability) [5–7].

There are 140,000–187,000 hectares of agricultural land lost to residential and industrial purposes every year in Indonesia, especially in Java [8]. The main negative impact (loss) from land conversion is the loss of "opportunity" to produce agricultural products, the value of which is directly proportional to the size of the converted land area and the loss of employment opportunities from the agricultural sector, which has both backward and forward linkages [9–11].

Considering the increasingly real impact of the pandemic and the massive conversion of agricultural land in Indonesia, a new strategy must be undertaken to maintain food security in the country [12]. To overcome the challenges mentioned above, Indonesia is committed to implementing a food security program [13] utilizing forest areas and developed through social forestry programs [14–16], land for agrarian reform (TORA) [17–19], and Food Estate (FE) [20,21].

The Food Estate program is one of Indonesia's National Strategic Projects (PSN) for 2020–2024. Food Estate development was carried out in Central Kalimantan, South Sumatra, North Sumatra, and East Nusa Tenggara [20]. Current FE policy is carried out by involving the community, while FE policy in the previous period was carried out by large corporations on a very broad scale for the benefit of expanding agribusiness such as state-owned companies belonging to the Ministry of Public Works, including PT Wijaya Karya and PT Pembangunan Perumahan, at Kuala Kapuas Regency, Central Kalimantan [22]. During the program's establishment, the companies prepared canals, irrigation construction, and rice field designs. The current government appears to have taken lessons from the previous period, particularly from the Merauke Integrated Food and Energy Estate (MIFEE) Project and the Delta Kayan FE Project, which negatively impacted the environment, triggering social and economic inequality [23]. Food Estate is a fitting strategy to apply in a pandemic situation where disease outbreaks become unconventional threats to national security. As a large-scale food business, FE utilizes capital, technology, and other resources to produce food in an integrated and sustainable manner. FE development in Central Kalimantan is targeted at 30,000 ha, consisting of 10,000 ha in Pulang Pisau Regency and 20,000 ha in Kapuas Regency [24].

The development of FE in this project was carried out by reusing an ex-PLG (peatland development) zone in Central Kalimantan [25] that was considered a failure and abandoned in 1995, and subsequently dismissed in 1999 [26–29]. This peatland zone was planned for large scale rice-field design. However, the preparation and spatial planning of peatlands for large-scale paddy fields are not in accordance with ecological principles. Canals were carelessly constructed so that peatlands drained quickly and became degraded and then very vulnerable to fires. FE programs on peatlands are full of pros and cons because the construction of large-scale food barns is considered to ignore the issues of deforestation, loss of biodiversity, social conflicts, and pressure on the surrounding communities [30–32]. It is feared that the cultivation of the peat ecosystem will make the area vulnerable to fires, which will cause a loss of biodiversity and increase carbon emissions into the atmosphere. Therefore, care is necessary when utilizing peat swamps to extensively develop food estates. However, the value of peat swamp forests for biodiversity remains poorly understood [33].

This research was carried out to examine the potential of peatland biophysical resources and the socio-economic environment of the surrounding communities and analyze the future risks of FE development on peatlands in Pulang Pisau Regency, Central Kalimantan Province. The results address the two main issues of FE development, namely, (a) what socio-economic conditions are needed to ensure that FE development can address the food crisis during and after the COVID-19 pandemic, and (b) what conservation measures are needed to avoid the repeated failure of the FE program, and to mitigate its negative impact on the social, economic, and ecological conditions of the area. This research offers strategic recommendations for the operation of sustainable food systems in tropical peatlands.

## 2. The Conceptual Framework

The development of FE on peatlands, as with other natural resource uses, encounters two conflicting interests: economic interests and increasing land productivity on the one hand, and conservation and resource sustainability on the other [34–36]. The future of tropical peat swamp forests depends on urgent conservation and policy action to maintain their existence [33], as merely disturbing the edges of the peat dome can affect the hydrology of the entire landscape [37]. To prevent the recurrence of past failures, FE development sites should be selected with careful consideration of resource sustainability, land productivity, and the socio-economic condition of local communities. It is expected that FE be able not only to overcome the food crisis in Indonesia, but also to preserve the ecological conditions and richness of biodiversity in its target locations.

In the past, when natural capital was still abundant while human needs were limited, natural capital was not a limiting factor in its use; Daly [38] called this the "empty world" era. However, in a situation where population growth and economic needs tend to increase rapidly, natural capital becomes a barrier to meeting socioeconomic demand [38] and should be prudently conserved for future generations. In our development strategy for FE on peatlands, the main principle is adherence to the concept of sustainability theory, which focuses on sustainable use (sustainability of natural resources and socioeconomics). However, we must be able to answer the question of what we must sustain. Answers to this question are divided into "strong" and "weak" approaches. "Strong sustainability" emphasizes the preservation of ecological goods, such as the presence of certain species or ecosystem functions. "Weak sustainability" ignores specific obligations to maintain certain goods and adopts only the general principle of making future generations no worse off than us. In terms of protecting old forests, for example, a strong view may favor protection, which requires prior development that will increase opportunities for future generations. A weak view might take into account the multiple benefits provided by old forests and then attempt to measure the future value of those benefits against the values created by development [39].

Neumayer [40], in his book, clarifies the difference between weak sustainability and strong sustainability based on the substitutability of natural capital. Neumayer argues that weak sustainability is built on the assumption of substitution of natural capital (as well as all other forms of capital). Hence, he calls this assumption the "substitution paradigm". In this paradigm, investment rules, while covering all relevant forms of capital, do not need to distinguish between specific forms of capital. If the investment in man-made and human capital is large enough to compensate for the depreciation in natural capital, an explicit policy of sustainable development is not even necessary, and sustainability is guaranteed quasi-automatically. On the other hand, the essence of strong sustainability emphasizes that natural capital is considered non-substitutable in the production of consumer goods and as a provider of utilities in the form of environmental facilities [41–44]. Daly [38] emphasized the key word for strong sustainability is "complementary". She highlighted that man-made capital and natural capital are complements, meaning that their supply is limiting. Since we are now in the era where man-made capital is not limited but natural capital is limited, the remaining natural capital has become the limiting factor. Therefore, we need to save and invest in the limiting factor and to ensure that natural capital can be maintained over generations.

The conditions that are required to achieve strong and weak sustainability are different. The difference between the two is seen mainly in four dimensions: (a) the definition of natural resources, (b) the function of natural resources, (c) their substitutability, and (d) the relationship between development and the environment [45].

With respect to natural capital as an input in the production of consumption goods, Neumayer [40] said that weak sustainability assumes three main points: natural resources are superabundant; the elasticity of substituting man-made capital for resources in the production function is equal to or greater than unity, even at the limit of extremely high output–resource ratios; and technical progress can overcome any resource constraint. Strong sustainability does not oppose weak sustainability; instead, it regards weak sustainability as an important, but not sufficient, first step in the right direction. In a sense, strong sustainability includes weak sustainability but adds further requirements.

In the context of which concept would be a better fit for analyzing the risks of developing food estates on peatlands, we believe strong sustainability will be more suitable for our conceptual framework, due to the substitutability of peatland as a natural resource. Many studies found that peat forests provide important ecological, climate, and socioeconomic benefits on both local and global scales [33,46]. Nevertheless, peat forest is a fragile ecosystem with irreplaceable roles and functions. Once peatlands are degraded, it is difficult to restore them to their original condition. This characteristic positions peatland as a non-renewable natural resource that needs wise and prudent care when managed. Currently, peatlands are experiencing changes due to anthropogenic and climatic pressures that could negatively impact and affect global peatland carbon stocks [46,47].

Based on those conditions, we formulated a conceptual framework (Figure 1) to highlight the structural elements necessary for sustainable FE development. It outlines the development of FE through policy intervention to reuse degraded peatland for FE development, its potency, and associated challenges, and finally formulates operational strategies for sustainable FE development.

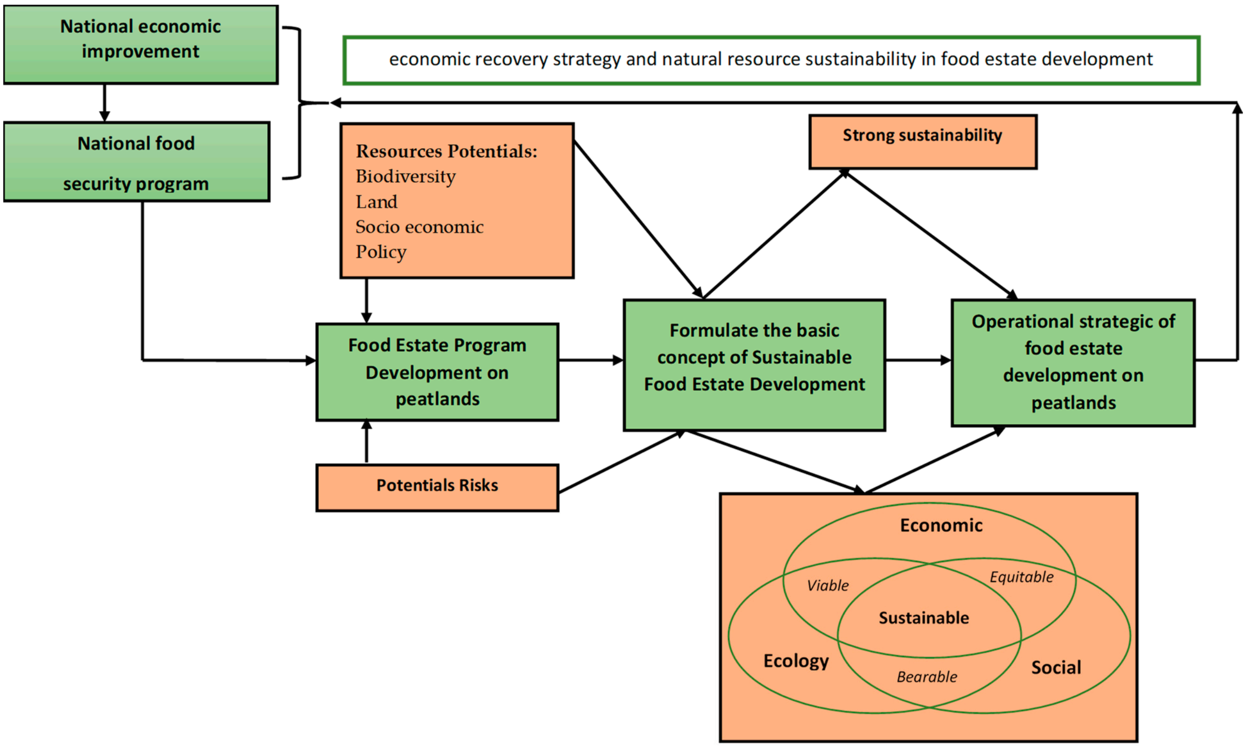


**Figure 1.** Conceptual framework for the operational strategy for food estate development on peatlands.

This conceptual framework (Figure 1) showed that one of the national economic recovery efforts is through the development of a food security program. Indonesia's food security programs are carried out on several types of land, including peatlands. The development of the food estate program on peatlands was studied based on the identification and analysis of two potential aspects, namely, (1) the biodiversity, land conditions, socioeconomic and policy possibilities, and (2) the potential risks. The results of the identification and analysis of these two aspects were then formulated as the basic concept of sustainability in food estate development, based on ecological, economic, and social aspects and using the strong sustainability theory. Strong sustainability argues in favor of a constant rule of natural capital, which is in line with the principle of strong sustainability from Daly [38]. Therefore, national development programs in Indonesia, especially in food estate development on peatlands, should consider the limiting factor of peatlands as a natural factor that has irreversible characteristics. Food production is limited not by production inputs but by the ecological conditions of the remaining peatlands.

Strong sustainability reduces damage to and scarcity of resources when managing production diversification and socioeconomic behavior. Therefore, strong sustainability indicates that developed societies should invest in natural capital. The measure of the success of the sustainable principle in the utilization of natural resources is not maximum production and consumption, but the characteristics, extent, quality, and complexity of the total disposition of capital, including the conditions and readiness of the community, which are part of a very dynamic open system. Furthermore, according to Onimisi [48], resource potential and risk are elements that need to be considered in the development of food estates, especially related to land typology, land suitability, and the potential for developing agricultural area expansion. The principles of development in Indonesia are oriented towards maintaining the sustainability of the economic, ecological, and social dimensions [49]. The implementation of the food estate program in Indonesia requires an operational strategy using the theory of strong sustainability and the concept of sustainable development to support national economic recovery and resource sustainability [50].

## 3. Methodology

### *3.1. Research Location*

The research was conducted in block B and block C of the ex-PLG area in Central Kalimantan Province (Figure 2). The area, which lies at coordinates between 113°34′35.503″ E–114°30′14.536″ E and 2°13′52.563″ S–3°28′8.115″ S, is a peat hydrological unit targeted for food estate development in Central Kalimantan as part of the 2020 national economic improvement programs. The area selected for socioeconomic development focused on the communities in Tumbang Nusa, Pilang, Garung, and Gohong villages. The villages were selected considering their location adjacent to the local community village (Dayak tribe) and their intensive interaction with the ex-PLG area.

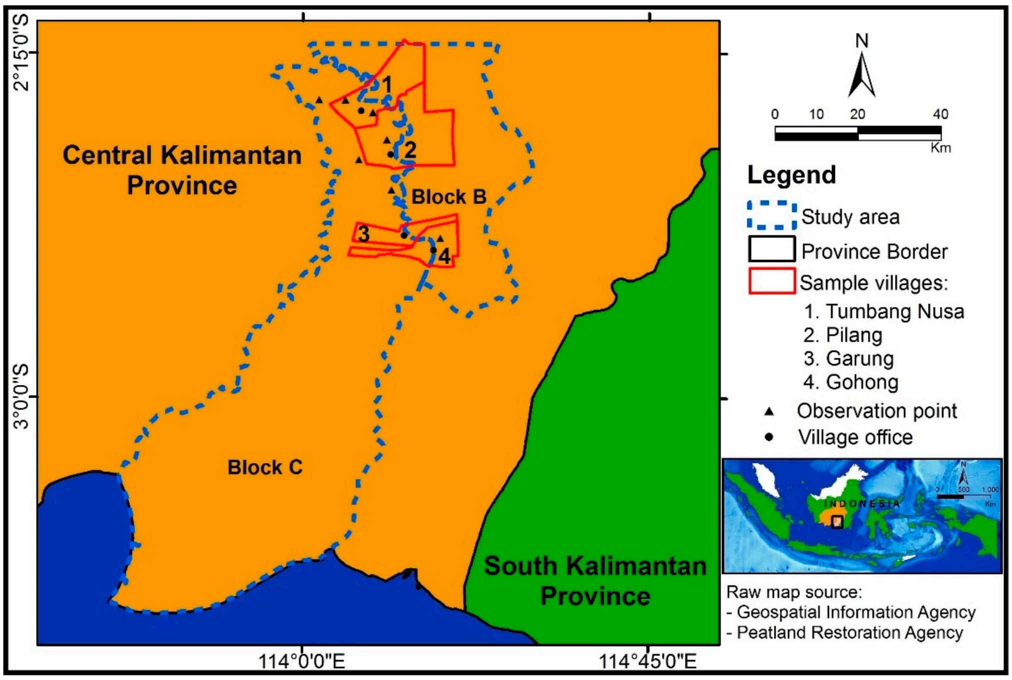


**Figure 2.** Research locations [51].

### 3.2. Data Collection Technique

The research was conducted from September 2020 to February 2021. To achieve the research objectives, data were collected on socioeconomic potential and risks, institutions, policies, flora and fauna, and land resources. Data collection on socioeconomic potential and risks was carried out through triangulation techniques, namely, a combination of interviews, field observations, and focus group discussions. Interviews were conducted involving 120 respondents selected based on stratification of the similarity in economic activity on peatlands [52,53], followed by field observations and FGDs. Institutional and policy data were collected through in-depth interviews with three key informants. Information on flora and fauna was collected from a survey of the community. Land resource data were collected from thematic land cover maps for 2020 [54], peat characteristics maps and administrative boundaries maps [51]. Based on the peatlands depth map, peat depths in the study area were categorized into shallow (0.5–<1 m), moderately deep (1–<2 m), deep (2–<3 m), very deep (3–<5 m), and extra very deep (5–<7 m) [55].

### 3.3. Data Analysis

Data were analyzed according to different aspects [56], namely, socio-economic conditions, institutions, policies, flora and fauna, and land resources. Qualitative analysis [48] was conducted to determine socioeconomic conditions, institutions, and diversity of flora and fauna. Content analysis [57] was used to describe the policy aspect. Spatial analysis was carried out to determine the potential of peatlands as FE areas. In spatial overlay analysis, we used an intersect tool in the form of land cover layers, village boundaries, area boundaries for blocks B and C, and peatland boundaries. Next, we tabulated the attribute table on the resulting layer [58]. The overall results of data analysis were validated through focus group discussions with experts and parties involved in the development of FE at the research site.

The overall results of the analysis were described qualitatively using risk analysis and theory. We performed a qualitative risk analysis using the AS/NZS matrix level 4360:1999 [59]. A risk is the chance of something occurring that will have negative effects. The level of risk reflects the likelihood of the undesired event and its potential consequences [60]. In the environmental context, risk is defined as the chance of harmful effects on human health or ecological systems [61]. Environmental risk assessment aims to assess the effects of stressors, often chemicals, on the local environment [62]. In risk analysis for FE development, we conducted a qualitative assessment using descriptive results to provide further support for the quantitative investigation and provide necessary information regarding risk management. Qualitative assessment is preferred for several reasons, as it (1) gives the perception of speed and ease of implementation, (2) appears to be more accessible and more easily understood by policy makers and others, and can be used when (3) there are insufficient data to conduct a quantitative assessment or (4) there are no mathematical means or facilities to assess risk [63]. We used the Delphi risk analysis method, a method for structuring a group communication process, to effectively reach a consensus of risk experts [64,65]. The Delphi technique was used because the issue under investigation does not lend itself to precise analytical techniques but rather can benefit greatly from subjective judgments on a collective basis [66].

To assess the likelihood and severity of risk, we adopted the risk matrix suggested by the European Commission [67] with a slight modification to the illustration description to suit the object of this study. There are five severity scales and five likelihood scales used in the literature. We modified and combined them with the descriptor from AS/NZS 4360:1999, as shown in Table 1. We conducted qualitative risk analysis based on matrix level of risk stated in the AS/NZS 4360:1999 [59].

**Table 1.** Description of risk severity and likelihood levels.

| No. | Scales | | Description |
|---|---|---|---|
| 1. | Severity level of risk | | |
| | Insignificant | 1 | Minor impact that can be recovered quickly and naturally; there are no tenure and horizontal conflicts; alternative sources of livelihood outside the agricultural sector are available; FE does not affect the social capital of the community; shallow peat <100 cm is more suitable for agricultural crops in successful rewetting efforts |
| | Minor | 2 | Causes a slight seasonal decline in tree and/or animal populations; absorption of unskilled labor; limited involvement by local workers (only members of farmer groups); emergence of latent social conflicts; FE affects social capital among farmer groups |
| | Moderate | 3 | Causes a decrease in forest cover for animal habitat and/or causes many species of wildlife to move in some areas; causes damage to crops or/and depredation of livestock; limited involvement by local workers (only the heads of farmer groups); there is a social conflict that can be resolved by discussion; FE affects social capital among farmers in one village; peat with a depth of more than 100 cm faces tougher challenges in water level management, where a failure or an ineffective rewetting process will make the water level difficult to control such that the greenhouse gas (GHG) emissions will fluctuate. |
| | Major | 4 | Causes habitat loss and habitat fragmentation; many wildlife species populations decline or leave the site; high competition for space and feed between livestock and wild animals; limited involvement of local workers (only high achieving farmer groups); open conflict occurs and conflict resolution in the negotiation process is more difficult; FE affects social capital among farmers in one sub-district |
| | Extreme | 5 | Forest cover has changed completely into cultivation areas that can no longer be used as habitats; almost all terrestrial wildlife species disappear or are moved from these locations; no increase in income; local workers are not involved; open conflicts occur; FE causes the loss of local wisdom in managing peat; peat with a depth of >200 cm has low fertility; the excessive use of fertilizers accelerates peat decomposition and exacerbates the physiological damage to peat; on thick peat, rewetting is more difficult, and failure to do so causes the peat to remain exposed, thereby emitting greenhouse gases. |
| 2. | Likelihood level of risk | | |
| | Almost certain | A | Expected to occur in most circumstances; has occurred in this location; no specific protection identified and applied |
| | Likely | B | Will probably occur in most circumstances; has occurred in this location; specific protection identified and applied |
| | Possible | C | Might occur at some time; has occurred in this landscape but not in a food estate |
| | Unlikely | D | Could occur at some time; has occurred related to FE development |
| | Rare | E | May occur only in exceptional circumstances |

Source: Modified European Commission risk matrix combined with descriptors from AS/NZS 4360:1999 [59].

## 4. Results

### 4.1. National Policy

Several policies issued by the Indonesian Government to support the development of FE areas in forest areas include (1) Government Regulation Number 23, 2021, concerning Forestry Implementation; (2) Presidential Regulation No. 86, 2018, concerning Agrarian Reform; (3) Regulation of the Minister of Environment and Forestry Number P.24/MenLHK/Setjen/Kum.1/10/2020, concerning Provision of Forest Areas for Food Estate Development; and (4) Regulation of the Minister of Environment and Forestry number 9, 2021, concerning Social Forestry Management. The provision of forest areas for the development of food estates was carried out through a scheme of releasing forest areas in conversion production forests, with one of its technical requirements being a strategic environmental study by an integrated team.

Forest estate development is also integrated with social forestry. Regulations related to social forestry management provide opportunities for communities that already have permits/approvals for social forestry management to utilize forest areas that are reserved for FE development. The Ministry of Agriculture also facilitates the ability of farmers to form farmer cooperatives that can run upstream of downstream agricultural businesses [68].

Through the Secretariat for the Acceleration of One Map Policy (PKSP), the government stated that there would be no clearing of forests and protected areas in peat ecosystems used for FE development. The government has carried out monitoring, supervision, and alignment of forest and peatland restoration activities since 2016.

We found that the direction of the FE development policy in Central Kalimantan optimizes the use of existing ex-PLG and non-ex-PLG lands [24]. Peatlands with a thickness of <300 cm can be used for agricultural cultivation areas. Peat areas with a thickness of >300 cm, areas that have high biodiversity (flora and fauna), and peat areas that have layers of sulfide sand and/or quartz are designated as Protected Areas [69–73]. Ministry of Environment and Forestry Regulation No. 24/2020, concerning Provision of Forest Areas for FE Development, allows the transfer of functions of protected forests and production forests for FE development. This regulation can pose a threat to the protected function of the landscape unit if such transfers are conducted without considering an environmental impact analysis.

### *4.2. Socio-Economics of Local Communities: Potential and Threats*

The characteristics of the population surrounding the FE candidate area represent a potential FE development actor. These human resources need to be involved in achieving the goals of increasing food production and developing the national economy. Several potential socioeconomic aspects include population demography, sources of livelihood, community interaction with peatlands, and farmer institutions.

The population density in the location was relatively low (30 people/km$^2$), and the population growth rate was also slow (<1%). The population in the four villages had a balanced sex ratio and was dominated by individuals of productive age (16–64 years). Most of the population had completed senior secondary education (SMA). The productive age population in Central Kalimantan was 1,413,780 people, with an open unemployment rate (TPT) of 4.25%. Approximately 5.4% of the working-age population was affected by COVID-19, i.e., not working (11.9 thousand people) or experiencing a reduction in working hours (92.58 thousand people) [74].

The main source of livelihood was closely related to the location of the settlement. Members of the Tumbang Nusa community, who live along the Kahayan River, mostly worked as river fishermen and at cage fisheries. The residents' side livelihood consisted of working as traders, because there is no suitable arable land for farming activities. Meanwhile, the people of Pilang, Garung, and Gohong villages, who live along the Trans Kalimantan road, mostly worked as farmers with secondary jobs as traders and in raising fish in ponds (Table 2).

**Table 2.** Socio-economic conditions of communities at the research location.

| Socio-Economic Aspect | Name of Village | | | |
|---|---|---|---|---|
| | Tumbang Nusa | Pilang | Garung | Gohong |
| Main livelihood | Fishermen | Farmers and rubber tappers | Farmers and rubber tappers | Farmers and rubber tappers |
| Side livelihood | Traders | Traders, rattan crafts | Traders, rattan crafts | Traders, fishpond farmers, rattan craft |
| Arable area | No arable land | 2–5 ha | 2–5 ha | 2–5 ha |
| Mean income/month (USD) | 172.118 | 137.69 | 172.118 | 172.118 |

Note: USD1 ≈ IDR 14,525.

Most people in Central Kalimantan have always used peat forest areas as agricultural land and settlements [75–78]. The community has a fairly large amount of arable land (2–5 Ha/HH), but with low productivity [79]. To earn additional income, residents generally cultivate green papuyu, patin, and catfish in their yards via a tarpaulin pond system. Other sources of livelihood include raising native chickens and broilers and swallow cultivation, which can increase income [80]. In Pilang, Garung, and Gohong villages, the communities also earned secondary income from weaving rattan into accessories and other products (bags, hats, and mats). This effort generated approximately 6.85–26.54 USD/year. This business is already quite developed and supported by the local government. Most respondents in the four villages had an average income of 137.7–172.18 USD/month. This income is lower than the Pulang Pisau Regency Minimum Wage (UMK) in 2020 of 202.92 USD.

To meet basic needs, the community takes products from forests, including both timber and non-timber forest products (NTFP), and cultivates peatlands for planting and agricultural development [81,82]. This shows the socioeconomic dependence of the people in these four villages on peatlands to meet their daily needs [83]. Figure 3 shows the reported collection of forest products, both timber and NTFPs, in the study area to meet daily community needs.

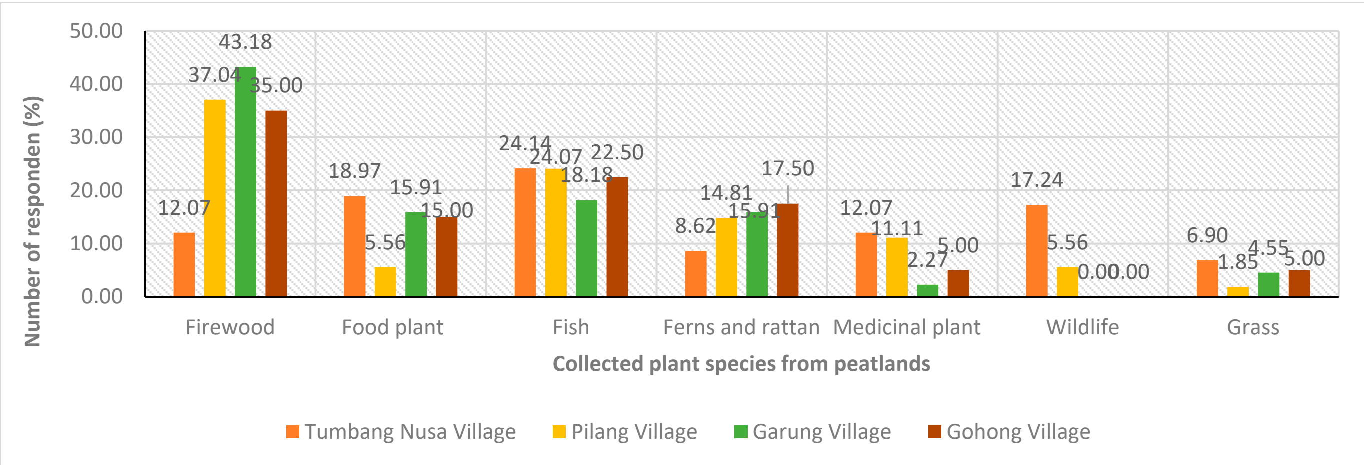


**Figure 3.** Community interactions with peatlands.

Most of the residents of Pilang, Garung, and Gohong villages use peatland as a source of firewood for their own consumption. Medicinal and non-medicinal forest products such as bajaka (*Patholobus littoralis* Hassk), kayu kuning (*Fibraurea tinctoria*), and forest honey are taken for sale. They also consume wildlife, such as *Rusa unicolor* and *Treron* sp. birds.

Harvesting activities on peatlands are generally carried out individually, not in groups. Meanwhile, for farming activities in forest areas, residents generally form groups known as farmer groups, community institutions, and village institutions. The various groups at the local level have the potential to be developed into FE actors (Table 3).

To date, there are eight groups of farmer institutions and village institutions that have the potential to become actors in FE development. Each institution has its own duty [7]. Most of these groups were formed as a result of government projects or programs. Although such groups have a limited number of members, it is hoped that the various activities developed can inspire and encourage other farmers to be more advanced. The group has great potential to become a forum for FE development on peatlands. However, FE development on a large scale will not succeed if it relies only on institutions at the village level. The FE program needs to be integrated with various other supporting programs and involve various stakeholders in various roles and responsibilities, including the central government level, local governments, private parties as investors, financial institutions, and other related stakeholders [7,84].

**Table 3.** Institutions with the potential to be developed into FE actors.

| No. | Institution Name | Number of Members in the Group (Person) | Purpose |
|---|---|---|---|
| 1. | Forest Farmer Group | ±15 | Conducting forestry business |
| 2. | Paddy and Vegetable Farmer Group | ±10 | Conducting agricultural business |
| 3. | Estate Crop Farmer Group | ±12 | Developing rubber or oil palms |
| 4. | Fishery Farmers Group | ±14 | Developing diversification and basic shares of marine and fishery production |
| 5. | Village-Owned Enterprises (Bumdes) | >3 | Improving the economies of village communities |
| 6. | Village Forest Management Institution (LPHD) | >16 | Managing forest area so that it can be of economic value for the welfare of its members |
| 7. | Fire Care Community groups | 20 | Controlling forest and land fires |
| 8. | Community groups that care about dams and water | 10 | Regulating the water level on peatlands |

### *4.3. Biodiversity: Potential and Threats*

Peat swamp ecosystems have specific characteristics, including variations in substrate surface temperature, low oxygen content, accumulation of toxic substances in peat, poor nutritional value, high acidity, high water levels, and excess humidity [85]. Therefore, they support unique biodiversity with distinct flora composition [33,85]. Most tree families and many genera of lowland evergreen dipterocarp rainforest are found in peat swamp forests [86]. Several species of wild flora are used by local people as food sources, including *Stenochlaena palustris*, *Calamus rotang*, *Sandoricum kotjape*, *Garcinia bancana*, and *Durio* spp. Several cultivated species have also been planted including, among others, fruits and vegetables such as *Solanum melongena*, *Capsicum annum*, *Sechium edule*, *Sauropus androgynus*, *Ipomoea batatas*, *Manihot esculenta*, *Durio zibethinus*, *Garcinia mangostana*, *Psidium guajava*, *Dimocarpus longan*, *Hylocereus domesticum*, *Hylocereus domesticum*, *Artocarpus heterophyllus*, *Artocarpus integer*, *Citrus sinensis*, *Persea americana*, *Carica papaya*, *Nephelium lappaceum*, *Syzygium aqueum*, *Pometia pinnata*, *Musa* spp., *Citrullus lanatus*, and *Elaeis guineensis*.

Tropical peat swamp forests provide habitats for a considerable proportion of the region's fauna and are important for the conservation of threatened taxa [33]. Usually, the abundance of wildlife is greater in mixed swamp forests on the periphery of the peat dome [87,88]. In the prospective food estate area, we found 51 species of birds and nine species of mammals. The mammals recorded were *Pongo pygmaeus wurmbii*, *Presbytis rubicunda*, *Hylobates albibarbis*, *Helarctos malayanus*, *Rusa unicolor*, and *Lutra sumatrana*, *Tragulus napu*, as well as two protected endangered species, *Sus barbatus* and *Callosciurus notatus*. We also found two reptiles, *Dogania subplana* and *Python breitensteini*.

A number of wildlife species in the prospective food estate area were found and utilized by local communities, including *Rusa unicolor*, *Sus scrofa*, *Tragulus napu*, *Dogania subplana*, *Python breitensteini*, *Treron* sp., and *Collocalia fuciphaga*. *Rusa unicolor* and *Tragulus napu* are endangered species protected by Indonesian law. Aquatic biota found and utilized by local communities include several fish species, such as *Channa striata*, *Channa pleurophylla*, *Channa micropeltis*, *Channa Lucius*, *Rasbora* sp., *Wallago laeri*, *Trichogaster trichopteris*, *Pagasius* sp., *Leptobarbus melanopterus*, *Helastoma teminckii*, *Crypterus* sp., *Anabas testudineus*, and two species of shrimp, *Macrobrachium roserbergii* and *Liopenaeus vannamei*. Local communities also raise fish species such as *Anabas testudineus*, *Pangasius* sp., and *Clarias* sp. Many people raise *Bos indicus* by releasing them in peat swamp forests for grazing. Some also harvest honey from wild bee species and rear *Trigona itama*. From the surrounding forest, local communities harvest flora and wildlife products from peat areas with 50–300 cm depth. The cultivation of plants and fish takes place on peat areas with 50–200 cm depth.

All wild species used by the community have commercial value. One *Rusa unicolor* weighing 100–257 kg is worth 206.54 USD, or 5.50 to 6.88 USD per kg. Each *Dogania subplana* is worth 0.69 to 1.37 USD. The skin of a *Python breitensteini* is sold for 34.42 to 68.96 USD, and the meat is commonly consumed by local residents. Species of cultured fish (*Anabas* *testudineus*, *Pagasius* sp., and *Clarias* sp.) are sold at a price of 1.37 to 4.82 USD [89,90]. Shrimp of the species *Macrobrachium roserbergii* and *Liopenaeus vannamei* cost 10.33 to 27.54 USD per kg [91,92]. Natural honey from wild bees costs 6.88 to 27.538 USD per liter.

Peat swamp forests support a substantial number of rare, specialized, and threatened species. Posa et al. [33] found that 45% of mammals and 33% of birds recorded in peat swamp forests had IUCN Red List status of near threatened, vulnerable, or endangered. Peat swamps are also important for the conservation of a number of endangered primate species. The richest habitats for orangutans are high-quality swamp forests and lowland alluvial forests [33,93]. The remaining peat swamp forest around the cultivated land can offer protection to wildlife disturbed by human activities [88,94–96]. In the proposed food estate area, we found endangered primates, namely, *Pongo pygmaeus wurmbii* and *Hylobates albibarbis*, and another endangered animal, *Lutra sumatrana*. Vulnerable wildlife such as *Helarctos malayanus* and *Rusa unicolor* are also often found in the proposed FE area. The conversion of natural peat swamp forests into massive cultivation areas will eliminate habitat attributes and cause the local extinction of various endangered and vulnerable wildlife species. Cultivated peat swamp forests are prone to severe fires, usually under extreme drought conditions, that can destroy thousands of hectares of biodiversity habitat [97,98].

Tropical peatland forests contain a number of valuable timber species, often at high densities, and have thus been intensively exploited all over Southeast Asia [33]. The proposed FE area is already largely secondary forest, where many high-quality tree species have been logged. Once the area is considered no longer productive for producing timber, exploitation continues by using it for agricultural land and the harvesting of non-timber forest products. These activities can threaten the integrity of the peatland forest as a habitat for various increasingly threatened endemic flora and fauna species. The threat increases since local people hunt such wild animals to meet their protein needs. Harvesting *Cervus unicolor*, *Tragulus napu*, *Dogania subplana*, *Python breitensteini*, and *Treron* sp. is detrimental to the conservation efforts being carried out by the government. The availability of flora and fauna in the proposed FE areas can directly substitute for the diversity of food species that can be developed to support food barns on peatlands. However, overuse results in the risk of reducing populations in nature. Protected forest and secondary forest are peat swamp forest areas with an average depth of >300 cm that are important to maintain for biodiversity conservation [99], especially for endangered species of wildlife such as orangutans, sun bears, kelawet, kelasi, and waterbirds [100,101]. These species require habitats with trees >20 m high for sleeping, socializing, feeding, and nesting [102,103]. However, the availability of food sources in this area is very limited; therefore, these animals sometimes travel to nearby settlements to eat fruits such as rambutan, banana, and durian and staple foods such as corn, hence inducing wildlife conflict.

The cattle breeding program in Jabiren Raya Sub-District, with the assistance of BRG (Badan Restorasi Gambut), was developed through the release of 38 cows into the peat swamp [104]. However, the release of Bali cattle could have an impact on peatland biodiversity and ecosystem function due to overgrazing and the emission of large amounts of methane through burning and flatulence [105,106].

### *4.4. Land Resources: Potential and Threats*

In their natural condition, peatlands play a major role in climate change mitigation because the accumulation of carbon content in them is able to offset the impact of methane and nitrogen oxide emissions. Drainage, tillage, and fertilization are agricultural activities resulting in rapid decomposition of peat. These activities turn peatlands into greenhouse gas (GHG) emitters. To reduce the rate of GHG emissions, actions to convert peatlands must be controlled and accompanied by rewetting and afforestation. If the land is cultivated as agricultural land, then the application of paludiculture can be a possible solution [107].

An overlay of four maps—a map of the area of interest for increasing food supply in Central Kalimantan, a map of forest areas, a map of peat depth, and a map of land cover—

produces a map of land potential (Figure 4). Potential indicative areas for development are in APL (area of other uses), HP (production forest), and HL (protected forest) with peat depth of less than 3 m and non-forest cover. Detailed results are presented in Table 4.

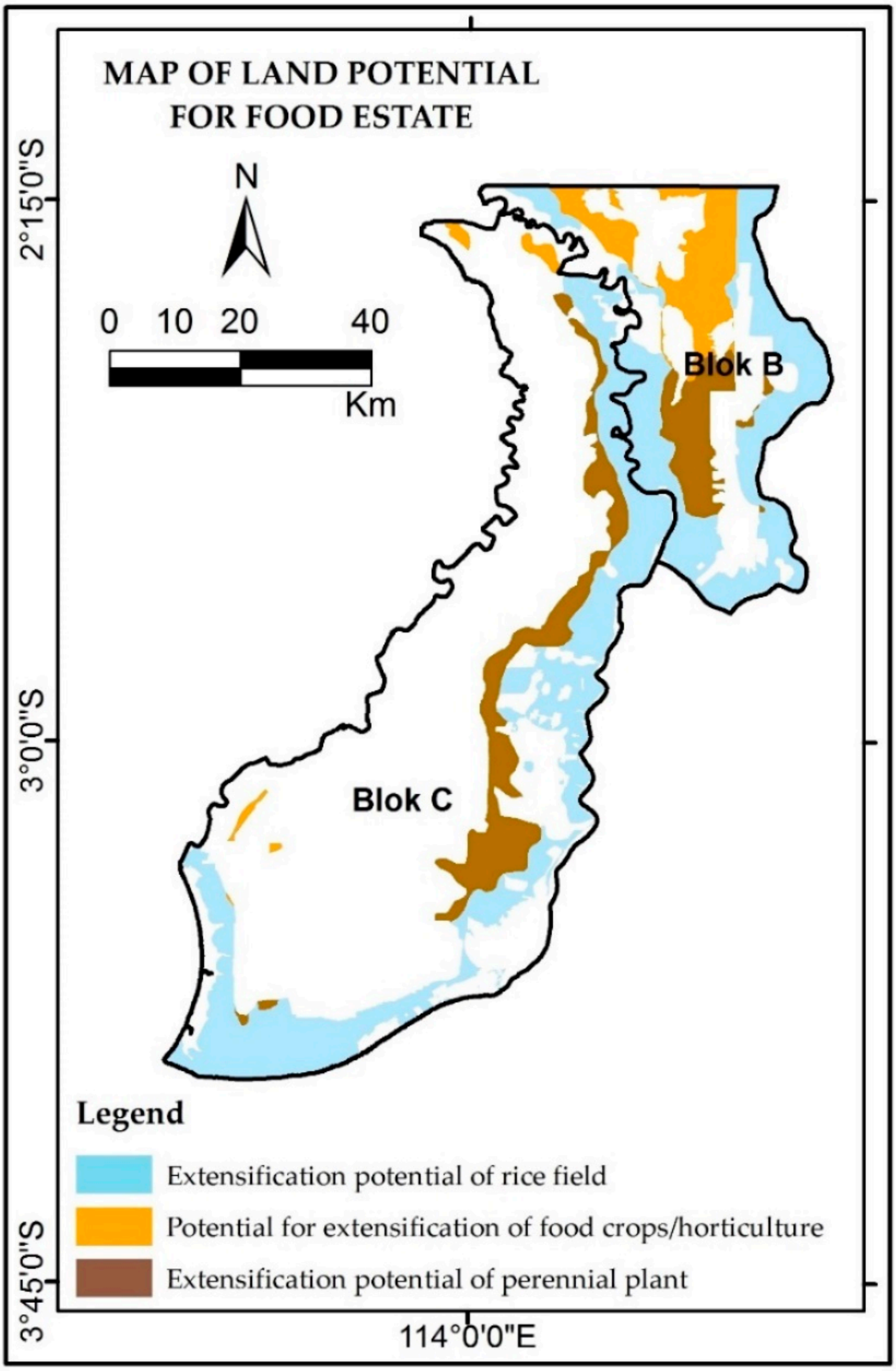


**Figure 4.** Result of spatial analysis of land potential for food estate development.

**Table 4.** Potential indicative area for FE development.

| Land Status | Peat Depth (cm) | Potential Area (Ha) | | | | Risk |
|---|---|---|---|---|---|---|
| | | Paddy Field | Horticulture | Perennial Crop | Total | |
| APL | Mineral soil | 74,984 | 730 | 190 | 75,905 | Low |
| | 50 < 100 | 5630 | 1 | | 5631 | Low |
| | 100–300 | 1457 | 926 | 5610 | 7993 | Moderate |
| HL | Mineral soil | 19,052 | 45 | 17 | 19,114 | Moderate |
| | 50–<100 | 11,787 | 125 | 406 | 12,318 | Moderate |
| | 100–300 | 1584 | 26,219 | 29,426 | 57,229 | High |
| HP | Mineral soil | 30,177 | 270 | 239 | 30,686 | Low |
| | 200–300 | 2026 | 814 | 15,106 | 17,946 | High |
| | Total | | | | 226,823 | |

APL, area of other uses; HK, protected forest; HP, production forest.

The results of the land potential analysis show that the greatest potential in blocks B and C of the ex-PLG area is in non-forest areas (mineral soils) with an area of 75,905 ha. Other potential mineral lands are in the HP area, totaling 30,686 ha. For peat soils, the land with the greatest potential is in the HL area, with a peat depth of 100–300 cm and an area of 57,239 ha. However, this area has a high risk because the function of peat in managed protected areas is not sustainable, and development can further worsen peat damage and affect the surrounding peat-protected areas. In such conditions, the food plants to be cultivated should be tree species proven to be able to adapt to humid or flooded areas [108]. This is important to note because the protected function of peat, even if it is later transformed into a FE area, should be maintained by adjusting the species and plant cultivation pattern.

The development of FE on peatlands also faces threats from the effects of climate change, in the form of a long dry season and an uncertain rainy season [109,110]. The conditions of open land in secondary swamp forest and a longer dry season due to El Niño occurred in 2015 [111], making Indonesia, including areas in Kalimantan and Sumatra, vulnerable to severe fire [112]. The impact of these fires can be seen in the four villages, specifically in Tumbang Nusa village. The fire area was approximately 2000 hectares, including 500 hectares of rubber plantations and secondary swamp forest, galam forest, mixed forest, and mountain rice farming land [77]. In addition, these fires also damaged the hydrological properties of peat, resulting in hydrophobic peatlands that have potential as fire raw materials [113] and causing soil to become flammable [114]. If not accompanied by rewetting efforts, the expansion of agricultural land and plantations planned in the FE program will cause a decline in the peat hydrological function, as peat tends to become drier in the dry season [115]. Without rewetting efforts, the expansion of FE is not in line with climate change mitigation, because drained peat remains a significant contributor to $CO_2$ emissions due to high organic matter decomposition [116]. Likewise, the number of waterways or canals for transportation has resulted in changes in the hydrological system. The hydrological system in the peat soils in the four villages tends to be horizontal; i.e., in the rainy season, the water level will be quite high, while in the dry season, it will be very dry and easily burnt [117].

### 4.5. Risk Identification

The FE program on peatlands in Central Kalimantan has received attention because its development takes place in an ex-PLG (peatland development) zone that has been degraded. Under conditions of a limited quality of land resources, FE is expected to improve people's welfare in the form of a multiplier effect, including employment, increased income for farmers, and growth in other sectors, which will affect regional economic development. After identifying several potential benefits and threats that might hinder the development of FE, we found possible risks to the substitutability of natural resources, which are detailed in Tables 5 and 6.

**Table 5.** Identification of risks if FE development on peatlands does not occur.

| No. | Activity | Risk Identification |
|---|---|---|
| 1 | Hunting or harvesting wildlife | Populations declining and threatened species to become extinct |
| 2 | Human activities in wildlife habitats | Edge effects and reduced space for animal activities |
| 3 | Conventional farming | Low productivity, low income |
| 4 | Free grazing husbandry | Competition with wild animals, transfer of disease |
| 5 | Farmer institutions have not been effective | Difficult to develop on a large scale or industrial scale (plantation) |
| 6 | Limited agricultural infrastructure, roads, and bridges | Distribution of food production is not optimal |

**Table 6.** Identification of risks if FE development on peatlands does occur.

| No. | Activity | Risk Identification |
|---|---|---|
| 1 | Drainage system | Habitat fragmentation, drought, fire risk |
| 2 | Extensive peat swamp forest conversion | Loss of habitat, reduction in peat swamp tree species, animal–human conflicts |
| 3 | Introduction of exotic animal and fish species | • Can become invasive to the detriment of native species<br>• Transmit disease to native species<br>• Become competitors and suppress native animal populations |
| 4 | Monoculture rice crop development | • Limited food sources and alternative income sources |
| 5 | Determination of FE area and infrastructure development does not accommodate the interests of all communities | Social conflicts that hinder the acceleration of local economic recovery |
| 6 | Mechanization of agriculture and modernization of the agricultural system | • Not all energy is absorbed<br>• Changes people's mindset and behavior (becoming more exploitative) |
| 7 | Development of FE requires a large investment | Possession of assets by several parties (corporations) |
| 8 | FE development location is not clear or clean | Potential for tenurial conflicts |
| 9 | Use of fire-prone peat areas | Degradation of habitat quality, destruction of habitat, destruction of various types of animals |
| 10 | Use of 100–300 cm depth peatlands in protected forest areas | High risk to surrounding peatlands |

Tables 5 and 6 show an increased risk if FE development is carried out on peatlands. However, from the possible risks that we identified, mitigation efforts can be made to minimize these risks.

## 5. Discussion

### *5.1. Risks Analysis and Mitigation*

From the possible risks we identified (Appendix A), we devised a mitigation strategy by considering past experiences in the same area. In this study, we did not quantify the risk but only obtained qualitative indications. Therefore, our recommendations are based on the prudence principle [118]. These mitigation measures are part of risk management, defined as an activity that integrates the recognition of risk, risk assessment, development of strategies to manage it, and risk mitigation using managerial resources. The strategies include transferring the risk to others, avoiding the risk, reducing its negative effect, and accepting the consequences of the risk [119].

Various anticipatory efforts are needed so that similar failures to those that happened in the past can be prevented. We identified nine risks to biodiversity with a scale of low to extreme severity, and offer a mitigation action strategy for each risk. The mitigation measures are developed to respond to the threats and introduce corrections [63]. The recommendations for risk mitigation shown in Table 7 indicate the required conditions to ensure that food estate development is achieved.

**Table 7.** Recommendations for risk mitigation strategies for biodiversity.

| Risks to Biodiversity | Category of Severity | Mitigation Management |
|---|---|---|
| 1. Hunting or harvesting of wildlife causes population decline and threatens extinction | Extreme | Foster animal husbandry, the captive breeding of wildlife, and freshwater fisheries to meet animal protein needs |
| 2. Human activities in wildlife habitats cause edge effects and reduce the space for wildlife activities | High | Minimize the activities of food estate workers on the edge of the conservation area and create a vegetation buffer on the conservation area |
| 3. Livestock species that have the same feeding habits as wild animals will become competitors and risk becoming invasive and suppressing native wildlife, hence causing decline or extinction of populations | High | Cattle should not be freely grazed in the wild, but rather should be raised and reared in fenced areas, and a feed garden should be created to meet the needs of animal feed |
| 4. Livestock species can transmit diseases to wildlife and cause population decline | Medium | Cattle should not be freely grazed, but rather should be raised and reared in fenced areas |
| 5. The introduction of exotic fish species into natural swamps can be invasive, which is detrimental to native fish species | Extreme | Conduct fish farming with a pond system that is not directly connected to open waters |
| 6. Diseases suffered by fish cultured in peat swamps can be transmitted to native species | Low | Conduct fish farming with a pond system that is not directly connected to open waters |
| 7. Agricultural development through draining swamps and building canals causes the habitat of wildlife and aquatic biota to shrink, causing the fragmentation of swamp habitats, which in turn can disrupt the survival of various species of wildlife and aquatic biota | Extreme | Connect the swamp landscape by creating canal corridors and green belts |
| 8. Agriculture in peat swamps is prone to land fires which can reduce habitat quality, destroy habitats, and destroy various animal species | High | Forbid slash and burn farming. Cultivate suitable swamp habitat plants so there is no need to dry the swamp |
| 9. Extensive peat swamp forest conversion via land clearing causes valuable peat swamp tree species to become scarce or unavailable | Extreme | Leave intact vegetated areas to conserve endemic tree species, especially in deep peat areas. Apply an agroforestry system that combines agricultural crops with local forest trees |

In addition to biodiversity risk, we also found twelve socioeconomic and land use risks with moderate to extreme severity scales. Table 8 shows the recommendations for socioeconomic risk mitigation and land management strategies.

**Table 8.** Recommendations for socioeconomic risk mitigation and land management strategies.

| Socio-Economic and Land Use Risks | Category of Severity | Mitigation Management |
|---|---|---|
| 1. The current FE development has not been supported by adequate community capacity | Moderate | Increase community capacity through training and education in peatland protection and management |
| 2. Farmer institutions at the village level causes the food value chain to not be inclusive or integrated from upstream to downstream | Moderate | Form institutions among stakeholders related to food estate development programs, both at the local and the central levels |
| 3. FE development requires a large investment, which causes asset control by several parties (corporations) | Extreme | Develop incentives and access to capital to manage and protect peatlands |
| 4. Uneven agricultural infrastructure assistance causes social conflict | High | Socialize the FE program in every village that has administrative boundaries with the prospective FE development area |
| 5. The selection of project locations causes unequal distribution of agricultural land | Moderate | Socialize the FE program in every village that has administrative boundaries with the prospective FE development area |
| 6. No clear and clean definition of the area status, resulting in tenure conflicts | High | Identification of potential FE areas with related stakeholder involvement |
| 7. Agricultural mechanization causes low absorption of labor | Extreme | Increase skill activities in various forms of business that can be developed |
| 8. Intensive technology and digitalization have changed community culture and behavior towards peatlands | High | Develop appropriate technology for the management and utilization of peatlands based on community knowledge |
| 9. Utilization of peatlands in protected forest areas with 100–300 cm depth has a high risk for the surrounding peat-protected areas | Moderate | Manage degraded peatlands in the development of FE in line with peat restoration efforts. |
| 10. Mechanization and technological input in improving land quality by chemical fertilizers treatment will cause biophysical changes to natural peatlands | Moderate | Form specific formulations for peatland farming that can maintain the organic cycle |
| 11. Limited infrastructure in the prospective FE locations can hamper food production distribution | High | Construct road and bridge adopting peat-friendly technology |
| 12. The use of similar plants (monoculture) limits alternative sources of income | Moderate | The use of various species in the context of integrated multi-business (agriculture, livestock, fisheries, and forestry) to increase the variety of income sources |

Based on the identification of risk sources (Appendix A), we found five sources of risk. The results of the analysis show that the development of FE on degraded peatlands has a moderate to high level of risk (Table 9).

Based on the evaluation of risk, we found that community activities and farming methods would be most at risk of being affected by FE development. Humans would be most affected by the development of FE because of the changes that occur. In addition, the development of FE would have an impact by changing farming methods from conventional to modern. FE development provides a low-risk impact in terms of aquaculture. Thus, the introduction of fish species in fishery activities to be developed in the FE area would have a low-risk impact.

**Table 9.** Recapitulation of risk analyses regarding food estate development.

| | Sources/Hazard Factors | Risk Analysis | | | | Total |
|---|---|---|---|---|---|---|
| | | Low | Moderate | High | Extreme | |
| 1. | Human | | 3 | 3 | 2 | 8 |
| 2. | Paddy development in peatland | | 1 | 1 | | 2 |
| 3. | Free-grazing livestock species | | 1 | 1 | | 2 |
| 4. | Farmed fish species | 1 | | | 1 | 2 |
| 5 | Farming method | | 2 | 2 | 3 | 7 |
| | Total | 1 | 7 | 7 | 6 | 21 |

### *5.2. Operational Strategy*

Considering the many risks that may occur when a food estate is operated, several strategic steps are needed that are based on strong sustainability principles. We propose strict adherence to our recommendations as follows:

(1) Landscape management;
(2) Maintenance of conservation value and vulnerable areas as protected areas;
(3) Prevention of fragmentation and maintenance of habitat connectivity via corridors;
(4) Land management system with low impact (paludiculture);
(5) Integrated multi-business development (agriculture, animal husbandry, captive breeding, fisheries, and forestry);
(6) Community-based food estate.

#### 5.2.1. Landscape Management

The food estate area is both a forest landscape and a hydrological system or watershed. Therefore, it must be managed on a landscape basis. Consequently, it must be managed in an integrated manner across the sectors involved to increase efficiency and effectiveness and minimize risks.

Land potential analysis shows that apart from mineral soils, the greatest potential for FE development is in protected forest areas, especially those with a peat thickness of 100–300 cm. This condition has high risk, so land management must pay attention to the suitability of the species and pattern of plant exploitation. At peat depths up to three meters, the appropriate cultivation is the development of fruit tree species or other non-timber forest products (NTFPs) and honey. The main consideration in designing the farming pattern on peatland to be developed is the low level of substitutability of peatland resources, with irreversible consequences. Hence, the challenge is to utilize degraded tropical peatland for agriculture while avoiding negative impacts and ensuring environmental sustainability [25].

Management of degraded peatlands for FE development must be in line with peatland restoration efforts. The construction of new drainage canals or ditches to lower the water table should be avoided because it will exacerbate the level of peatland degradation [120,121]. Drained peatlands cause peat that should be in moist conditions to be exposed [122]. Through chemical reactions and biological processes, exposed peat will exacerbate the impacts of climate change [123], causing changes in hydro-physical characteristics [124,125] that disrupt the peatland's hydrological balance [121] and increase fire vulnerability [126]. Therefore, burning during land preparation is forbidden because of the risk of uncontrolled fires that expand the area of degraded peatland and have other socio-ecological impacts [121]. Changes in the biophysical conditions of peatlands resulting from various activities will threaten the sustainability of land use and food security in peatland areas. This is a consequence of human actions in the use of high-risk natural capital. On the other hand, these changes increase the potential for the presence of various types of commodities in peatlands. Therefore, an assessment of the characteristics of peatland damage is needed to achieve a sustainable food system [127]. Specifically, farming that can maintain the organic matter cycle in peatlands will better ensure sustainability [128]. The organic matter cycle will overcome subsidence problems [129], mitigate hydrological disasters [130], manage land acidity, and avoid exposure to pyrite materials [131].

#### 5.2.2. Maintenance of Conservation Value and Vulnerable Areas as Protected Areas

The development of FE on peatlands has a high risk of extinction of threatened species. Areas that are kept intact must maintain valuable biodiversity. Vulnerable deep peat areas may also be converted unintentionally. This, of course, will be detrimental and risky. Therefore, it is recommended that areas with intact forest and deep peat areas be maintained as protected areas. One effort is to carry out restoration, especially in areas where the protected function is degraded. Restoration is conducted using local species that function ecologically and can be utilized by the community without damaging the trees, such as in the form of non-timber forest products (NTFP) [132]. Restoration should involve the community so as to increase their knowledge regarding the importance of the peat ecosystem and its sustainable use [133].

#### 5.2.3. Prevention of Fragmentation and Maintenance of Habitat Connectivity via Corridors

The development of a large-scale FE will have an impact on the fragmentation and degradation of habitats that are important for the survival of biodiversity [134,135]. Areas still intact should not be converted, as habitat connectivity might be cut off, reducing biodiversity [136]. Therefore, the development of FE should leave intact forests and other areas that have high conservation value, and create connecting corridors in fragmented habitats [137]. Corridor construction should be planted with animal feed tree species, especially for primate orangutan species that usually enter community gardens, often during the fruiting season, causing conflict [138,139]. To maintain peatland forests in good condition, protecting and conserving their ecosystem structure, including biodiversity and peat depth conditions, is necessary [140].

#### 5.2.4. Low-Impact Land Management System (Paludiculture)

Sustainability innovation has normative goals, particularly related to the United Nations Sustainable Development Goals (SDGs) to eradicate poverty, promote social justice, and protect life-supporting systems. Sustainability innovation is underpinned by strong sustainability, and paludiculture is an option that can meet the SDGs [141] by offering habitats for biodiversity, conserving carbon stocks and restoring sinks [142], regulating and purifying water [143], and providing cultural value and recreational opportunities [144].

The application of paludiculture is the best alternative for FE development programs on peatlands that face various challenges and risks in development. Paludiculture requires the development of plants that are native to peat or capable of adapting to wet peatlands [132]. This requirement is closely related to the implementation of the strong sustainability concept, which requires using only the original species or species that can adapt to wet peat to ensure the ecological and sustainability of peatland with limited natural resources.

In addition, considering the ecological impact of agricultural development on peatland and the inability of dryland species to support peat formation, Giesen and Sari [145] suggest that agroforestry can be an alternative, mixing species such as jelutung with horticulture species such as mangosteen that are suitable in acidic peat conditions.

Management of degraded peatlands as sustainable food sources can overcome the constraints of peat's physical and chemical properties and achieve the objectives of environmental protection and poverty reduction. Its implementation includes sustainable agriculture practices [146] and good agricultural practices [147]. These practices are carried out to restore soil quality and mitigate degradation, are essential for food security, and optimize the sustainable use of resources. Various strategies have been developed and can be adapted to achieve sustainable agriculture on peatlands, such as the application of paludiculture techniques [148], the development of local community agroforest systems [149], and the use of environmentally friendly agricultural materials [150].

Optimal land use with paludiculture principles is believed to ensure the sustainability of peatland use [151,152]. The application of paludiculture is highly recommended because it is in line with the use of undrained peatlands or rewetted peatlands [153]. Ideally, planting in the FE would use several economically viable food-producing native species. Under certain conditions, it could be combined with tolerant introduced species that support rewetted peat conditions to create a nearly ideal ecosystem for the growth of climax species [122].

Giesen [145,154] indicated four species groups for paludiculture that can be developed on degraded peatlands: namely, fast-yielding species (*Eleocharis dulcis*, *Ipomea aquatica*, *Memordia charantia*, *Nephrolepis biserrata* and *Stenochlaena palustris*), proven commercial species (*Aquilaria beccariana*, *Melaleuca cajuputi*, *Metroxylon sago*, *Dyera polyphylla*, *Nothophoebe coriacea*, *Nothophoebe umbelliflora*), commercial plants that still require yield testing (*Garcinia mangostana*, *Nephelium lappaceum*, *Syzygium aqueum*, *Aleurites moluccana*, *Pometia pinnata*, *Syzygium polyanthum*), and potential species that require further ecological studies and market studies (*Mangifera griffithe*, *Dyera costulata*, *Rattan sega*). To improve an environment's sustainability, the degraded areas of peatland must be restored with species that are suitable for each peat depth, as well as with improved hydrology by maintaining a ground water level that is the same height as the ground level and can store carbon [140]. The plants that can be developed can be of NTFP species such as *Palaquium* sp., *Payena leerii*, *Garcinia parvifolia*, *Gonystylus* spp., and *Aquilaria* spp. These species of plants can be planted at a peat depth of less than 50 cm.

In implementing large-scale paludiculture, economic feasibility is one of the important factors to consider [132]. In the economic sense, the type of plant that is cultivated will affect the profits obtained. For example, although the sago palm is very ecologically compatible with the paludiculture concept, further government support is still needed. It is necessary to develop derivative products from sago, superior seeds with high productivity, and market breakthroughs at national and international levels [153].

#### 5.2.5. Integrated Multi-Business Development (Agriculture, Animal Husbandry, Fisheries, and Forestry)

An alternative to improve the community's economy can be achieved with social forestry programs by the harmonization of land management considering protection and cultivation functions [139,155]. However, agricultural cultivation on peatlands should be executed carefully, since some studies revealed that agricultural cultivation on peatlands in Indonesia was not agronomically suitable. Only parts of peatlands are suitable for food crops, horticulture, and plantations due to low levels of peat maturity, obstructed drainage, flooding, organic matter, acid content, low nutrient content, and broad plant roots [25,108,156–158]. A study by Firmansyah et al. [159] found that rubber farming in Jabiren Village, Pulang Pisau Regency, was categorized as marginally suitable with better management, when land suitability could potentially be improved.

Biophysical differences within peatlands make it impossible to integrate food cultivation, livestock, fisheries, and forestry in one large area. However, it is possible to combine several business activities (multi-business development) that can be carried out by one business group. Peatland management is profit-oriented. Integrating various kinds of businesses can minimize business risk. The business model for peatland FE that can be developed would combine rice cultivation with captive swiftlets, captive breeding of unicolor deer, rearing of fish, and cultivation of food plants commonly used by local people as food sources, medicinal plants, raw materials of handicraft, and horticulture. On degraded peatlands with secondary forest cover, various alternative peat-friendly species such as *Shorea balangeran*, *Dyera costulata*, and *Gonytsilus bancanus* can be cultivated, having both economic and ecological benefits.

Some villages that have implemented social forestry village forest schemes can be encouraged to increase their group capacity in order to become a Social Forestry Business Cooperative (KUPS) of the silver to platinum category. This category has a work plan and business units to support business success.

However, integrating multi-business development with the availability of various resources, including land, water, and farmers, alone will not be sufficient to achieve the goal of FE development without policy support from the government. Nizami et al. [21] indicated several supporting policies that should be provided by the government, including financing to increase grain production, building new dams and maintenance of ongoing dams, and rehabilitation of irrigation canals in FE development areas.

#### 5.2.6. Community Based Food Estate

The policy of providing forest areas for FE use and the integration of social forestry programs entails the use of natural capital for community welfare. A social forestry program is a harmonization of land management considering both protection and cultivation functions [139,155]. Integrating ecological and economic interests in the development of FE is a win-win solution; thus, the objectives of FE development are to ensure that food security can be achieved while considering peatland conservation. The limited capital available for farming, the low capacity of farmers, the high dependence of community economic resources on peatlands, and the lack of optimal community institutions indicate that there is a moderate level of risk associated with the sustainability of FE on peatlands. Various efforts are needed. Hence, certain human actions that can lead to irreversible consequences should be prevented as early as possible. Various efforts to increase farmers' capacity include (1) increasing knowledge, skills, and community assistance, (2) facilitating the opening of marketing networks, and (3) establishing inter-stakeholder institutions both at local and central levels. Community-based peatland management carried out without adequate technical guidance from related parties will end in failure [158,160,161].

Furthermore, the management of peat ecosystems through FE development must involve the community [157,158,160], starting from planning the involvement in choosing plant species that are economically profitable, socially acceptable, and ecologically suitable for peat ecosystem characteristics.

Involvement in socioeconomic and ecological aspects is strengthened by increasing the role of existing institutions at both village and district levels. Institutional support is crucial to the development of degraded peatland management programs as stimulants and facilitators for increasing peatland productivity [25,158]. Village institutions are needed to improve the welfare of the community, especially in increasing the productivity of commodities while still taking into account ecological aspects.

Several ministries and implementing agencies, such as the Ministry of Public Works and Public Housing, the Ministry of Agriculture, the Ministry of State-Owned Enterprises (BUMN), the Ministry of Villages, Development of Disadvantaged Villages, and Transmigration, and the army, police, and provincial and district governments can collaborate and coordinate with the community in the sustainable management of FE in peatlands.

### *5.3. Constraints and Limitations*

There are requirements to ensuring that the development of FE can overcome the food crisis, improve the national economy during and after the COVID-19 pandemic, and reduce negative impacts on social, economic, and ecological conditions; these requirements are peat-friendly policies, human resources, and technology.

Regarding policy, the FE development area should not be on peatland in a protected area or with a peat depth of >300 cm or more. Based on Government Regulation No. 57/2016, peat with a depth of three meters or more is designated as a protected area and therefore is not used for plant cultivation activities. In addition, the FE program needs to be integrated with various other supporting programs and involve stakeholders with various roles and responsibilities, including the central government, local governments, private parties as investors, financial institutions, and other relevant stakeholders.

Until now, the capacity of the community in developing FE has remained limited, in terms of both skill level and capital. Therefore, human resources must be encouraged to increase their capacity through farmer groups and financing agricultural businesses to increase food production. The government should be able to facilitate the construction of blocking canals so that the goal of rewetting efforts can be achieved. Farmers are also encouraged to adopt the use of superior seeds of adaptive species to increase their productivity and abandon the slash-and-burn method for land preparation. In the downstream sector, the market availability of agricultural products is one of the selection criteria for crop species. Government facilitation and private support are needed so that farmers have the skills to increase the added value of agricultural products, and the market must be accessible so that what is cultivated has economic attractiveness [79].

Prerequisites for the use of sustainable peat-friendly technology must include proper use and balanced development and management based on characteristics. The important factor that must be understood in the management of degraded peatlands is their ecological condition [162]. Peatlands, especially those with a thickness of more than one meter, are wetlands that are not intended for intensive cultivation of dry land food crops. Natural peatlands, which should always be wet, will reduce GHG emissions and prevent fires. Utilization of degraded peatlands for FE must align with rehabilitation efforts through rewetting so that food crops can be cultivated through paludiculture. In practice, peat's physical and chemical characteristics do not permit all crop species to adapt well and produce optimally, while excessive amelioration efforts can exacerbate peat degradation. On the other hand, peatlands have the potential to support food security through sustainable fish production, where several local species have beneficial economic value. Therefore, sustainable FE development can only be carried out on peatlands that meet the requirements, or through intensifying the farming of food crops on abandoned/marginal lands with mineral soils.

## 6. Conclusions

The operation of food estates on degraded peatlands poses a moderate to high level of risk. Based on an evaluation of risk sources, five risk sources were found, and communities and changes in farming practices were deemed most at risk of being affected. The low substitutability of peatland as a natural resource requires mitigation as part of risk management, to be carried out with great care. Once human activities damage the biophysics of peatlands, this may have irreversible consequences or require tremendous and lengthy efforts to repair the peatlands. As the characteristic position of peatland is a non-renewable natural resource, it needs to be managed wisely and prudently. Therefore, the operation of a sustainable food system on peatlands must be based on a strong sustainability perspective. Various community activities that have impacts on biophysical changes in peatlands, resulting in irreversible consequences, must be avoided. The main strategy that must be followed includes protecting natural resources and replacing exotic cultivated plants with native peat plants. Six strategic steps must be carried out: (1) landscape management, (2) maintaining conservation values and vulnerable areas as protected areas, (3) preventing fragmentation and maintaining habitat connectivity with corridors, (4) low-impact land management (paludiculture), (5) integrated multi-business development (agriculture, animal husbandry, fishery, and forestry), and (6) community-based food agriculture.

These six strategic steps refer to the understanding that food cultivation is not only limited to rice and seasonal crops but also should include various native peat plant species such as vegetables and food-producing trees, along with animals that can be raised. Commodities developed on peatlands will be more sustainable if they are in accordance with the biophysical conditions of the area and pose minimal risk to local commodities. Other determining factors are policy support and the ability of business-oriented farmers to find existing market opportunities; hence, various choices of commodities will maximize social, ecological, and economic benefits. Utilization of biodiversity and cultivation techniques with low impact can ensure the sustainability of FE on peatlands.

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## Appendix A

**Table A1.** Matrix of Risk Analyses of Food Estate Development to the Substitutability of Natural Resources.

| Sources/Hazard Factors | Hazards and Risk Identification | Analyses | | | | | | | | | | Evaluation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Likelihood (L) | | | | | Consequences | | | | | |
| | | A | B | C | D | E | 1 | 2 | 3 | 4 | 5 | |
| Human | 1. Hunting or harvesting of wildlife causes population decline and threatens extinction | A | | | | | | | 3 | | | A3 (Extreme) |
| | 2. Human activities in wildlife habitats cause edge effects and reduce the space for animal activities | | B | | | | | 2 | | | | B2 (High) |
| | 3. FE development is not currently supported by community capacity, causing low land productivity | | | | D | | | | 3 | | | D3 (Moderate) |
| | 4. Institutional farmers at the village level prevent the food value chain from being inclusive or integrated from upstream to downstream | | | | D | | | | 3 | | | D3 (Moderate) |
| | 5. The development of FE requires a large investment, encouraging asset control by several parties (corporations) | | | | D | | | | | | 5 | D5 (Extreme) |
| | 6. Unequal agricultural infrastructure assistance causes social conflict | | | C | | | | | 3 | | | C3 (High) |
| | 7. The choice of project location causes unequal distribution of agricultural land | | | | D | | | | 3 | | | D3 (Moderate) |
| | 8. The location of FE development is not completely clear and clean, resulting in tenure conflicts | | | C | | | | | 3 | | | C3 (Hight) |

**Table A1.** *Cont.*

| Sources/Hazard Factors | Hazards and Risk Identification | Analyses | | | | | | | | | | Evaluation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Likelihood (L) | | | | | Consequences | | | | | |
| | | A | B | C | D | E | 1 | 2 | 3 | 4 | 5 | |
| Paddy rice development on peatland | 1. Limited infrastructure in the prospective FE locations can hamper food production distribution | | | | D | | | | 3 | | | B3 (High) |
| | 2. The use of similar plants (monoculture) limits alternative sources of income | | | C | | | | | 3 | | | C3 (Moderate) |
| Free-grazing livestock species | 1. Livestock species with the same feeding habits as wildlife will become competitors and have the opportunity to become invasive and suppress native animals so that their populations decline or become extinct | | B | | | | | | 3 | | | B3 (High) |
| | 2. Livestock species can transmit diseases to wildlife and cause population decline | | | | | E | | | 3 | | | E3 (Moderate) |
| Farmed fish species | 1. The introduction of exotic fish species into natural swamps can be invasive, which is detrimental to local fish species | | B | | | | | | | 4 | | B4 (Extreme) |
| | 2. Diseases suffered by fish cultured in peatland can be transmitted to native species | | | | | E | | 2 | | | | E2 (Low) |
| Farming method | 1. Agricultural development via draining swamps and building canals causes the habitat of wildlife and aquatic biota to shrink, causing the fragmentation of swamp habitats, which in turn can disrupt the survival of various species of wildlife and aquatic biota | | B | | | | | | | | 5 | B5 (Extreme) |
| | 2. Agriculture in peat swamps is prone to land fires, which can degrade habitat quality, destroy habitats, and destroy various species of animals. | | | C | | | | | 3 | | | C3 (High) |
| | 3. Extensive peatland forest conversion through land clearing causes valuable peat swamp tree species to become scarce or unavailable | A | | | | | | | | | 5 | A5 (extreme) |
| | 4. The cultivation of peatlands in protected forest areas with a depth of 100–300 cm poses a high risk for surrounding peat-protected areas | | | | D | | | | 3 | | | D3 (Moderate) |
| | 5. Mechanization and technological input for improving land quality in the form of chemical fertilizers will cause biophysical changes to natural peatlands | | | | D | | | | 3 | | | D3 (Moderate) |
| | 6. Agricultural mechanization results in low absorption of labor | | | C | | | | | | 4 | | C4 (Extreme) |
| | 7. Intensive technology and digitalization result in changes in cultural patterns and people's behavior towards peatlands | | | C | | | | | 3 | | | C3 (High) |

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