Potential of the ‘Renewable Energy Exodus’ (a Mass Rural Remigration) for Massive GHG Reduction in Japan

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Abstract

For the utilization of renewable energy from sources widely distributed in low-density non-urban areas the grid augmentation for its transmission to urban areas of high population density is often discussed under the premise that the present demand distribution remains invariant. Instead of grid augmentation, this study examined an alternative option of creating a power demand close to renewable sources and inducing population movements (i.e., Renewable Energy Exodus). First, the capacity of renewable energy to maintain populations in hilly and mountainous farming areas of Japan was evaluated from two perspectives: Task (1) a challenging nationwide balance based on possible energy demand saving scenario for the future, and Task (2) a conservative nationwide balance based on the current per capita energy demand and on the region-by-region generation-consumption matching concept. Because Task (2) indicated that Hokkaido, the northern-most island, has a huge capacity, Task (3) was conducted for Hokkaido by examining both energy balance and economic evaluation including job creation for the following two scenarios: (A) a supply to Tokyo scenario and (B) a local demand generation scenario, keeping the same conservativeness as Task (2) by using the current data for energy consumption per capita. The nationwide Renewable Energy Exodus estimates gave 48 million people for Task (1) (with the future per capita energy demand) and 10 million people for Task (2) (with the current per capita energy demand and region-by-region self-sustained balance), respectively. For Hokkaido Task (3) (with an additional economic assessment) gave 1 million people. The Renewable Energy Exodus concept combined with the green economy promotion was found to have a significant merit for a sustainable future of countries like Japan where economic and social disparities are serious between urban areas and non-urban areas.

Keywords: Massive GHG emission reduction; Renewable energy supply/demand matching; Mass rural remigration

1. Background and Objectives

Energy policies in many countries has been shifting to increase the weight of renewable energy in their energy supply not only to respond to the international pressure for low carbon energy transition but also to intensify their energy security and economic affordability for industries and end users as critical issues to deal with [1]. Japan, experienced a severe nuclear plant accident on March 11, 2011, is particularly in the dilemma to deal with maintaining energy security and reducing greenhouse gas emissions at the same time without relying highly on nuclear power [2, 3].

Concerning energy supply chains, the embedded nature of socio-technical issues such as resilience, flexibility and adaptability is crucial [4]. Accordingly, in many industrial countries, they have been locked into a “carbon lock-in” condition poised on the conventional fossil fuel-based energy systems [5]. Regarding it as a key problem for the UK, Hogget [4] suggests that smaller scale technologies are more likely to support and enable a secure, low carbon energy transition by the comparative analysis between supply chains for PV as an example of small scale technologies and nuclear power as an example of large scale technologies. For the security and resilience of energy systems with renewable energy sources, it has been argued the importance of decentralization of supply systems [6, 7]. In Japan, where electric power generation and distribution has been dominated by the regional electric company by law there have been only limited cooperation between regions. Still being under the strong influence of centralized energy supply system, the reinforcement of intra and interregional transmission grids have been argued as one of the critical energy policy issues [8,9] for the secure transmission of the renewable based electricity to urban, particularly to metropolitan, areas of high population density from non-urban areas of low population density.

However, some studies show a skeptical view about the transmission of rural renewable energy to megalopolises in terms of its effect on rural economies because of its exploitative nature to the local supply side in remote areas [10].

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OECD [11] reported that a top-down and large-scale approach to renewable energy is causing communities to oppose installations in a number of rural areas, and recommended developing a “place-based” approach that combines renewable energy with rural development. Heffron and MacCauley [12] argue this issue through “energy justice” concept by introducing current UK research, including Todd and Zografos [13], which showed that the poorer and less powerful groups/areas are often challenged by the injustice. This issue is not only one of the mid to long-term issues but also quite an urgent political one related to the justice in policy-making, particularly in countries like Japan where many rural areas with abundant renewable resources face the threat of deprivation of their natural resources by business from outside that tend to show no regards to their present difficulties including serious depopulation, ageing and economic deterioration.

Over the last century, urban areas where modern industrial and commercial development has occurred have been continuously attracted migrants from rural areas. In some countries like Japan, this tendency intensified after WWII due to the introduction of oil, coal, and natural gas as imported energy sources, which allowed intensive energy conversion in urban centers at coastal locations. The current urban vs. countryside population divide and economic unevenness are a consequence of fossil fuel utilization with the above mentioned industrial siting. Thus, the massive fossil energy replacement by the utilization of alternative energy sources, which are distributed thinly but widely over the land, could bring a chance of fundamental redesign of the social demand distribution. Once demand distribution is adjusted to the source distribution, it would reshape the source (supply)-to-demand (consumption) energy unevenness of the existing ‘modern’ society. However, in contrast to the enthusiasm for arguing temporal matching of renewable electricity generation and consumption, so far professionals and policy makers have neglected the spatial matching issue which is also the issues of minimizing the total grid enforcement cost. Moreover, the spatial matching issue has been dealt only with the countryside-to-urban transmission grid construction issue on the premise of no change in the present urban area distribution [14].

In Japan, the inter-islands high voltage grid augmentation plan is under discussion to cope with the rapid increase in supply capacities after the introduction of Feed in Tariff (FIT) scheme in July 2012 particularly from recently planned and/or installed mega PV stations and also with the projected huge increase from the to-be-installed wind farms. METI (Ministry of Economy, Trade and Industry) has conducted a study on reinforcing interregional transmission grids [9]. This study reported that, due to the outstandingly high potential of wind power in Hokkaido (the northern-most island of Japan), a reinforcement of some 5.9 GW increase for the internal and Hokkaido-Honshu (the main island) inter-islands transmission grids, including the new seafloor cable laying, has to be conducted. The cost has been estimated as some 11billion dollars (\$1=Yen 107). WWF Japan [15] also estimated the necessary capacity of inter-islands transmission grid with the electric supply and demand simulation toward 2050 when 100 % of energy demand is supplied by renewables is achieved under their scenario. In the estimation, the capacity of wind power in Hokkaido was set much lower than the real taking into account the too high construction and operation costs for the inter-islands transmission through the sea floor cables. In this paper we first raise an alternative option of the mass rural remigration and local demand creation against the current government scenario of a national master plan that almost all the energy generated from renewable sources in rural areas is to be transported to the megalopolitan areas of large electric demands. Next we estimate of potential population remigration capacity in rural areas in Japan from the potential amount of renewable energies under the assumption of self-sustaining of energy within areas. Then we focus on Hokkaido, we apply economic evaluation on the two scenarios and discuss: Power supply to Tokyo scenario (Scenario A) and Local demand creation scenario (Scenario B).

2. Methods

The present task of nationwide estimation of the population holding capacity of renewable energy, i.e. the potential of renewables based mass rural remigration, was divided into the following two sub-tasks:

Task (1) a futuristic estimate, i.e., an estimate of the national level, based on the future average per capita energy demand for an era when a substantial GHG emissions reduction is achieved (cf. 3-1), and

Task (2) a conservative estimate based on the current per capita demand and on the local region-by-region generation-consumption matching with some examination on the scale effect of matching area (cf. 3-2).

As we obtain a notion from Task (2) that Hokkaido has a huge potential capacity, we move to Task (3) to examine two scenarios to fulfill the capacity based on a preliminary economic analysis focusing on job creation potential as seen in 4 for the following two cases:

(A) Supply to Tokyo scenario, and

(B) Local demand creation scenario (i.e., a scenario where we utilize Hokkaido’s renewable energy potential to revitalize its domestic economy and society by providing new economic investments).

3. Estimates of Potential Remigration Capacity

3-1 Nationwide average estimate

3-1-1 Migration capacity estimation Table 1 shows the number of household and population in 2005 for four areas of different land use. Among these we focus on hilly and mountainous farming areas for the migration capacity estimation because in these areas the demand/resource imbalance is significant. Table 2 shows a rough estimate of renewables' resources in these areas.

The current (2009) data and an estimate for a future (say 2050) situation (i.e., after a substantial GHG reduction completed) for per capita energy consumption in hilly and mountainous areas are shown in Table 3. The future demand was calculated based on appropriate/available technology data. With these data we estimated the surplus energy in the future hilly and mountainous areas by subtracting the future demand from the available renewable energy. For simplification, we assumed that biomass is utilized only for heating and other energy sources are for cooling, lighting, moving etc. as shown in Table 4. This is because of the fact that the domestic biomass resource in Japan was found not sufficient for the future heat demand. For the remaining heating demand, we assumed that electricity is used for heating.

Table 1 Households and population in different area (2005)

	Households		population
	%	number	
Urban area	80.5	39,495,337	100,603,432
Flat farming area	8.6	4,219,378	10,747,696
Hilly farming area	7.9	3,875,940	9,872,883
Mountainous farming area	3.0	1,471,876	3,749,196
Sum	100.0	49,062,530	124,973,207
Hilly and Mountainous areas subtotal	10.9	5,347,816	13,622,079

Source: White paper on food, agriculture and farmland, MAFF 2008 [16]

Number of households: Population census, MIC 2005[17]

Table 2 Renewables' resources in hilly and mountainous areas

Type of energy	Heat	Electricity
	PJ/yr	PsJ/yr
Wood biomass	4.6	-
Hydro	-	92.1
Geothermal	-	14.8
Wind (on shore)	-	720.8

Source: 2005~2008 METI and related data

Hydro power potential includes only less than or equal to 100MW undeveloped sites.

PJ=10⁶GJ=10⁹MJ

Table 3 National average energy consumption per capita for year 2009 and future

Energy Consumption MJ/(person.yr)	Heating	Hot Water	Lighting & Electric Appliances	Cooling	Mobility	Total
2009*	4,915	6,108	7,009	404	Gasoline: 8,750**	27,186
future (~2050)	2,775	4,000	4,625	200	EV: 1,750	13,350

*) Source: Household Energy Handbook 2009, Jukankyo Res. Inst. [18]

**) Per capita gasoline consumption is assumed to be total gasoline consumption divided by population. Annual total gasoline consumption for private cars used by household was taken from the energy balance table of the total energy statistics of Japan of METI.

Table 4 Future energy demand of the present population and the potential renewable energy surplus in hilly and mountainous farming areas

PJ/yr	Available wood Biomass (B)	Future demand corresponding to the present population		Potential surplus heat (S1 =B-H1-H2)	Available renewables (E: Hydro, Geothermal & Wind)	Future demand corresponding to the present population			Potential surplus renewable electricity (S2=E-L-C-M)	Available renewable electricity =S1+S2
		Heating (H1)	Hot water (H2)			Lighting & electric appliances (L)	Cooling (C)	Electric mobility (M)		
Demand and surplus	4.6	37.8	54.5	-87.7	827.8	63.0	2.7	23.8	738.2	650.5

From these data we obtain:

Renewables based potential mass rural remigration = 48.7 million persons.

3-1-2 Corresponding CO₂ emission reduction effect To estimate CO₂ emission reduction we took into account both reduction for the present population (E1) and for the population newly migrating (E2). For the former we assumed that the direct CO₂ emission by year 2050 in hilly and mountainous areas should be negligible since all fossil based energy consumptions there should be replaced by renewables. Then E1 becomes equal to the present direct CO₂ emission in the hilly and mountainous areas and E2 becomes roughly equal to the present CO₂ emission due to the electricity consumption in urban and flat farming areas for population migrating from there to the hilly and mountainous areas, where the precise effects of CO₂ emissions from mobility and transportation are neglected. As the sum of the following E1 and E2 we obtained a rough image of the scale of mass rural remigration in terms of CO₂ emission reduction:

E1= CO₂ emission reduction by replacing all fossil based energy with renewables for the present population in the hilly and mountainous areas
= the present direct CO₂ emission in the hilly and mountainous areas
= 31.9 Mt-CO₂/yr

E2 = CO₂ emission reduction due to migration from the urban and flat farming regions to the hilly and mountainous areas
= the present CO₂ emission from thermal power plants relevant to the migrating urban people's consumption
= $48.7 \times 10^6 \text{ (person)} \times 27.2 \text{ (GJ/person/yr)} \times 83 \text{ (kg-CO}_2\text{/GJ)} / 1000 = 110.0 \text{ Mt-CO}_2\text{/yr}$

Total=E1+E2 = 141.9 Mt-CO₂/yr

The above values represent the most aggressive estimate for the future, in terms of both its futuristic energy demand assumption and its nationwide macroscopic nature for supply and demand matching.

3-2 Conservative but region-by-region estimates

3-2-1 Procedures In this section we make more conservative but more precise estimates. First, the current value of per capita energy demand is directly used for the demand except for mobility. Only mobility is assumed to be completely converted to electric vehicles. Second, the surplus calculation is conducted by utilizing the renewables' distribution data with 1km² mesh for the energy-supply calculation and also by introducing the scale factor for demand areas to make demand and supply self-sustaining. Also the population density issue is taken into account by introducing the historical maximum population density of each area to limit the migration. This is again a little conservative requirement because at the time when we experienced the maximum population in hilly and mountainous areas we did not have high-rise buildings in countryside, which might not be so in the future. However, the limitation could be still realistic because the living area per capita in the past was much smaller than that today. This population density limitation is however waived later for Tohoku (Northeast six prefectures of Honshu) and Hokkaido because the urbanization of these areas started some time later than the rest of the country. The distribution of migration potential was obtained by applying similar self-sustaining calculation for each regional area as **3-1** to obtain renewable energy surplus for the area. For energy demand calculation the current data for each region (cf. Table 5) were applied.

Since the potential of solar in hilly and mountainous areas is not as high as in flat areas, only the yet-unutilized resources of on-shore wind (mean velocity $\geq 7.5 \text{ m/s}$) and of micro-hydropower (construction cost $\geq 1 \text{ MYen/kW}$), and 'utilizable' forest biomass and geothermal (density $\geq 1590 \text{ kW/m}^2$) resources were taken into account based on MIC (Ministry of Internal Affairs and Communications)'s Guideline for Green Decentralization 2011 [19]. As in **3-1** biomass was basically used for heating (boiler efficiency of 85% assumed) and the gap demand was fulfilled with electric heating.

For the historical maximum population data the FY1950 borders of municipalities were used, since the year 1950 was right at the beginning of the country-to-urban mass migration.

The number of migration is calculated in **3-2** as the difference between the renewables based population holding capacity minus the future (2035) population projected by National Institute of Population and Social Security Research (NIPSSR) [20]. Because the projection is available only for the current municipality boundary but not for the spatial grid, future population density of 1km² mesh were estimated by spatial interpolation from municipality based population density of FY2005. To superpose purely renewable based capacity and historical maximum capacity

defined above, the historical capacity was used as the upper limit, i.e., if 1950 population was smaller than NIPSSR projection no remigration was concluded.

Table 5 Regional energy consumption per capita for conservative but region-by-region estimates

Energy Consumption MJ/(person·yr)	Heating	Hot Water	Lighting & Electric Appliances	Cooling	Mobility**	Total
Hokkaido*	14,936	7,236	7,670	25	EV: 1,750	31,617
Honshu						
Tohoku*	9,015	5,828	7,096	100	EV: 1,750	23,789
Kanto*	3,643	6,678	7,555	326	EV: 1,750	19,952
Hokuriku*	6,429	6,081	7,377	339	EV: 1,750	21,976
Tokai*	2,553	6,008	6,864	395	EV: 1,750	17,570
Kinki*	2,682	6,384	7,543	526	EV: 1,750	18,885
Chugoku*	3,506	4,957	7,389	450	EV: 1,750	18,052
Shikoku*	2,926	5,166	7,683	621	EV: 1,750	18,146
Kyushu*	2,447	4,618	7,133	503	EV: 1,750	16,451

*) Source: Household Energy Handbook 2009, Jukankyo Res. Inst.[18]

**) Energy consumption for mobility was assumed to be the same as of Table 3 for electric vehicles.

3-2-2 Results As illustrated in Figure 1, in which the 1955 municipalities' data were used for the scale of self-sustaining area, the potential remigration capacity based on renewables' utilization is quite large and the population density limitation, i.e. to ensure the living space, seems to be the major controlling factor. The renewables' potential and population density limitation (historical (1950) maximum capacity) again coincided particularly in Tohoku and Hokkaido, where the settlement had been still not completed to develop sufficient number of urbanized areas by 1950. Thus it seems to be reasonable to make an estimate by waiving the historical population density limitation for these two areas. On the other hand, the potential capacity based on the renewables' rather than the historical capacity is found to be dominant in the west part of Honshu. Table 5 summarizes the whole results in total potential remigration capacity. Note that these estimates are based on, first, the present energy demand and, second, only on household consumption. Since the household consumption in the future can be made half and since the renewables' capacity is still remaining high, there should exist some room for introducing industries as well to create work.

Figure 1. Mass remigration capacity estimates for 1955 municipality scale [people/km²].

Now it is interesting to see the effect of choosing the scale of self-sustaining area. Figure 2 shows the scale effect of self-sustaining area ('unit' in Fig.2), i.e., the scale of area for matching between renewable energy generation and consumption, on the energy surplus effective to accept remigration, where the data for 5561 units correspond to the case of 'considering both A & B' in Table 5. The reason of this scale effect is that the very close neighbourhoods of renewable energy sources have not been preferred for habitation and accordingly that their historical maximum population limits become overwhelming. The potential migration number of the renewable energy exodus increases with widening the area. Since a circular area of 30 to 50km radius should be an appropriate local transmission area, the reasonable self-sustaining area could be as wide as 2700 to 7500 km². Then, we obtain 7 to 7.5 million as an estimate

for potential conservative remigration, which is 1/6 of the most aggressive estimate made in 3-1 but a still sufficiently big number worth to develop a new renewable energy remigration policy.

Table 5. Summary of conservative and region-by-region estimates

Condition for estimation	A: Renewables based	B: Limited by historical maximum population	Considering both A & B	Waving B for Hokkaido and Tohoku
Million people remigration	32	15	4.7	10
Mt-CO ₂ /yr reduction by mass remigration	64	30	9	20

Figure 2. The effect of the area scale of the matching between renewable energy generation and consumption to estimate the potential migration number

4. Economic Evaluation for Mass Migration to Hokkaido

4-1 Methods

As shown above Hokkaido was found to have a huge potential of renewables, and accordingly, mass migration capacities. To make the potential real the following two different approaches are applied: A: Supply to Tokyo scenario, where almost all energy generated by local renewables is sent to Tokyo area (a business as usual Tokyo-centred scenario); and B: Local demand creation scenario. Scenario A is close to the METI's study [9] including Hokkaido Electric Power Co.'s present forecast shown in Fig. 3. On the other hand, Scenario B is related to the government's local comprehensive development plan [21] and Hokkaido government's Back-up Hub Vision of Hokkaido [22]. However, on Scenario B no serious evaluation has been so far challenged. So in the following a preliminary evaluation of the two scenarios is conducted.

Figure 3 Hokkaido-Honshu transmission grid and existing plans for its empowerment
(Drawn by the present authors based on material [9] and other information)

In this section we consider wind and mega solar also in flat areas (e.g., 1.87GW of wind power and 0.9GW of solar power). In Scenario A, we assume that the internal grid of Hokkaido is reinforced for renewables to transmit the power through the to-be-added three seafloor cables (0.6 GW each) and through the to-be-added Tohoku core and 2nd Tohoku-Tokyo transmission grids.

In Scenario B, we assume that the new types of sustainable industries are developed in Hokkaido counting on its renewables resources. Referring previous plans noted above, we assume ‘renewables electricity’ based industries and services such as (a) ICT data centres, (b) capital function support, (c) electrified agriculture, (c) electricity based heavy/chemical industries, (d) tourists’ theme-parks.

In the present economic evaluation we conducted cost effectiveness analysis and impact analysis.

In the cost effectiveness analysis we adopted the annual CO₂ emission reduction assuming that coal fired power generation is reduced by the introduction of renewable power stations. The thermal efficiency of coal fired power generation was set as 42% (HHV base) according to the present best available technology [23]. The cost was estimated by subtracting the available cost for thermal power plant construction from the additional cost of constructing renewables’ power plants and relevant infrastructures and converting the value into annual cost adopting the conversion rate of 8% [9].

In the economic impact analysis we focused on potential employment increase in Hokkaido, analysing the induced effects of demand changes from the developments of new types of industries, applying the inter-industry table’s regional I-O open model that includes 344 sectors combined with the I-O table of Hokkaido (provided by METI) and with the National I-O table (provided by MIC) and adding the employee incomes, household consumption expenditures and technology vectors of solar voltaic and wind powers. In the impact analysis we treated the household sector as one of the endogenous sectors and the demand as an exogenous variable. All the input-output table data are for FY 2005. Then we evaluated the induced demands in the infrastructure construction phase and those in the operation phase for Hokkaido and for the national level. For Scenario B we assumed that the production increase in Hokkaido reduces the reduction of the same amount in the rest of the country. Only one exception is the electricity-based agriculture. We assumed that the new development is for export and does not affect the production in the outside. From these, we estimated the possible number of migrants by multiplying the newly induced employment income by the current workers’ per capita income. In Scenario B we followed the Japan Foodpia [21]’s plan and assumed the agricultural and food exports will increase from the present 0.5 trillion Yen to 8 trillion Yen. In the present calculation 11.8% of this increment which is 7.5 trillion Yen was allocated to Hokkaido for Case 1 of Table 1 and 50% for Case 2).

Further details of parameter estimation and calculation procedure are summarized in A1 to A6 of Appendix.

4-2 Results

The results are summarized in Tables 6 and 7 for scenarios A and B, respectively. Roughly 1 million migrants are possible from Scenario B compared with only 4000 from Scenario A. This big job creation effect is legitimized strongly by the CO₂ reduction effect 5,722ktCO₂/yr with 112.6 billion Yen/yr of Scenario B compared to 3400 ktCO₂/yr with 134.8 billion Yen of Scenario A. Comparison of the results here, i.e. about 1 million people, with those in 3-2, where we had some 5million increase by waving the historical population limit for Hokkaido and Tohoku, shows that the economy or income issue really limits the migration capacity. Accordingly, to make the Renewable Energy Exodus real the green economy/industry promotion should become a key issue.

Table 6-1 Cost effectiveness analysis (CEA) of Scenario A: Supply to Tokyo

	Items	estimated values
Cost	local grids construction in Hokkaido	16.0 bill.¥/yr
	Additional Hokkaido to Tokyo grid construction	54.4 bill.¥/yr
	FIT electric purchase	103.4 bill.¥/yr
benefit	avoidable cost	39.1 bill.¥/yr
Overall	cost – benefit	134.8 bill.¥/yr
CO ₂	Reduction	3,400kt-CO ₂ /yr
CEA	CO ₂ reduction cost	39,600 ¥/t-CO ₂

Table 6-2 Economic impact analysis of Scenario A

	Domestic (Hokkaido)	Outside
Employee by Construction	87,170	104,908
Employee/yr by Service	2,114	-7,818
Potential migrants*	3,810	

*) Potential migrants=[induced employees’ income] / [mean per capita income in Hokkaido]

Table 7-1 Cost effectiveness analysis of Scenario B: Local Demand Creation

Items	cost – benefit
Case1: Domestic grid construction + FIT electricity purchase – Avoidable cost	109.2bill.¥/yr
Case 2: Construction cost for loop grid is added to Case 1	234 bill.¥/yr
(a) ICT data centres	-2.1 bill.¥/yr
(b) Capital function support	5.5 bill.¥/yr
(c) Electricity based agriculture	-1.4 bill.¥/yr(Case1) -6.1 bill.¥/yr(Case2)
(d) Electric based heavy/chemical industries	—
(e) Tourists' theme parks	0 bill.¥/yr
Overall (Case 1)	111.2 bill.¥/yr
Overall (Case 2)	231.4 bill.¥/yr
CO ₂ reduction (Case 1)	5,722kt-CO ₂ /yr
CO ₂ reduction (Case 2)	11,371kt-CO ₂ /yr
CEA: CO ₂ reduction cost (Case 1)	19,429¥/t-CO ₂
CEA: CO ₂ reduction cost (Case 2)	20,350¥/t-CO ₂

Table 7-2 Economic impact analysis of Scenario B

Case 1 (cf. Table 7-1)	Domestic (Hokkaido)	Outside
Number of Employees by Construction	28,727	34,572
Number of Employees/yr by Service	220,730	16,121
Potential migrants	498,363	
Case 2 (cf. Table 7-1)	Domestic (Hokkaido)	Outside
Number of Employees by Construction	78,255	94,179
Number of Employees/yr by Service	520,786	315,127
Potential migrants	977,912	

5. Discussion

From the Age of Exploration that took place over mid15th to mid17th Centuries, sometimes spontaneous and sometimes government supported mass migration has been seen many places in the world, many of which were related to colonialism and sometimes invasion. Also after the Industrial Revolution people's migration from countryside to urban area has been common in many countries. Although in the development countries such trends are still ongoing both domestic and international, they would cease soon with the maturation of their modernization. These mass migration issues may have exited from the main stage. However, the 'modernization' so far took place has been based much on fossil and nuclear energies that are supposed to deplete within a century. Also, both energies have emission/waste issues, i.e., global warming and climate disasters for fossil fuels and high level waste and possible severe accidents issues for nuclear energy. Now that the renewable energies' widely and thinly distributed and decentralized nature is giving us a completely different boundary condition for industrial and residential siting, it is extremely important for the society to recognize it and reorganize long term planning free from 'carbon locked in' thinking. In the above estimation, we have confirmed the remigration policy from urban to countryside is much effective.

Indeed, Japan's rural areas are rich in renewable energy of various kinds. In regard to biomass, 67% of Japan's national land is covered by rich forest of some 50 years old timbers. In regard to hydropower, Japan's mountainous land structure and the long coastline as an island state in monsoonal climate create a unique hydropower potential. Furthermore, Japanese volcanic islands are rich in geothermal resources. These situations provide uniqueness for Japan among most of the developed countries but commonness in some Asia Pacific and Oceania countries. Also the mal-distribution of population between hilly/mountainous areas and flat areas is quite distinct, which could create a serious unbalance between the local renewable resources and the energy demand by domiciled population.

In the case of Hokkaido, the government supported settlement started from Meiji reform of 1868. The Meiji government sent ex-legionary troops to Hokkaido to reclamation and protection of new settlers. After WWII Hokkaido accepted people returned from outside and its population has grown rapidly during the 1950s as shown in Fig. 3. Compared with the increase that time of about 1million/decade, the present estimation made above in 4 (cf. Table 7-2) is not at all unrealistic to organize. This increase could increase population density of Hokkaido roughly 20%, which is

only 15 person/km² from the present 73 person/km² (2005 Census). Since average density in 2005 was 343 person/km², increment of such size should not change the wilderness of Hokkaido at all.

More important issue of mass remigration should be its social aspects particularly incentives for both present residents and new comers. Once tax, subsidy and regulation policies that are supportive for new industries are introduced, companies would locate their facilities into local areas as just happened the rush of data centre siting in Oregon, US [24]. Even so, the key issue should be how to promote endogenous development for both local community and economy with a good collaboration of existing business and residents with new coming ones. In the case of Hokkaido, the decaying economy has been supported by the central government after shut down of almost all coal mines in the 1980s. Thus their economy at this moment is far from independence, but there is a challenge to recover its own leadership to a draw long term perspective as reported by Tambo [25]. Future research should be focused further to promote remigration with the endogenous development principle.

Figure 3 Population trend of Hokkaido (drawn by the present authors using MIC data.)

6. Conclusions

The effectiveness and significance of the Renewable Energy Exodus concept, i.e., mass rural remigration for regional renewables utilization, in Japan was confirmed through the following three estimation steps: (1) a challenging nationwide balance based on possible energy demand saving scenario for the future, giving a remigration potential of 48 million people, (2) a conservative nationwide balance based on the current per capita energy demand and on the local generation-consumption matching concept, giving 10 million people as a minimum and to realize the potential, (3) realistic migration estimates for Hokkaido by examining both energy balances and economic evaluations focusing on job creation for the following two scenarios, A: Supply to Tokyo and B: Local Demand Creation, by using the current data for energy consumption per capita, giving almost 1 million people remigration with the sufficient economic basis. Thus the result shows a significant merit for a sustainable future of countries like Japan where economic and social disparities are serious between urban areas and non-urban areas. However, the result of our study also indicates that a drastic change must be introduced into the national-regional policy, which so far has been just subsidizing its weak economy and planning to utilize its rich renewable energy resources by transmitting electricity outward. However, economy or income issue really limits the migration capacity. To make the Renewable Energy Exodus real the green economy/industry promotion planning is necessary for rural areas. Further work is needed to draw a roadmap to realize the concept into a new policy.

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Appendix

A1 Evaluation of wind power potential in Hokkaido

The potential of additional implementation of on shore wind power in Hokkaido has been evaluated as 140 to 200 MW with no special modification to the present infrastructure, 500 to 790 MW if load control is performed to meet load changes and 3.39 to 4.02 GW if augmentation of inter-regional transmission lines is conducted [26]. Although MOE evaluation of the potential was conducted by exempting areas where the distance is less than or equal to 500m from residential areas. Taking into account the report of Tachibana [27] on the effect of noise pollution, the appropriate minimum distance for wind power could be 1500m from residential areas. In the present calculation we assumed that we only take into account on shore wind power implementation together with the inter-regional transmission line augmentation. Concerning with the minimum distance from residential places, 1500m was adopted since even with this strict condition the potential of Hokkaido remain 2/3 of the case of minimum distance of 500m although the power potential of nationwide average is reduced to 1/2.

A2 Assumptions for Supply to Tokyo Scenario (Scenario A)

A2-1 Costs estimation

METI interim report [9] showed that the wind power and mega-solar (MPV) potentials are 1.87 GW and 0.9 GW, respectively, and the construction of the transmission grids for these (2.7 GW) are 200 bill. Yen for inner-Hokkaido line (730km), 500 bill. Yen for Kita-Hon HVDC Link (i.e., Hokkaido-Honshu Link (193km) = 600MW×3) and 400 bill. Yen for Tohoku (i.e., the Northeast part of Honshu) core line, from which the cost for Hokkaido was evaluated as 180 bill. Yen in proportion with the tentative weight (45%) of renewable electricity from Hokkaido in the sum of those from Hokkaido and Tohoku area to Tokyo area. Thus we have 880 bill. Yen for transmitting 2.7 GW of renewable electricity from Hokkaido to Tokyo.

The annual renewable electricity production in Hokkaido for export is obtained as 4.1 bill. kWhr by using utilization rate of 20% for windmills and 12% for MPVs [4] (i.e., $(180000\text{kW} \times 0.2 + 90000\text{kW} \times 0.12) \times 8760$).

Since the conversion factor from initial cost to annual cost as depreciation is 8% about transformation and transmission facilities [4], we obtain 17.2 Yen/kWhr.

By using the FY 2014 procurement prices of FIT (i.e., 22 Yen/kWhr for wind ($\geq 20\text{kW}$) and 36 Yen/kWhr for solar ($\geq 10\text{kW}$) for the electricity price for end consumers we have 103.4 bill. Yen for the total electricity purchase cost but the consumers' tax was neglected since some more cost reductions can be expected in the future.

A2-2 Benefits

Here benefits are evaluated from avoidable costs for the electricity generation. The cost of power generation to be avoided by Supply to Tokyo scenario is obtained as 9.53 Yen/kWhr (maximum price) from TEPCO's IFB outline for wholesale electricity supply, which is close to the value of 9.98 Yen/kWhr shown in METI's notification for setting preventable unit cost etc. (notification no.144) announced on 18 July 2012. By multiplying 4.1 bill. Yen obtained in A2-1 to 9.53 Yen/kWhr we have 3.91 bill. Yen.

The CO₂ emission reduction is estimated by annual renewable electricity generation $\times$ CO₂ emission coefficient of the source of avoided electricity. For the emission coefficient we used 0.83kgCO₂/kWhr assuming ultra-super critical (USC) boilers of 42% thermal efficiency as the best available technology (BAT). Then total annual CO₂ emission reduction amounts 3400 ktCO₂ (=4.1bill. kWhr $\times$ 0.83kgCO₂/kWhr).

A3 Assumptions for Local demand creation scenario (Scenario B)

A3-1 Common issues

A3-1-1 Local transmission line development cost

Following METI interim report [9] we expected that renewable electricity of 3.935GW can become connected to the grid if a sufficient domestic transmission grid from the northern part to the central region of Hokkaido is developed with the cost of 290 bill. Yen. With the 20% utilization rate of the annual renewable electricity generation is obtained as 6.9 bill. kWhr. The annual operating cost of the local transmission cost is estimated as A2-1, 23.2 bill. Yen (=290 bill. Yen $\times$ 0.08). Thus the cost per electricity becomes as 3.4 Yen/kWhr.

If a domestic electricity demand is created massively, the above transmission line would not be sufficient. In such cases we would need a loop transmission grid. The length was estimated as 1000km. By assuming 5mill. Yen/km from the data of Deloitte Touche Tohmatsu LLC [28], the domestic loop grid construction cost is estimated as 500 bill. Yen and 5.8 Yen per kWhr.

Summing up the above costs, we obtained the grid construction cost for the local demand creation scenario (Scenario B) becomes 3.4 Yen/kWhr (without a loop grid) to 9.2 Yen/kWhr (with a loop grid).

A3-1-2 About load following capability

In the present evaluation, the additional investment for load following capability is not included. If we add LNG power plants of the same capacity as of wind power stations it would cost roughly 200bill. Yen. However, on this issue we need some temporally extending nature of those facilities. In Hokkaido a new LNG power station of 1.7GW

(Ishikari-bay) and a pumped storage power plant of 600MW (Kyougoku) are under construction/planning. Since these can play some good role in our scenario, we neglected the additional cost for load following capability development.

A3-1-3 Other

The basic data for cost evaluation of power generation to be avoided by the installation of renewable electricity is the same as in the case of Scenario A.

A3-2 Local Demand Creation Sub-Scenarios

A3-2-1 ICT data centre City Scenario

The market scale of data centres in Japan was 1.2 trill. Yen and is estimated to grow to 1.5 trill. Yen by FY2016 [29]. Assuming this trend lasts until 2030, the market scale then will become 2.4 trill. Yen, with 1 trill. Yen as a growth. Although the major siting of data centres in Japan has been in central part of Honshu, their siting to rural area and particularly to Hokkaido will become more common from such viewpoints as cloudization, energy saving and disaster risk management. In the present scenario we assumed 10% of new data centres corresponding to the above growth increment would choose Hokkaido as their sites.

The electricity consumption of data centres are on the average 5.22GWhr/bill. Yen sales [30]. However, in Hokkaido it is estimated as 3.15GWhr/bill. Yen sales since air conditioning energy can be 89.9% less in Hokkaido than in Tokyo and since 44% of the electricity consumption by data centres in Honshu is for air conditioning [31]. Based on these data, the electricity consumption in science-information cities in Hokkaido in the future can be as high as 315GWhr/year and the benefit of siting them in Hokkaido can be as high as 2.1 bill. Yen/year (10 Yen/kWhr was assumed).

For super computers, we assumed that three exascale supercomputers will be introduced in the science-information cities in Hokkaido by 2030. This is a reasonable estimate because 32 supercomputers of rank above 500 in the world were in operation in Japan in 2012 and because we can assume similar number of exascale supercomputers will be in operation in 2030. Assuming that the electricity consumption of an exascale supercomputer amounts 3 times of the Japanese fastest supercomputer K, we estimated the electricity cost of 3.1 bill. Yen and adding the constant expenses of 16.2 bill. Yen to it, we obtained the total operation cost per one supercomputing station as 16.2 bill. Yen. For the three supercomputing stations, we can expect 273MWhr/year and 48.6 bill. Yen/year.

A3-2-2 Capital Function Supporting City scenario

The total number of the national government employees for the regular government service in Japan was 340,613 in FY 2011. In the present study we assumed 10% of them, roughly 30,000 people are moving to Hokkaido. The office buildings for them was estimated as 120,000m² and their construction cost as 69.2 bill. Yen from the latest cost for the central government office complex No.2 completed in 2003 was 72.2 bill. Yen for 125,171m² [32]. This is assumed to be the initial cost to establish metropolitan function supporting.

The value of production of their social service is then estimated as 610.5 trill. Yen/year based on the FY 2005 input–output model data of central government.

A3-2-3 Electrified Agriculture Region scenario

In this concept we assume the fossil fuel consumption, i.e., petroleum products (basic sector 2111-011 to 019 of MIC input-output table) and city gas (basic group 5121-011), to produce agricultural products (0111-01 to 0121-099) is replaced by electricity. The scenario for agricultural production increase is estimated based on ‘Japan food-pia plan’ [33], where it is planned to intensify agricultural export of 0.5 trill. Yen of 2013 to 8 trill. Yen by 2030. In the present calculation we assumed 11.8%, 885 bill. Yen/year (case 1) to 50%, 3.74 trill. Yen/year (case 2) of the increment of 7.5 trill. Yen/year corresponds to the export from Hokkaido. The benefits were estimated by multiplying input coefficients with final demand of each sector. The benefit for case 1 and 2 defined above was 1.4 bill. Yen and 6.1 bill. Yen, respectively. The cost for electrification is not included because it should be done ordinary replacement of equipment.

A3-2-4 Tourists’ Theme-park City scenario

Three major themes, casinos, medical centres and image industries are assumed in this scenario.

In Singapore foreign tourists increased roughly 2 mill. people/yr after their integrated resort started operation [34]. Hokkaido Future Research Inst. (HFRI, now merged to Hokkaido Research Organization) evaluated economic effect of a casino as 18 bill. Yen for its direct revenue and 4.2 bill. Yen for wining and dining as well as product sales just assuming visitors only from Hokkaido and Tohoku [35]. Assuming as many foreign visitors as Singapore, we shaped their direct revenue three times as big as HFRI’s estimate of 54 bill. Yen and additional sales as 12.6 bill. Yen. Electricity consumption by casinos was assumed to be similar to ‘sports facilities, gardens and amusement parks’ sector of FY 2005 input-output table as 41.44GWhr, and the one for wining, dining and product sales was assumed to be equal to ‘amusement, eating and drinking establishments’ sector as 9.45GWhr.

The market size of medical tourism in Japan is expected to become 168.1 bill. Yen by 2020 [36]. Assuming this trend can last until 2030, it could become 340 bill. Yen. Since Hokkaido is on a leading position in medical tourism [37], 20% of the increment, i.e. 68 bill. Yen, is allocated in this study to Hokkaido. Their electricity demand is estimated as 43.2 GWhr/year from ‘medical care (medical corporations etc.)’ sector’s input-output data of MIC.

The market size of contents business including image industries is expected to reach 5 trill. Yen/yr by 2020 [38], in which 1.6 trill. Yen is the sales increase in foreign countries. According to the Sapporo Contents Deregulation Zone’s

data, the share of image industries is 40% of the total market of contents business in Japan [39]. Thus we have 1.2 trill. Yen increase for image industries' sales in Japan. Although at present Hokkaido's share of the 'image production and distribution' sector's sales of 1.6 trill Yen (2005 input-output table of MIC) is about 1.3%, we assume 5% for it for 2030 for the demand creation for renewable electricity. Then the sales creation of image industries in Hokkaido is expected to become 63.8 bill. Yen/year and electricity demand 12.4 GWhr/year, where nationwide average value of the 'image production and distribution' sector is used.

A3-2-5 Electricity-intensive heavy industrial park city

So far the competitiveness of developed countries in refinery, chemical and material industries has been based much on the postponement of facility life prolongation. However, there should come a high time in the future to replace those high carbon facilities by low carbon ones much beyond the present common practice based on exergy regeneration and co-production principles [40]. Indeed, METI of Japan put exergy loss minimization technology on the top of a list in their Energy Saving strategy 2011 [41]. In an industrial complex based on such innovative principles, appointment of combustion heating processes shall be minimized and heat should be recycled in the system by heat-regeneration with compression work done by electricity. Furthermore, energy-intensive industries such as metals smelting can enjoy renewables' electricity of Hokkaido. Although these scenarios seem worth to consider, they were not really taken into account in the present calculation because their effects are rather well known classical ones once business investments are made. Accordingly, the present calculation should be understood as a minimum and additional population capacity should be expected from investment of innovative low-carbon heavy industries.

A4 Outline of IO Matrix for analysis

The matrix we used for IO analysis took into account Hokkaido and other regions' (i.e., rest of Japan (ROJ)) regional input-output relations in which the above new industries for local demand creation were included. Rows and columns representing household spending, employee income, MPV and wind power generation were added to those for 344 sectors of Hokkaido's regional IO matrix developed by Horiguti and Ii [42]. Each performance of electricity production sector was expressed in terms of GWhr unit instead of prices so that electricity trading can be seen clearly. For the newly introduced industry sectors only input coefficients corresponding to each sector, but none of other sectors, were defined. Accordingly the demand generated from a newly introduced industry sector should affect other regional sectors weighted by the input coefficients of it.

A5 Final demand estimation

The final demand of each sub-scenario was defined positive for the demand arose directly from the scenario and negative for the part of baseline demand replaced by the former.

A5-1 Baseline scenario

In the baseline scenario it is assumed that if a demand was not generated in Hokkaido another demand of the same amount is generated in the other regions. One exception is the treatment of agriculture where the increased production are also included in the baseline scenario of Hokkaido but with fossil energy utilization.

A5-2 Supply to Tokyo Scenario (Scenario A)

In this scenario the investment for transmission grid construction was allocated to 'electric power system construction' group. Maximum possible amount was allocated for 'renewables' electricity' group. This renewable electricity was supposed to replace the one from fossil fuel fired conventional sources connected to the Tokyo grid and the same amount of electricity was allocated as a negative demand in the 'utility power' group.

A5-3 Local Demand Creation Scenario (Scenario B)

In this scenario the investment for domestic grid construction was allocated to Hokkaido. For the demand by the newly introduced industries was allocated to Hokkaido with positive signs and to ROJ with negative signs.

A6 Estimation of Migration Population

The migration population, R, the number of people who can economically live in Hokkaido based on the economic effects created by each of the present scenarios both direct and indirect, was calculated based on the induced household spending in Hokkaido obtained from the present IO analysis and on the per-capita household spending data of Hokkaido in 2005. However, in general, the total employee income and household spending do not coincide since real income includes family owned business (i.e., including agriculture and fishery), pensions and other family supports. In this work a preliminary estimation of R is conducted by using employee income by the following equation:

$$R = b \times (h/e) \times (p/h) = b \times p/e$$

1 where b is induced employee income by demands for sectors from newly introduced industries, h is the sum of
2 household spending column for Hokkaido, e is the sum of employee income row, 10,201,626 mill. Yen (2005), and p
3 is the present total population of Hokkaido, 5,627,737 (from the national population census 2005).
4 If agriculture, forestry and fishery overwhelm in the newly induced demands, the above scheme could give an under
5 estimation.

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10

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