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Bounce Forward: Economic Recovery in Post-Disaster Fukushima

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Abstract: After the cascading disaster—earthquake, tsunami, and nuclear accident—in Fukushima on 11 March 2011, the Fukushima region is facing a significant reconstruction challenge. Contamination, economic downturn, depopulation, labor shortage, a damaged reputation, and public distrust must be overcome in order to ensure the future economic recovery of Fukushima. Based on field surveys of the affected areas and unstructured interviews with key informants such as local residents, government officials, and local businesses, this study analyses economic recovery in Fukushima. By exploring four key "pillar" areas of Fukushima's economic recovery—renewable energy, manufacturing, agriculture, and tourism—this paper gives an overview of how to rebuild industry in the shadow of nuclear pollution. The results show how the economic recovery in Fukushima has required adaptation and innovation by the local people, and the economic downturn has been reversed and subsequently improved. Across the pillar industries, innovative reconstruction projects have been pioneered and led by local residents and businesses. Fukushima's industrial recovery has been facilitated by the efforts to make the livelihoods of local residents sustainable. It is argued that creative and sustainable economic recovery makes full use of people's and businesses' existing resources to transform the disadvantages caused by disasters into opportunities.

Keywords: adaptive capacity; economic resilience; nuclear pollution

1. Introduction

The earthquake, tsunami, and nuclear accident that occurred in East Japan on 11 March 2011 was one of the worst disasters in human history. These disasters severely impacted the local government regions of Fukushima, Iwate, and Miyagi in Japan's Tohoku area; 19,824 people lost their lives or disappeared, over 10 million people were evacuated, and more than 1700 km^2 were contaminated by nuclear materials [1].

In addition to the severe impact on humans and the environment, the economic consequences caused by the disasters were enormous. The costliest natural disaster ever, it caused direct economic losses of 211 billion USD, including housing, infrastructure destruction, and other asset losses. Across the Tohoku region, 656 companies went bankrupt [2]. The economic interruption caused by the disaster was not only limited to the Tohuku region but also had a devastating national impact on Japan's economy, particularly in the manufacturing and energy supply chain.

Whether a disaster-affected area can achieve long-term sustainable development depends on the quality of their economic recovery and reconstruction. Since 2011, the central government of Japan and the local governments in the Tohoku region have launched a series of post-disaster economic and social rehabilitation projects, and most of the affected businesses, economic sectors, and communities have revived. As the Fukushima prefecture was situated closest to the nuclear power station, it was the area most affected by nuclear pollution—their post-disaster economic recovery has consequently been slower than the other Tohoku regions. Due to the long-term effects of the nuclear pollution, the existing dominant economic industries in Fukushima, such as agriculture, manufacturing, and tourism, have faced numerous problems, including the inability to conduct business, the loss of orders and customers, reduced working hours as staff were evacuated, lost jobs, and a decline in visitors [2].

The main purpose of this study is to answer these questions: How can Fukushima achieve economic recovery under the long-term impact of nuclear pollution? How effective is the industrial reconstruction after the disaster? This paper aims to provide an overview of Fukushima's economic recovery based on field surveys of the affected areas and unstructured interviews with key informants. It describes how local government and companies respond to problems caused by nuclear pollution and how they use existing local resources to rebuild agriculture, manufacturing, and tourism innovatively, while also striving to achieve energy self-sufficiency.

The current research on economic resilience in the context of disasters mainly focuses on definition and measurement. Although this is of great significance for the construction of economic resilience theory, examples of how to construct economic resilience in real post-disaster scenarios are still scant [3]. Furthermore, because of the scarcity of high-level nuclear disasters, research on the regional economic recovery of areas that are affected by nuclear pollution is rare. Not only does this study contribute to studies on economic resilience, but it also provides a unique perspective by considering the economic fall-out of a nuclear disaster. By exploring the largest nuclear disaster since Chernobyl in 1986, analyzing economic recovery in Fukushima can provide insight and inspiration for the future recovery from nuclear disasters in other areas of the world.

2. Economic Resilience as a Process: A Conceptual Framework

The Latin etymology of resilience is resilio, meaning to "rebound". Stable and growing economic development promotes regional disaster resilience, while unhealthy or declining economies indicate increased vulnerability [4,5]. There is no universally agreed definition of economic resilience [6]. Rose has defined two types of resilience—inherent resilience and adaptive resilience. The former refers to resilience under normal or non-crisis conditions, and the latter refers to the resilience generated by creativity and extra effort under crisis conditions [7]. Norris et al. argued that economic development should be closely considered in relation to a local community's capacity [8]. There are many interconnecting components that make up a regional economy, and because that economy is dynamic, it makes studying regional economic resilience very complex [9].

An area's resilience is improved through the diversification of the local economy (diversification of economic sources) and high economic volumes (an indicator of economic growth, employment, income, and property). Communities with high economic volumes before a disaster make an easier recovery, while communities with unfavorable economic conditions before a disaster have greater vulnerability [8]. At the same time, relying on a single related industry before the disaster, such as tourism, makes it much harder for a community to adapt and recover after a disaster [10]. Communities with economic diversity before a disaster usually have sufficient relative substituted industries to replace those that have been seriously affected so that they can recover and rebuild more quickly. A well-developed economic system is an important factor in improving disaster resilience, where diversity and high economic volumes allow the community to deal with the problems that could cause vulnerability.

Economic resilience can also refer to the use of resources for economic rehabilitation and reconstruction, which aim to quickly reduce both the duration of business interruption and any negative impacts. Strategies can include the absorption of losses (static resilience) and accelerated recovery (dynamic resilience) [7,11]. Static economic resilience refers to how existing resources are used at a given point in time to maintain inherent functionality, while adaptive dynamic economic resilience refers to the timeline for recovery and reconstruction. Economic resilience can be viewed in terms of microeconomic (individual firms, households, businesses), mesoeconomic (economic sector), and macroeconomic terms (individual units and markets combined) [12]. In practice, economic resilience is mainly achieved through the provision of various services for restoration, reconstruction of enterprises and industries, and the promotion of business continuity industries. Resilience can be generated by internal (to the organization) incentives and by private or public policy incentives (including public infrastructure) [13]. Most resilience strategies utilize both inherent and adaptive approaches [14].

There have been some theoretical and practical studies on economic resilience under disaster scenarios, and these have focused mainly on the meaning and the measurement of economic resilience [10,14–16]. Most researchers examine economic resilience through quantitative methods [17,18]. Quantitative studies emphasize functionality—measured through indicators like Gross Domestic Product (GDP), and the flow of goods and services [3]. These quantitative studies consider economic resilience as an outcome that can be measured, while this study views economic resilience as a process.

Cutter viewed resilience as a process [19]. She developed the definition of static and dynamic resilience to interpret static processes as relating to measurable outcomes, while dynamic conditions relate to resilience as a process [19]. Rose viewed resilience as a process that increases both individual and societal competencies [20]. As Rose described,

"All definitions [of resilience] relate to reducing losses from disasters. All emanate from a survival motivation. Nearly all emphasize the importance of adaptive behavior. Most view resilience as a process and emphasize the need to expand resilience capacity at multiple levels. Most emphasize interactions within a broader community" [20].

Simmie and Martin [21] have argued that regional economic resilience needs to be viewed as an evolutionary process. They connected regional economic resilience to adaptation through Panarchy and proposed the "evolutionary adaptive cycle model of regional economic resilience" to describe the dual dynamics of regional economic change and stability. Taking an evolutionary perspective, this model assumes that the regional economic adaptive system goes through four phases of exploitation, conservation, release, and reorganization, and repeats these phases in different periods. The four phases differ in three ways: (1) The potential of the system to accumulate resources. The resources include the capabilities of individual companies, the skills of local workers, and various infrastructures, which depend on the previous structures of economic and social development in the region. (2) The internal connectedness of system actors or components Internal connectedness refers to the pattern of trade and non-trade interdependence between local companies, including supply inputs, horizontal intercompany divisions, local trust networks, knowledge spillovers, formal and informal business associations, and labor mobility patterns. These are also affected by previous economic developments in the region. (3) Resilience, a measure of system vulnerability to shocks, disturbances, and stresses. High resilience is associated with a creative and flexible response. Creative and flexible responses depend on factors like the innovative capacity of local firms, the formation of new businesses, institutional innovation, access to investment and venture capital, and the willingness to re-start [21].

According to the evolutionary adaptive cycle model, the cycle is divided into two loops—one is about the path of emergence, development, and stability, and the other about the path of recession, reform, and restructuring. The different degrees of potential, connectivity, and elasticity determine the corresponding dynamic characteristics of the four stages. This model emphasizes that regional economic resilience is a process rather than a constant feature, and continuous adaptation and change is the key to regional economic development.

In this research, it is argued that achieving sustainable development of the disaster areas is at the core of post-disaster economic recovery. This is especially important in areas with nuclear contamination. Sustainable development refers to reducing the vulnerability of disaster areas [22], by implementing local reconstruction [23–26], strengthening the cooperation of multiple stakeholders [27–29] in complex social and environmental changes after the disaster, and realizing the stable development of local industry recovery with the affected residents in a leading role. The sustainable development of the disaster-stricken economy depends considerably on whether the affected residents have access to sustainable livelihoods. The concept of sustainable livelihoods emphasizes people-oriented, multi-level, and all-round development [30]. A livelihood is not only about employment but more about whether people struggle to earn a living. This includes abilities and means of living (including food, income, and assets) [31]. Diversity and dynamism are critical to ensuring sustainable livelihoods [32]. Livelihoods are sustainable when they can cope with and recover from stress and shocks, maintain or strengthen their capabilities and assets, and provide security for future generations [33]. Sustainable livelihoods will help reduce vulnerability and enhance resilience to disasters [32].

Case studies of economic resilience in disasters are still sparse [3], especially in the case of post-disaster economic reconstruction under nuclear pollution scenarios. Given that context is crucial to understanding a specific region's economic resilience [20], in this study, we will focus on how a specific region that suffers a nuclear accident builds economic resilience and recovers from the challenges of the disasters. By theorizing the issue of resilience as a process, rather than a static phenomenon, Simmie and Martin's approach is a useful model to help illustrate the complexity of economic resilience in Fukushima, therefore it will be used as an analytical framework in this study.

3. Economic Recovery in Fukushima

Haas first proposed a "time-series" model for post-disaster recovery, where "recovery" was conceptualized as a linear, phased sequence of post-disaster recovery processes and outcomes [34]. Similarly, in "Economics of Natural Disasters", the post-disaster economic recovery is divided by Douglas in a way focusing on "time," into a short-term adjustment phase and a long-term recovery phase [35]—post-disaster economic recovery is both a process and a result [36]. At present, research on post-disaster recovery has surpassed the early one-dimensional, phase-oriented, and linear conceptualization and instead theorizes post-disaster economic recovery though dynamics, diversity, and differences in recovery processes and outcomes [37]. This paper, through Simmie and Martin's framework, examines the economic recovery of the Fukushima area from long-term nuclear pollution through its differentiation, iteration, and nonlinear processes and experience [37].

Since the Fukushima nuclear accident in 2011, the central government of Japan and the local governments in Northeast Japan have launched a series of post-disaster economic reconstruction projects. However, due to the complexities caused by the triple disasters [38], and the worldwide lack of experience in dealing with nuclear pollution, Fukushima's post-disaster economic reconstruction has been a difficult and challenging process. The existing literature on post-disaster recovery in Fukushima mainly focuses on the physical reconstruction of houses [39], monitoring of nuclear radiation content in the natural environment [40], changes in energy policies [41], and public mental health issues [42,43]. The occurrence of the Fukushima disaster not only poses a great threat to the living environment of the disaster area and people's lives and property [44], but it also has a serious impact on social and economic development, yet there are relatively few studies on the post-disaster economic recovery of Fukushima. Different scholars study the Fukushima disaster economy recovery process from the perspectives of GDP, employment rate, income level, house prices, and changes of the residents' livelihoods [45–48]. For example, Hitoshi analyzed the economic recovery of Fukushima after the nuclear accident by comparing pre- and post-disaster data on housing construction, agricultural production recovery, employment growth, and industrial output in Fukushima [45]. Ofuji looked at the energy supply shift after the Fukushima nuclear accident. His research shows that restoring and supporting thermal and hydropower will help eliminate electricity supply problems and may boost the local economy [49]. Chew and Jahari's research shows that the Japanese government responded promptly and adopted a series of effective measures to quickly restore the post-disaster tourism market in Fukushima [50]. Brumfiel et al. analyzed the recovery of the agricultural sector in the post-disaster reconstruction of Fukushima after the effect of nuclear pollution. The study has shown that consumers have different opinions on Fukushima agricultural products, and the import rate of agricultural products has been high [51].

The East Japan earthquake was the most devastating large-scale disaster in postwar Japan. Since this disaster, the financing measures and the financial system has evolved, and many new laws and policies for reconstruction have been enacted. Reconstruction fundraising is based on the Reconstruction Funds Act (promulgated on 30 November 2011), and a new time-limited reconstruction agency was established under the East Japan Earthquake Reconstruction Special Zone Act (promulgated on 7 December 2011). Since 2012, the Special Tax Account for the reconstruction of the east Japan earthquake has been established. In addition to these new systems, there is a strong financial relationship between the central government and the local government for reconstruction resources, such as the East Japan Earthquake Reconstruction Grant, and the Special Tax for East Japan Earthquake Reconstruction [52,53].

Most of the current research on Fukushima's post-disaster economic recovery focuses on just one aspect of the wider Fukushima economy. Meanwhile, in the existing research, economic recovery is a time-dynamic process in which disaster-affected areas overcome the effects of disasters [54]. Economic recovery is not only about eliminating the impact of disasters to restore the pre-disaster economic level but also must emphasize measures to reduce exposure to future disasters [55,56].

This paper will summarize the overall economic recovery situation of the Fukushima, through field surveys of four key areas of economic recovery in Fukushima—renewable energy, manufacturing, agriculture, and tourism—as well as unstructured interviews with key informants in these economic areas. Although the global share of nuclear power is declining, some countries, such as China, Russia, and India, are building a number of new nuclear power plants [57]. The new plants are still under construction, but it is expected that, once they are operational, nuclear power will account for an increasing share of global electricity generation. Disaster risks and economic losses caused by nuclear power are expected to increase in the future. Thus, research on economic recovery case studies like the Fukushima nuclear accident can be used as an important reference for nuclear disaster prevention and control and post-disaster reconstruction in areas affected by nuclear pollution.

4. Method

In this study, the research methods were observation through field surveys and unstructured interviews, with audio recordings made. Most studies in economic recovery use quantitative methods to measure economic recovery [17,18]. However, researchers frequently emphasize the difficulties they encounter in gathering enough data to input into these recovery models [10]. Rose stressed the importance that research into economic recovery should venture into new and often expanding areas of inquiry and develop new analytical tools to deal with them [3]. A qualitative research design allows researchers to provide a rich background and explanation, with an exploratory approach undertaken [58].

We chose four industries as subjects for field investigation. The four "pillar" industries—renewable energy, manufacturing, agriculture, and tourism—were selected because they are industries that (1) considered to be key to revitalization and development in disaster recovery plans of the country, regions and communities; (2) provide sustainable livelihoods for Fukushima's residents; and (3) show "creative recovery"—high innovation in adapting to the post-disaster environment (the long-term existence of nuclear pollution).

The research team conducted a field investigation of the disaster-affected area in Fukushima prefecture, Japan, with interviews undertaken between 15 and 20 January 2018. In the field investigation, both non-participatory observation method and in-depth interview were adopted for data collection. The main research sites are divided into five types related to renewable energy, agriculture, manufacturing, tourism, and other general sites (see Table 1). During these visits, 12 key informants were interviewed (see Table 2). By observing the reconstruction efforts, a deeper understanding of the region's economic recovery was realized.

Table 1. List of sites.

Category	Sites Code	Name of Sites
Renewable Energy	E1	The Former Energy Hall of Fukushima Daiichi Nuclear Power Plant (FDNPP)
	E2	The Hometown Reconstruction Mega Solar Power Plant of Okuma Town
	E3	Fukushima Renewable Energy Institute of the National Institute of Advanced Industrial Science and Technology
	E4	Tsuchiyu Hot Spring Binary Power Station
Agriculture	A1	Wonder Farm (Soilless Tomato Plantation Farm)
	A2	Fukushima Agricultural Centre
Manufacturing	M1	Kikuchi Seisakusho Co. Ltd. (Precision Production Manufacturing Factory)
	M2	Naraha Remote Technology Development Center of Japan Atomic Energy Agency
Tourism	T1	Spa Resort Hawaiians
	T2	Alpine Rose Restaurant in J-Village
General	G1	Namie Town (Former Evacuation Zone)
	G2	Environmental Regeneration Plaza in Fukushima
	G3	Evacuation Zones

Table 2. List of respondents.

Respondent Number	Respondent Code	Respondents Specialization	Theme
1	E1P1	TEPCO Staff Member	Current Situation of FDNPP
2	E2P1	Engineer	Solar Energy in Fukushima
3	E3P1	Supervisory Coordinator	Renewable Energy in Fukushima
4	E3P2	Senior Researcher	Renewable Energy in Fukushima
5	A2P1	Staff Member	Agriculture Innovation in Fukushima
6	M1P1	Staff Member	Robot Manufacturing
7	M2P1	Staff Member	Remote Technology
8	T1P1	Manager	Responses and Reconstruction to the Disaster
9	T2P1	Chef / Owner	Responses and Reconstruction to the Disaster
10	G1P1	Government Official	Disaster Response and Reconstruction
11	G2P2	Staff Member	Environmental Regeneration in Fukushima
12	G3P3	Local Activist	Disaster Response and Reconstruction

In the recovery of Fukushima, the residents may have up to three roles [59]:

- Role 1: fundraiser—residents can fund businesses operating in the post-disaster recovery industry and post-disaster reconstruction. Even evacuated residents who have not yet returned to Fukushima can contribute to recovery through this fundraising.
- Role 2: operator or practitioner—operators help manage the business, while practitioners are the employees. Through these positions, the residents are engaged in industry recovery across businesses that were present pre-disaster, as well as new business that was created post-disaster.
- Role 3: customer—the residents become users of products and services as customers.

The 12 key interview informants who offered the richest insight into the four pillars are listed in Table 2. Only one respondent (code G1P1) is a government official, while the remaining 11 participants are local residents, who are all living and working in Fukushima prefecture.

Field surveys and interviews focused on the following question: What did the local government and residents do to rebuild Fukushima's pillar industries to enable economic resilience? In the data collection, we used the adaptive capability framework proposed by Cinner et al. to recognize five aspects of information: 1) the assets that people can draw upon in times of need; 2) the flexibility to change strategies; 3) the ability to organize and act collectively; 4) learning to recognize and respond to change; and 5) the agency to determine whether to change or not [60].

5. Study Area

Fukushima is the southernmost prefecture of the northeastern region of Japan (see Figure 1) and is the third-largest prefecture of Japan, with an area of 13,782.75 square kilometers and a population of approximately 1.91 million before 2011 [61]. Prior to the disaster, the manufacturing output of the prefecture accounted for almost a third of Northeastern Japan, ranking first in the region. Many industrial parks existed in the prefecture, which focused on electronic component design and production, as well as high-density machining. In terms of agriculture, rice production was an important area in Fukushima, and their premium sake (made from the rice) was award-winning. The prefecture also boasted high-quality fruits such as peach and pear, which were exported nationally and internationally.

Figure 1. The location of Fukushima Prefecture.

Fukushima prefecture remains the most severely affected area from East Japan's triple disaster in March 2011. In the earthquake and tsunami, 4013 people died, and two went missing. The total destruction and semi-destruction of Fukushima's houses have reached 96,026. As of 23 March 2012, the total financial loss in public facilities including road traffic, agriculture, forestry, fisheries, culture, and education was 599.4 billion JPY (5.45 billion USD) [62]. As a result of the nuclear accident, the Japanese government established an evacuation area with a 20km radius, where all the residents that lived in that area were forced to evacuate. In May 2012, the number of evacuees in Fukushima prefecture reached 164,865. The great destruction caused by the earthquake and tsunami, and the long-term influence of nuclear pollution, have brought serious social decline and economic recession to Fukushima (Figure 2).

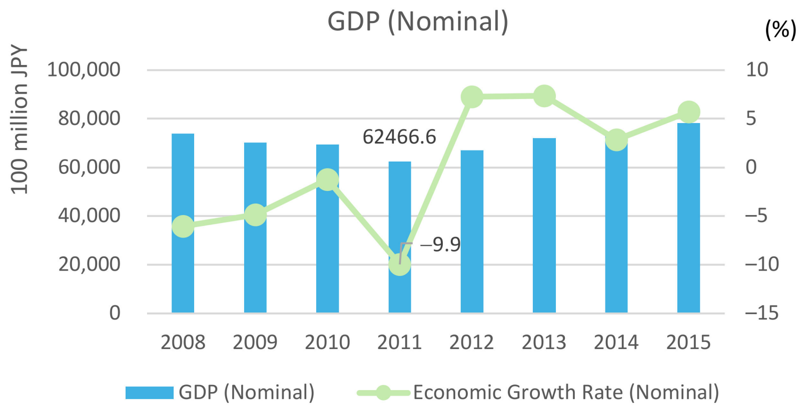

Figure 2. Nominal GDP and economic growth rate in Fukushima [63].

There were three main problems faced by Fukushima in its economic recovery. First, the numbers of both business staff and customers have dramatically decreased because of voluntary and compulsory evacuation caused by the nuclear accident [45]. The reduction in the labor force creates considerable challenges in maintaining normal operations and production, meaning that many enterprises have struggled to recover quickly after the disaster. The enterprises located in Fukushima, especially small and medium-sized businesses, suffered a great impact because of the evacuation of their customers. Second, the nuclear accident had a considerable negative impact on the reputation of Fukushima's products and the tourism industry in the prefecture. Nuclear pollution meant that agriculture in the disaster area could not resume production and sale for a long time until decontamination was confirmed. Third, the compulsory evacuation meant some businesses needed to rebuild their production sites and delay the resumption of production activities. Meanwhile, the considerable damage to Fukushima's infrastructure also hindered the recovery of enterprise operations. Until the 2011 disaster, the Fukushima prefecture was the main supplier of electricity to the majority of the metropolitan areas of Japan, but the disaster seriously affected their electricity capacity.

In response to these problems, the Fukushima prefectural government has formulated a series of post-disaster rehabilitation policies to enable rapid economic and social recovery. A strategy for comprehensive industrial recovery has been issued after the disasters: the Fukushima prefecture Business and Industrial Promotion Basic Plan—Shinsukue Fukushima Industrial Planning. Within this strategy, a series of industrial revitalization plans were launched to promote the sustainable development of the economy. This plan mainly includes the following three aspects: (1) The regeneration of the traditional original agriculture, forestry and fishery industries, and tourism. In addition to the decontamination of agricultural land in Fukushima prefecture, the inspection system for agricultural, forestry and marine products before shipment was strengthened to ensure product safety. At the same time, through sustained public relations activities, Fukushima disaster-related information is released to Japan and overseas, rebuilding confidence in Fukushima's products and tourism. (2) The creation of new industries. This focuses on promoting the development of renewable energy and the integration of medical-related and robot-related manufacturing industries. (3) Promoting the reconstruction of small and medium-sized enterprises (SMEs). In addition to providing facility maintenance, recovery costs, and operating capital loans, the Fukushima prefectural government also established a joint group of Fukushima reconstruction professionals and public-private partnerships to provide consultancy support for disaster-affected companies. Furthermore, by helping companies establish sales channels and guarantee human resources, they have strengthened the management support system for SMEs in commerce and industry and promoted the restart of businesses. Under the influence of this series of measures, the GDP, per capita income and employment rate of Fukushima prefecture in 2015 has reached or exceeded the pre-disaster level (see Figures 2–4).

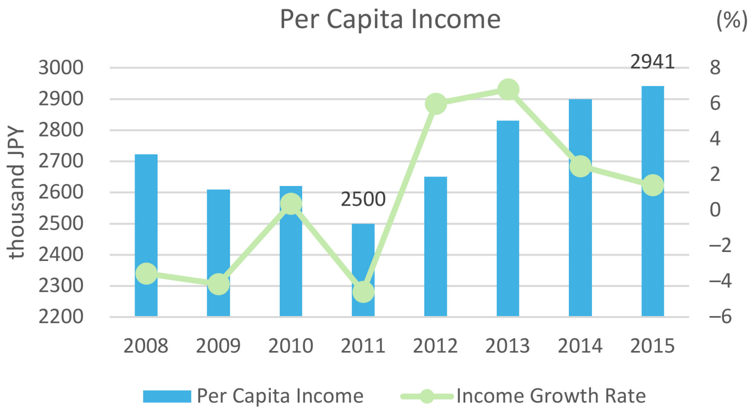

Figure 3. Per capita income and income growth rate in Fukushima [63].

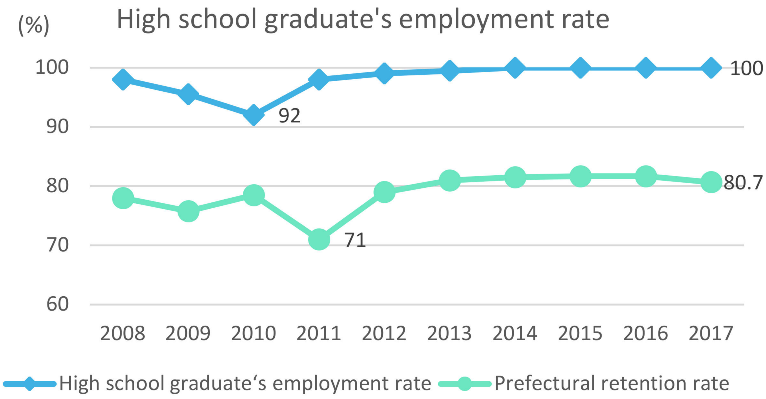

Figure 4. High school graduate's employment rate and prefectural retention rate in Fukushima [63].

Due to the damage from nuclear radiation, most of the local industries have not been able to recover within the intensive recovery period (2011–2015). Therefore, the GDP contribution in the years after the disaster mainly arises from post-disaster reconstruction, not from industrial recovery and the development of new industries. In the first few years after the disaster, the rapid recovery of GDP could be attributed to the following reasons: (1) considerable funds (discussed throughout this paper) were invested in the reconstruction of the lifeline (transportation, communication, water supply, drainage, power supply, gas supply, and oil supply), and key infrastructure after the disaster [52]; and (2) due to the nuclear radiation, post-disaster reconstruction by the government, (especially decontamination), requires a large amount of more expensive labor, which also becomes a part of GDP [64].

6. Results

Interviews with government officials and government reports show that among the affected areas, the biggest post-disaster contribution to GDP is in the decontamination and construction industries, both of which are growing due to the demand for post-disaster recovery. The former is due to the need for nuclear decontamination, while the latter is due to the need for residential reconstruction, including both private and public disaster-prone housing. But both decontamination and construction are "temporary" industries. After the post-disaster recovery is completed, the contribution of these two areas to GDP may gradually decline and is therefore unsustainable. However, the relatively stable and sustained recovery of post-disaster economic growth in Fukushima prefecture has benefited from the adjustment and recovery of industrial policies after the disaster. The development of the four industries—renewable energy, manufacturing, agriculture, and tourism—has had a relatively significant impact on economic recovery.

6.1. Renewable Energy

The nuclear accident in Fukushima resulted in a severe interruption of the power supply, which had a tremendous effect on Fukushima's ability to recover. Before the disasters, Japan got 30% of its energy supply from nuclear power [65], and the Fukushima Daiichi power plant was one of the biggest nuclear energy suppliers in Japan [66]. The local people's attitudes to nuclear power has changed tremendously since the disaster, with considerable negativity toward nuclear power and a move toward the use of renewable energy generated from natural sources. The participants saw renewable energy as a significant part of their future economic and social stability. E3P3 commented,

> "Renewable energy is crucial to the long-term stability of our area. Without it, we cannot attract people back to the (Fukushima) region."

Renewable energy was seen as a hugely important part of the recovery and reconstruction efforts because it was thought to be safer. The elimination of risk was a key factor in why participants said they preferred renewable energy. One participant (E3P2) summarized other benefits of nuclear energy as

> "Renewable energy produces little or no waste products (such as radioactive materials) is environmentally friendly ... the facilities are easier and safer to maintain than with nuclear power."

Seven participants argued that nuclear power was damaging, and they wanted a sustainable alternative. As a local woman (G3P3) told us,

> "We don't want nuclear power for our children, it should not be their future."

This focus on creating a better life and future for the children in Fukushima came up thematically in four interviews. For these participants, the whole purpose of economic renewal was to ensure a safe, sustainable future for younger generations.

Given that the nuclear power disaster happened in Fukushima, the Fukushima prefectural government has made the shift to renewable energy its main priority, and they aim to install renewable energy ahead of any government targets (see Figure 5). This investment, alongside the implementation of an improved electricity transmission network, will support Fukushima's industries and homes, as well as reduce future energy shortages caused by any future disasters. In 2016, renewable energy met 28.2% of the prefecture's energy needs, accounting for about 60 percent of its electricity consumption (see Figure 5).

As part of the move to renewable energy, the Fukushima prefecture's objective is to meet the prefecture's entire energy needs by 2040 through the introduction of a renewable energy plan (shown in Figure 5).

As Figure 6 shows, there has been a dramatic increase in solar power in particular. The solar power plant in Okuma Town (E2) and the Fukushima Renewable Energy Institute (part of the National Institute of Advanced Science and Technology) (E3) foster research into renewable energy and the production of solar energy that helps in boosting the solar energy supply in Fukushima. Large areas of land in the region have now been devoted to solar power plants. As E3P2 put it,

> "Solar power is a crucial part of the prefecture's economic development now."

As a result, solar, hydropower, wind, geothermal, and biomass energy sources are commonly used in Fukushima (shown in Figure 6).

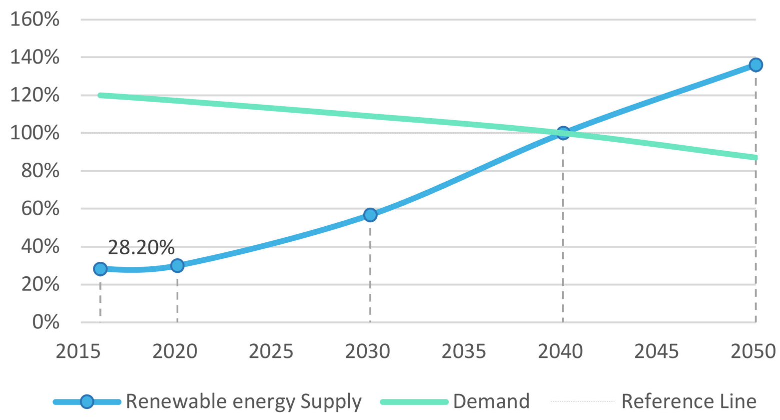

Figure 5. Fukushima renewable energy introduction target plan [63].

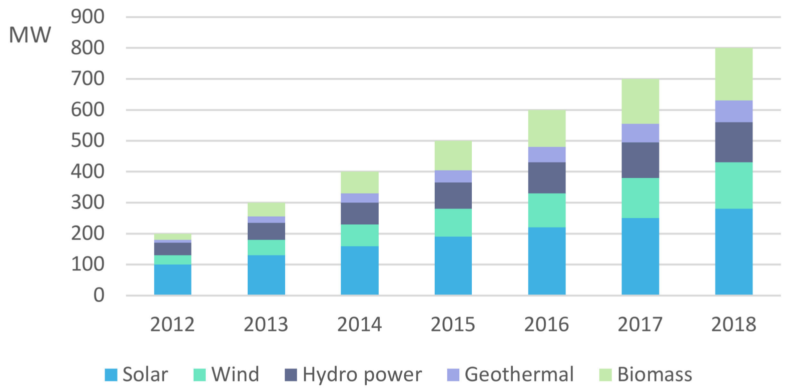

Figure 6. Projection of renewable energy generated from various natural resources (source: Fukushima Prefectural Government).

To address the energy demand created by the disaster, the Fukushima government has three major strategies. First, the government is trying to evolve from a centralized power system to a decentralized power supply. Together with local NGOs, the government is achieving this through encouraging local people to install solar panels in their homes and farms. As well as advertising this scheme, it is also incentivized through a feed-in-tariff (FIT) scheme, which promotes the use of renewable energy through payments for those who feed in extra electricity to the power grid. The FIT scheme favors the installation of a solar photovoltaic (pave) system, accounting for about 90 percent of the scheme's activities. Second, the money that is invested in renewable energy in Fukushima can only be circulated in the prefecture, and any profits must return to the area. This strategy means the renewable energy industry in Fukushima can also boost other related industries and make job opportunities for the local people. Finally, the prefectural government has developed international partnerships (such as the partnership between the Embassy of Denmark in Japan and the Ministry of Environment of the state of North-Rhine Westphalia and the Fukushima prefecture) to lessen import dependency, increase the diversity of sources of energy production, and provide efficient services for sustainable development.

In the interviews, government and business officials continually spoke about how the area was working to attract international talent in the field of renewable energy to Fukushima. As described by a member of staff (E3P1),

> "We are so proud . . . the prefecture's efforts in supporting research at the Fukushima Renewal Energy Institute and providing funding for researchers means we have excellent collaboration with international communities. It is this international collaboration that has allowed us

to meet the energy demand, as well as promoting a shift from the nuclear power to safer renewable energy generation."

Research at the Energy Institute is part of attempts to create a safer environment as well as reducing the Fukushima communities' vulnerability to disasters. Given that the disaster severely impacted the power supply, participant E3P2 said,

"We have made lots of innovations [after the] disaster, such as innovative solutions to power storage."

One innovative research outcome was the initiation of distributed energy resources, where the energy generation and storage and no longer stored in one central place but instead are performed across a network of small, grid-connected devices to enable future resilience. Improved energy storage systems (ESS), heat utilization technologies, and converting electricity into hydrogen ensure that solar energy is more productive, and the energy is used and stored more efficiently.

In addition, education is starting to play a role in the development of the new industries. The National Institute of Technology, Fukushima College (NIT-FC) plans to train engineers as specialists in renewable energy so they can deliver renewable energy policies and also train the younger generation with the knowledge and skills to rebuild the Fukushima area. Since it will take decades to fully and safely dismantle and terminate the Fukushima nuclear power plant, Japanese higher education institutions like NIT-FC will have to form partnerships with the Japan Atomic Energy Agency (JAEA) to train a large number of engineers with knowledge of nuclear power plant technology and radiation for several decades. In addition, in order to solve the problems in the Fukushima prefecture, NIT-FC established an "Office for Regional Rehabilitation" (ORR) in January 2012. From 2011 to 2015, with the budgetary support of the Ministry of Education, Culture, Sports, and Science and Technology, the ORR was responsible for the implementation of a project that developed higher education training for rehabilitation and safety in Fukushima, which focused on three areas: renewable energy, nuclear safety and disaster reduction. In 2013, NIT-FC launched a special course on regional rehabilitation. In addition, the ORR develops human resources training for regional rehabilitation and conducts research on regional industrial development [67].

6.2. Manufacturing

The manufacturing industry was greatly affected by the triple disaster in Fukushima (see Figure 7). After the disaster, as one government official (G1P1) put it,

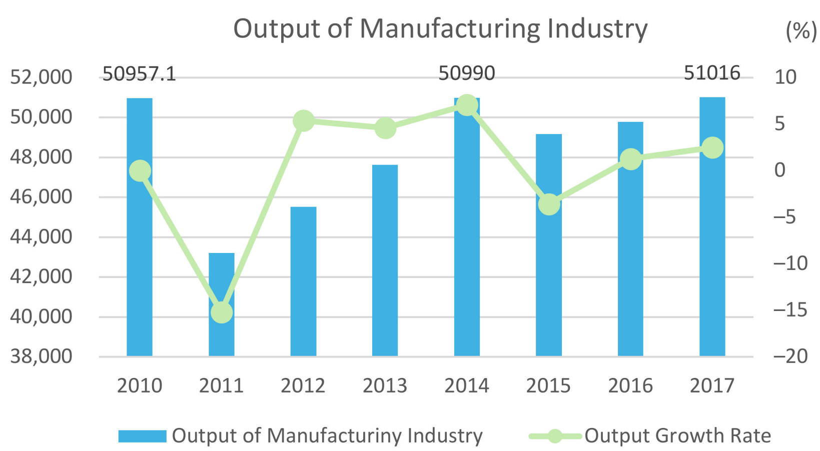

Figure 7. The Output of the manufacturing industry in Fukushima [62].

"It became urgent to develop policies that supported high technology within Fukushima prefecture to improve the economy and promote production activities, which is done through the Innovation Coast Framework."

The Innovation Coast Framework of Fukushima is part of the "Fourth Industrial Revolution," the Japan-wide push for more national technological output. The strategic focus has been on "industries of the future" in order to sustain the nation's activities and ensure continuous development and collaboration with other international bodies, supporting business continuity, as well as promoting recovery and reconstruction. The aim was to drive technology intelligence in local staff and support high-income generation through improving the quantity and quality of production. M1P2 emphasized the importance of highly trained and educated staff for future economic recovery:

> "Staff are crucial. They are the ones that are doing the important work of recovery."

International partnership was also essential to economic recovery within technology [68]. The Kikuchi Seisakusho Company (M1) is a manufacturing specialist in the production of machine parts (tool and die processing), bonding and cutting of mechanical components, and advanced press technologies to process metal sheets. M1P1 described how their survival after the disaster was facilitated by another of their factories in Hong Kong.

> "We are known internationally for our tool and die technology. Our production stopped for a period after the disaster. And we started again from 2015. We kept manufacturing going with our international partners, and it's very important for the recovery."

Part of Fukushima's strategic focus is to produce robotics that can be used in disaster response, medical care, agriculture, and physical distribution. A participant described the use of robotics as crucial to the economic and environmental recovery of Fukushima:

> "Robotics and AI (artificial intelligence) are the future. Robotics is very important to help our recovery. We designed robots for disaster response and medical care, especially to work on jobs that are difficult and harmful for human beings, like helping decommission the nuclear reactor." (M1P1)

Several robots have been developed in robotic factories in Fukushima. Most of the robots are employed in supporting people with lifting and walking, and the long-term overall aim is to provide support and substitution for human activities with robotics. This was due to the risks inherent from the disaster, where most of the lifting activities during evacuation were conducted by humans, leading to increased risk of injury as well as nuclear radiation exposure from dust and debris. The tasks conducted by the robots can include firefighting, rescuing, rubble removal, breaking through walls and doors, and the operation of machinery. Using new and innovative technology like robots also allows the decommissioning operations in the power plant to be faster and more cost-effective.

A robotics facility has been established in Nahara [M2] to support robot production and robot test facilities that are used for decommissioning activities. There was also the establishment of the robot development and demonstration center in Minamisōma City, and plans are in place to facilitate the development of a Fukushima robot test field. The robot development center in Minamisōma provides facilities and offers technological support to facilitate private and public activities in research and demonstration for land, sea, and air robots that can be used in disasters. M1P1 described how Fukushima's economic recovery necessitates attracting the best robotics and technology specialists, from both nationally and internationally.

> "Artificial intelligence and digital simulations help us work out best how to manage the disaster and handle the nuclear reactor. We are constantly working to develop our skills and knowledge in artificial intelligence, as well as showcase our disaster robots to the rest of the world." (M2P2)

While Fukushima is not currently developing machine learning in the robots, which instead utilize automation, there are plans to further develop artificial intelligence in the future.

As well as developing robotics for decommissioning, Fukushima aims to be the world leader in the medical support field. Robots are manufactured to aid the elderly in standing and walking. Given that Japan is the fastest ageing population in the world, these innovations are crucial to caring for elderly people, as well as showcasing the innovation potential of Fukushima.

In addition to manufacturing robots, the Fukushima Innovation Coast Scheme has gained more support from Japan's Ministry of Economy, Trade, and Industry (METI) to develop innovative medical and environmental technologies. As outlined by one of the participants [M1P2], this Innovation Coast scheme has allowed the development of a new type of drone for flying emergency supplies into areas that are isolated by large-scale disasters and has attracted overseas attention. Thus, with an emphasis on pioneering robotics for disaster relief, Fukushima is trying to turn their difficulties into becoming a global leader in advising others in the case of disaster.

However, the manufacturing industry has been facing a shortage of labor and insufficient funds. Government subsidies for manufacturing and tourism are mostly supported by corporate grants, and there are no separate statistics, as these costs are absorbed within other budgets. For example, the "SME Group grant," established to support the reconstruction of SMEs in the affected areas, subsidizes the repurchase of facilities and equipment when damaged SMEs are rebuilt. National subsidies are 50%, while subsidies at the Fukushima prefecture level are 25%, which is an unprecedented subsidy support system. In practice, however, priority is given to national supply chain companies and large local companies, excluding small businesses that cannot form groups. Many of the companies that suffered in the disaster did not qualify for subsidies [53].

6.3. Agriculture

The Fukushima prefecture's rice paddy fields were contaminated by the nuclear accident. Many local farmers, who once relied on the land for their livelihood, are still unable to effectively do so. With much of the land closest to the nuclear power plant still evacuated, it is those farmers who were the most affected by the disaster. While some of them have been able to use their land, many have had to find other employment. One participant described,

> "The disaster wiped out my home and livelihood. I had nothing—no way of making money and nowhere to live. But I kept going and tried to focus on the positive." (G2P2)

For those farmers who are able to produce crops, the challenge is to sell them. To counter this, vigorous testing has been conducted. A staff member from the Fukushima Agricultural Centre (A2P1) argued that

> "The radiation contamination testing of all marketed agricultural produce from Fukushima is now the most stringent and extensive in the world. We work to vigorous standards, no rice, marine fish or shellfish have exceeded the government radiation limits since 2015."

Despite this testing, the Fukushima region battles caution from countries that previously bought Fukushima's rice crops due to continual concern about contamination. These problems seriously hinder the agricultural recovery of the region, where trading and sales of produce from the region still remain negatively impacted and are slow to recover (see Table 3 and Figure 8). Given that rice is a staple primary ingredient for much of the Japanese cuisine, government strategy has focused on both decontaminating the rice yield and improving the reputation of the crop so that export is possible.

In Fukushima, land shortage due to contamination is being solved with innovation of local people. Traditional agricultural cultivation is now being replaced by soilless agriculture. Hydroponic crop farming, aeroponics, and specialist biotech crops (or genetically modified crop production) have also been promoted since 2011.

Table 3. Fukushima Prefecture agricultural recovery statistics [62].

Recovery Factor	Regional Agricultural Land	Reconstruction of Agricultural-Based Facilities
Extent of Damage	Area of land effected by the 2011 Tsunami: 4725 ha (Sq.)	Districts requiring restoration following the 2011 Earthquake and Tsunami (radiation fallout damage not included): 2263 Districts
Agricultural Resource Management presence	Viable land available for agricultural resumption: 2542 ha (Sq.)	• Restoration Work Completed to date: 1721 Districts • Restoration Work started: 1908 Districts
Current Recovery Progress	53.8%	Started = 84.3% Completed = 76.0%
Aggregated Date	APR 2017	DEC 2017

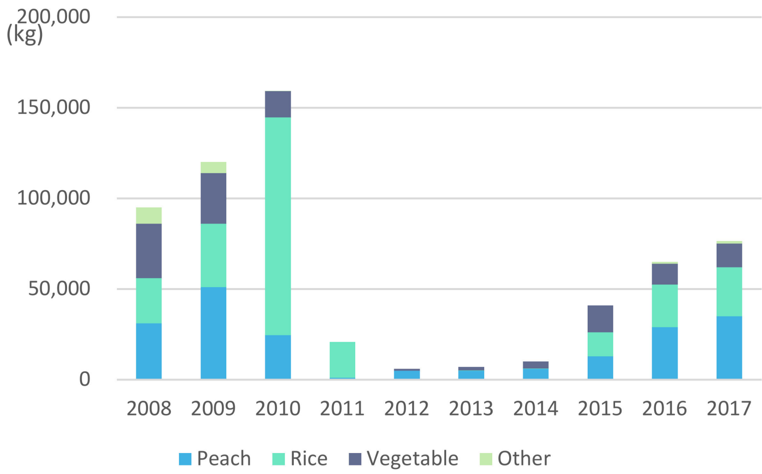

Figure 8. Output of agricultural products in Fukushima [63].

Soilless agriculture enables safe and sustainable cultivation in a controlled environment, effectively negating risk of radiation contamination. Lighting, the level of nutrients, humidity levels, temperature levels, and CO2 levels are all measured by sensor technology to ensure optimum conditions. However, a disadvantage is that the cost of overhead in soilless cultivation is high, due to the need for continual manning to ensure system stability and management, in addition to power usage, which currently equates to over 9% of the region's power usage [69]. Ongoing government and private company investment in renewable energy has helped improve eco-farming using renewable energy through solar and wind farming.

Though not the first to lead in the initial creation of such science, the people of the Fukushima prefecture are strong believers in its capability. As evidenced through the large amount of financial investment in technology behind hydroponic and aeroponic cultivation within the region where large companies such as Fujitsu, Bosch, and NNT docomo have made net investments of over 4,509,694 million JPY between 2016 and 2017 [69]. Innovation and partnership like this were described by all the government officials as the key to economic success. For example, A2P1 said,

> "Agricultural innovation is important for the region's recovery. Farming is such a crucial part of local people's livelihood, and it cannot stop because of the environmental damage. And innovations are also very important for ensuring food safety."

Drawing on the strengths of Fujitsu, who were already conducting soilless clean production agriculture in Fukushima, several multi-billion-dollar asset companies such as Sony, Nokia, and Bosch are also operating within the region on soilless agriculture engineering, employing extensive biological testing data to help assure higher production rates and survivability rates. This technology utilizes highly concentrated nutrient solutions with little physical space required—when comparing outputs to traditional land-based cultivation, the results are much higher. Furthermore, wastage is negligible, as soilless agriculture is biodegradable and suitable to further processing either into further crop food supplementation or to be added to livestock foodstuffs. Additionally, production is not affected by norm factors such as drought, flooding, the weather, insect infestations, and disease. Low-impact, high-gain agricultural production methods have given new hope to the region and are key to recovery.

Product export-import and cultivation statistics are released into the public domain monthly via the website of Ministry of Agriculture, Forestry and Fisheries (MAFF). The government aims to be as transparent as possible in the publication of these results, a strategy they see as crucial to regaining wider trust in Fukushima food production. Public relations efforts such as success stories of potential future partnerships and educational resources for children aim to help local people understand the benefits of this new soilless technology.

Additionally, a field visit to Fukushima Wonder Tomato Farm shows small-scale solutions can help build innovative adaption for the local people by educating on domestic food production (Figure 9). Through adapting greenhouse cultivation and soilless farming, locals are able to maximize solar radiation to reduce reliance on the Japanese national energy grid. Whilst not at an industrial scale, the Wonder Farm sees its role as educating and promoting the benefits of this type of small-scale soilless farming. Through the education process, it is hoped that these methods could be used by locals after a future disaster.

Figure 9. Soilless farming in the Wonder Tomato Farm. (Source: photo taken by Hui Zhang in Fukushima).

6.4. Tourism

With a shrinking and aging population, Fukushima must attract tourists, as well as sell local goods outside, for recovery. Tourism is central for local SMEs [70], which means it must be sustainable, create jobs, and balance the needs of Fukushima's local people and tourists to ensure future economic resilience. The tourism industry in Fukushima has been seriously affected by the disasters, but it has gradually recovered since 2012. In 2017, it had finally recovered to the pre-disaster level. As shown in Figure 10, the number of domestic Japanese tourists had reached 92% of the pre-disaster level in 2016, and the total number of international guests in Fukushima has exceeded the pre-disaster level in 2017.

Efforts to promote tourism were led by both the government and local resident groups, who wished to attract more people into the region. There is no specific government budget designated for tourism. The total Fukushima prefecture budget was 1.72 trillion JPY (1.57 billion USD), while 12.8 billion JPY (116.63 million USD) would be used on countering harmful rumors about Fukushima, promotion to tourists, and realizing the opportunities afforded by the Tokyo Olympic Games and

Paralympic Games 2020 [71]. All tourism materials used positive public relations messaging and scientific statistics to promote the region's environment and food as safe. In the first five years after the disaster, there was an emphasis on reviving domestic tourism and attracting tourists from neighboring countries. More recently, in conjunction with the efforts to promote the Japanese Olympics, there has been a renewed focus on marketing to international countries, most recently with a tour of Fukushima for foreign diplomats from 23 countries in 2019.

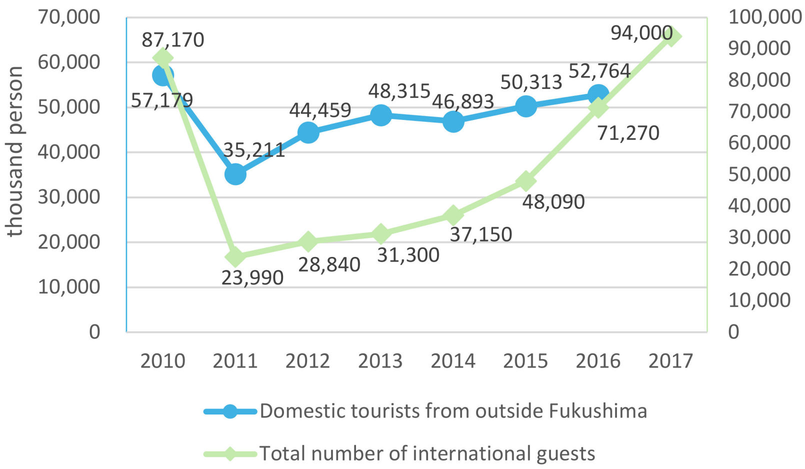

Figure 10. Changes in the number of tourists in Fukushima [62].

The revival of tourism relied mainly on local people and existing resources. Firstly, natural and historical tourist attractions (the five-colored Goshiki-numa Lake, and the 80-million-year-old "Abukuma Cave" in Tamura City), which used to draw people to the region, are being re-promoted, especially through featured local events and traditional festivals. There is an emphasis on social media and online articles to promote the region as both safe and interesting to visit. The Fukushima prefecture is also promoted as part of the tourist route known as the "Diamond Route," which also includes a visit to Tochigi and Ibaraki prefectures.

The second strategy has focused on rebuilding and reopening old tourist attractions, like Spa Hawaiians (a spa and leisure complex) and the Daishichi Sake brewery. Spa Hawaiians holds the record for being the biggest open-air bath in the world. Revived shopping areas, including Kokonara Shotengai and Machi Nami Marche in Namie Town, cater to Chinese tourists who want to shop. The building of the Prince William Park in Motomiya City, a traditional British park, that was opened in late 2017, inspired by Prince William's visit after the disasters, aims to symbolize the reconstruction of the area.

Local tourism businesses saw their recovery as situated within the overall success of the whole region. For example, Spa Hawaiians viewed their business strategy as crucial to the overall recovery of the area. Spa Hawaiians described how they worked as quickly as possible to rebuild their spa, opening up again in less than a year after the disasters. They argued,

> "We had lots of difficulties since the disaster, but we have kept on adapting ourselves to the new environment and have made lots of new strategies. We have recovered. We create job opportunities and attract tourists. More visitors mean that the local community flourishes. We are looking towards the future." (T1P1)

While initially visitor rates were down by 60% after opening, they have now recovered to the pre-disaster levels of around 1.45 million visitors a year.

Fukushima's negative reputation means that countering harmful rumors is a strategic focus for the Fukushima government. With some areas only able to attract limited evacuees back to their hometowns, some interviewees recognized that an increase in tourists helped create much-needed jobs. G3P3 said,

> "People will not come back unless there are jobs for them. Tourism is a way to help revitalize the area and create new jobs. Because of what happened to Fukushima it is essential that it is locals who tell outsiders what happened here."

Encouraging locals back to the area was thought to strengthen the traditional Fukushima culture and community. The central facet of the tourism strategy also tries to make the region's disadvantages become opportunities. For example, there is a design radiation pollution study tour for visitors, as well as educational study tours on disaster resilience run by the prefectural government and conducted by local people. Thus, there is an emphasis on what the international community has to learn from the events in Fukushima. Locals wanted outsiders to hear their stories. Local residents give talks to visitors because they can recount the challenges in a way that explores both the positive and negative, meaning negative rumors could possibly be dispelled. G2P2 described,

> "I am grateful for the support from all over the world. Tourism is so necessary to our area. People need to understand what happened to us."

Interviewees explained how they wanted tourists to appreciate the strength and determination of the local residents who have overcome considerable adversity but are still resolutely working towards reconstruction. The emphasis is on positive events that can showcase the Fukushima culture—the locals and the government try to organize other cultural activities to attract visitors, including a horse race festival in Minamisōma.

7. Discussion

Disaster recovery is a worldwide problem for sustainability [72,73], especially in the nuclear pollution disaster–affected areas. Through a method that utilized field surveys and unstructured interviews, this research reviewed the recovery of Fukushima's local industries to showcase some variability in recovery across the four pillars. The results show that Fukushima's industrial reconstruction has facilitated local economic recovery after the disaster. Sustainability meant not just about disaster recovery but about positively adapting to the new environment and mitigating future problems for the younger generation.

The Chernobyl accident is the only nuclear event on the same scale as the Fukushima disaster. In both Chernobyl and Fukushima, the dominant public protection response from the authorities was to evacuate large numbers of people from the surrounding areas [74]. This large-scale population relocation has seriously hindered the sustainable development of the post-disaster economies of Chernobyl and Fukushima. According to the conclusion of the World Health Organization's Chernobyl Forum Health Experts Group [75], "The Chernobyl disaster clearly shows [that] communicating information to the public in a timely and accurate manner after the release of radiation or toxic substances is most important." After the major nuclear accidents at Chernobyl and Fukushima, the attitude toward public information for post-disaster recovery and reconstruction from the two governments is in sharp contrast. At Chernobyl, the Soviet Union adopted strict secrecy, and opaque communication led to constant fear, where the local people blamed Chernobyl for any health problems [76]. The Soviet government controlled the spread of radioactive materials by the construction of sarcophagi to seal the contaminated areas and by prohibiting agricultural and industrial activities. These contaminated areas in Chernobyl became unmanned, and economic recovery was impossible [77]. The Japanese government adopted a more active risk communication strategy by closely monitoring the radiation levels in Fukushima prefecture and then releasing this as timely information to the public [78]. With the reduction of radiation and the reconstruction of infrastructure, the government is gradually reopening the evacuation zone. Evacuees are returning home to participate in post-disaster reconstruction and the local economy is gradually recovering [79]. Analysis of Fukushima shows that recovery from a major nuclear accident is not a linear, but a long and chaotic process of uncertainty—effective risk communication should be integrated into all aspects of this cycle [80].

According to the adaptive cycle model of regional economic resilience by Simmie and Martin [21], it can be regarded that the four industries in Fukushima are in different phases of resilience.

(1) **Renewable Energy Industry: Exploitation Phase.** In the exploitation stage, connectedness is low but increasing, while resilience is high. Production, human resources and knowledge resources are accumulating in the renewable energy industry, while regional industrial comparative advantages are gradually forming, and external resources (like human resources, technology and funds) are gradually accumulating in Fukushima. After the nuclear accident, the residents' aversion to nuclear energy increased rapidly, which enabled the development of renewable energy policies and industry. The Fukushima government and residents plan to make the Fukushima prefecture a "pioneer" of renewable energy, through introducing renewable energy industry, and then by promoting the post-disaster recovery solely with renewable energy.

(2) **Agriculture and Tourism: Release phase to Reorganization Phase**. Agriculture and tourism, predominantly functioning through SMEs, are traditional industries of the Fukushima prefecture. Due to the tsunami and the long-term effects of nuclear pollution, the operators of the agriculture and tourism industries suffered severe issues. Their original business models were unsustainable, and the localized businesses lost their influence. Old modes of production and institutional governance were dismantled, while resources were released. These huge changes stimulated the evolution from the Release phase to the reorganization phase, where new types of business activities begin to emerge, characterized by innovation, experimentation and reorganization. The reorganization stage has a low connectedness, a high potential to create new paths, and an open development track, so it has a high degree of resilience. With the development of new activities, with an emphasis on technology (e.g., the initiation of hydroponic crop farming, aeroponic and specialist biotech crops), new comparative advantages are released, and a new round of regional growth and accumulation began.

(3) **Manufacturing Industry: Reorganization Phase**. The manufacturing industry faced difficulties like labor shortage, facilities destruction and a lack of capital. After evolving through the release phase, with the adjustment and implementation of the revival policy, the industry has gradually entered a reorganization phase, which is shown in the fact that the manufacturing export volume has exceeded the pre-disaster level. In this Reorganization stage, a lot of innovation and restructuring begin to appear (particularly with robotics for disaster relief), connectedness is low, and resilience is increasing.

Resilience is not just about having the necessary resources, but also about the willingness and ability to translate resources into effective adaptation action. Informed by the adaptive capability analysis framework proposed by Cinner et al. [60], Fukushima's post-disaster economic recovery relies on the following elements:

(1) **Assets**. Assets, whether from the private or public sector, are the financial, technical, and service resources that people can access [60]. After a disaster, when people have assets available, they are usually better able to recover and adapt. The assets dimension in Fukushima's post-disaster industrial reconstruction mainly comes from the government, enterprises, overseas investors and the residents. The role of government is for 1) the formulation of general and local revitalization laws and regulations, 2) the establishment of reconstruction assistance funds, and 3) the promulgation of redevelopment funding financing regulations. The main role of overseas investors is to cooperate with Fukushima's local operators to provide technical support and financial assistance. Residents can also fund businesses operating in the post-disaster recovery industry and reconstruction. Even evacuated residents who have not yet returned to Fukushima can contribute to recovery through this fundraising.

(2) **Flexibility**. Flexibility refers to the opportunity to switch between adaptation strategies, and the diversity of potential available adaptation options [60]. For example, a farmer can choose

to adopt soilless cultivation or give up farming for another career. In the process of recovery of the four pillars, we can observe the flexibility in the post-disaster response strategies of various entities such as the government, enterprises, and residents. After local nuclear power was boycotted, energy policies and development strategies were adjusted to introduce renewable energy technologies. After the soil was contaminated, farmers began to adopt soilless cultivation techniques and install solar panels on abandoned farmland to generate electricity. Tourism operators began to develop educational tours on environmental issues and nuclear pollution after the disaster. The disasters in Fukushima provided a "window of opportunity" for local residents and enterprises to build flexible, response capacity and adjust their livelihood strategies. Under normal circumstances, these kinds of adjustments would be more unlikely as they may require more costs and are perceived as a greater risk.

(3) **Organization**. Organization makes cooperation, collective action, and knowledge sharing possible (or impossible). Formal and informal networks between individuals, communities and organizations can help people to cope with change by providing social support and access to knowledge and resources [60]. Importantly, social organization is multi-scale in nature, including three dimensions of individual, collective and organization. Across the pillar industries of renewable energy, agriculture, manufacturing, and tourism, innovative reconstruction projects have been pioneered and led by local residents. Participants stressed that this kind of self-organization is crucial to the process of recovery. As the "situation on the ground" usually changes rapidly after disasters, local residents, with their local knowledge, social networks, and resources, are most familiar with the culture of the disaster area. These factors enable them to have more social capital to develop adaptive strategies according to local conditions and to creatively solve local problems.

(4) **Learning**. Learning reflects people's ability to generate, absorb and process new information about risks and disasters, adapt to choices, and deal with and manage uncertainty. Learning can be either experimental or experiential, occurring on or across multiple scales of organization, space, and time [60]. In Fukushima, flexibility and learning go hand in hand. Creative recovery makes full use of people's and business' existing resources to transform the disadvantages caused by the disasters into opportunities. Fukushima has led a renewed focus on innovation, particularly through technology, as the main way to recover. There has been a focus on international partnership within renewable energy, manufacturing, and technology, with many of the participants stressing how much the international community has to learn from the disaster and the subsequent recovery of Fukushima. The post-disaster recovery strategy, which is shaped by local residents and focused on restoring livelihoods, enables Fukushima to demonstrate its adaptability and self-organization within the new environment after the disaster.

(5) **Agency**. Agency generally refers to the ability of people—individually or collectively—to make free choices in response to changes in the environment. It depends on people's belief in their ability to handle and manage expected situations and control the events that affect them, including aspects of empowerment, motivation, and cognition [60]. Agency is especially important in the complex environment of the post-disaster Fukushima. Local businesses and residents need to be able to manage and adjust beliefs, perceptions, and motivations, so the recovery process can proceed smoothly. The government, residents and businesses have all developed an awareness of the new environment after the disaster, and businesses have adjusted their strategies to cope with the long-term situation. Most notably, the residents have reframed their thinking to focus on the long-term by rebuilding Fukushima for their children's future. The promotion of renewable energy enables residents to gradually achieve a safe, reliable and sustainable energy supply without nuclear power. The reconstruction and renewal of manufacturing and tourism has provided jobs for local residents, making the local industry more diverse and dynamic. The promotion of soilless agriculture has enabled some local farmers to regain their livelihoods and provide safe and reliable food sources for Fukushima residents.

8. Conclusions

In conclusion, to study Fukushima's economic recovery from the perspective of industrial revitalization, four pillar industries of Fukushima were selected for investigation. By using qualitative methods to describe the specific situation of Fukushima's industrial reconstruction, it proposes that post-disaster economic resilience should be dominated by the affected residents, with a sustainable livelihood as the strategic goal. Viewing economic resilience as a dynamic process, and centering local people's perspectives through an interview methodology, is relevant to disaster experts, policy makers and public organization leaders to help them make better decisions for post-disaster reconstruction.

In post-disaster Fukushima, the economic downturn and business disruptions has been reversed and subsequently improved. Business continuity is a key driver of economic resilience. The outputs of the manufacturing industry and tourism numbers have not only recovered but have exceeded the pre-disaster levels. Agricultural output has not reached the pre-disaster level, but there is a new focus on innovations like soilless agriculture. Underpinning these advancements, both the Fukushima and the local people believe that the move to renewable energy will greatly increase the prefecture's long-term economic resilience and sustainability. By 2040, it is expected that the prefecture target to meet all energy demand through renewable energy will be fully realized.

In Fukushima, a consequent reduced labor force and an ageing population, means that their continuous long-term recovery should be a research focus. The key to building adaptive economic resilience is to make sustainable livelihoods for the affected residents a core emphasis, and to make local residents become dominant participants in their own industrial recovery. This strategy can promote long-term economic and social recovery in the post-disaster area and will help develop local capacity to resist the impact of future disasters. Local people, as both the labor force and major consumers of local products, are a primary factor to consider in post-disaster recovery. Their sustainable livelihood is not just about job opportunities, but also includes other factors, like a sustainable income, a safe living environment, and a self-sufficient energy supply. Future research could focus on examining in detail how these different factors contribute to economic resilience—the emphasis should not just be on the meeting of economic targets, but how they are met, and how that affects the local people.

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