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# Transition to renewable energy generation to mitigate climate change: implication on Japanese energy policies

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**Abstract**

The trend of dependency on fossil fuel is not down globally. Therefore, measures are needed to be taken in the direction of developing renewable energy sectors as a means to transit from conventional fuels to eco-friendlier options, particularly in the light of the global warming concern. Japan mostly depends on other countries for their energy supply of fossil fuels. Before the Fukushima Daiichi nuclear disaster, the fossil fuel and the nuclear energy sector shared 88% of the total energy production of Japan. This contribution presented as an ongoing research, the challenges and opportunities to adopt renewable energy sources as going forward including adaptation of zero emission vehicles in Japan. The three scenarios were considered for decreasing dependency on fossil fuels for power generation in Japan including the effects of introduction of electric vehicles on the power generation sector. Solar and wind power generation sources were the two major renewable power generation sectors that have been mainly focused to push the share to 50% of the total energy generation by year 2050.The objective is to make Japan's entire energy generation system pragmatically as clean as possible over the next 30 years.

*Keywords: Air pollution, Japan Energy policies, renewable energy, solar, wind, climate change, zero emission*

## 1. Introduction

With an increase in vehicular pollution, the automobile sector has come under scrutiny of the environmental protection agencies worldwide. Concrete steps have been taken by the automotive industries with various advanced changes in engine design, fuel quality and using alternative fuels to limit the production of suspended particulates and emissions in air which are the main causes of deteriorating air quality in cities [1] [2] [3] (Fig. 1).

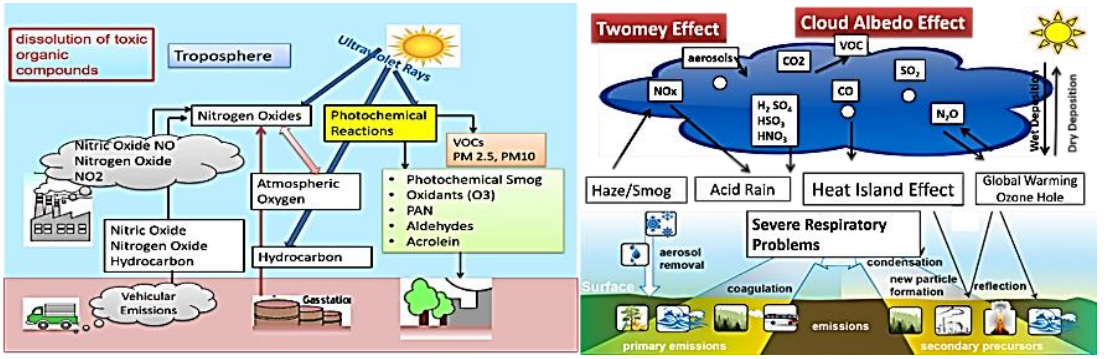


Fig. 1. Formation of particulates and gaseous pollutants resulting from automobiles exhaust.

As the dependency of nations on fossil fuel is showing an increasing trend globally, measures are

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steered in the direction of developing fuel cell technology, promoting use of hybrids and electrical vehicles and more importantly looking for renewable energy sources to mitigate climate change [4] [5] [6] [7]. High cost of electrical vehicles (EV), availability of charging stations and renewable energy supply present a hurdle in going green with EVs [2]. The investment in renewable energy sectors is the must to overcome the environmental and the global warming problems with greater priority and urgency [3] [8] [9]. The current study deals with need for the improvised energy generation policy in Japan with a view to improve renewable energy generation sectors and switching fuel of automobile industry in near future as a strategy to end use of conventional fossil fuels [10] [11].

## 2. Current Japanese Policy Goals

Japan depends on other countries for their energy production and supply such as fossil fuels. Before the Fukushima Daiichi nuclear disaster 2011, the fossil fuel and nuclear energy sector shared 88% of the total energy generation [12]. After the nuclear disaster, the dependency on fossil fuel was up-to 88% as` all nuclear power plants were off-line [5] [12] [13]. The renewable energy contributed to 3.2% in 2014. The current energy policy goal set by Ministry of Economy, Trade and Industry (METI), Japan is to increase the energy generation from renewable sources to 22% by the year 2030. [14]. According to METI, the government of Japan has set the target to increase the sale of next generation vehicles to approx. 50-70% which is 3 million by 2030 (Fig. 2). This study illustrates the increase in energy demand by the transition to next generation vehicles and how these demands can be met through renewable sources.

The graph below shows the trend of next generation vehicle sales in Japan over the next 30 years. With the current rate, Japan will make a complete switch to next generation vehicles by 2045. All the passenger vehicles sold will be next generation, zero emission vehicles[15] [16 [17]. This switch will result in increase in energy demand, which needs to be addressed with renewable energy generation sources [18] and will have an equivalent increase of 0.136 million GWh of energy per year by 2050.

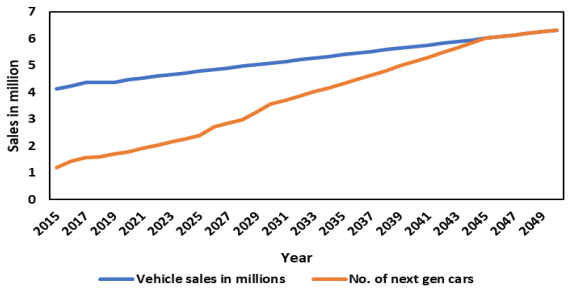



Fig 2. Trend of next generation car sales

Source : Trend of next generation /zero emission vehicle and policy in Japan, METI, Japan, April 2018

## 3. Improvised Power Generation Scenarios

The objective of this research is to make Japan's entire energy generation system as clean as possible over the next 30 years. The energy needed to power the electric vehicles should come from renewable sources which can be achieved by eliminating the nuclear power generation by generating more than 50% of the total energy from renewable sources. This transition would assist Japan to reduce its $CO_2$ emissions and use of imported fossil fuels and substantially contributing on meeting Japan's commitment in reducing the greenhouse gases emissions according to Paris COP25 [6] [19] [20]. This research presents three different categories of low, medium, high intensity scenarios for switching to renewable energy power generation sources and reducing the dependency on fossil fuels by the year 2050. The focus is to boost the solar and wind power generation sources. Based on the current energy demand [6] [21] [22] [23]

and generation trends, the energy generation for the next 30 years is predicted, and the three scenarios are considered, each scenario puts emphasis either solar, or wind or nuclear energy or combination of them.

The predicted total energy generation by the year 2050 will be 1.82 million GWh. The fossil fuel contributing over 74% of the total share. However only about 18% of total energy will come from the solar and wind combined. The Fig. 3 explains the detailed distribution of the share of energy generation if no change is made to the current trend of "business as usaul (BAU) case".

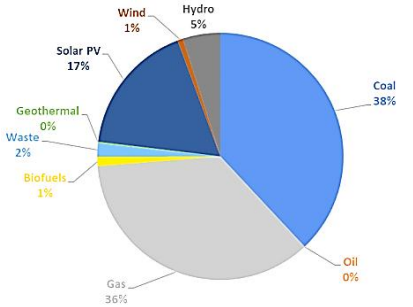



Fig. 3. Predicted energy generation by fuel by 2050

### *3.1. Scenario 1*

Scenario 1 aims to reduce the energy generated from coal and gas by 25% of the predicted value of BAU case for the year 2050. This is achieved by increasing 30% share of biofuels and energy from municipal solid waste and increasing 60% shares of solar and wind sources. The geothermal and hydro power sources have no change considered in their power generation capacity. Even though there might be some room to optimize and increase in hydro power generation as most of the hydropower had been considered developed in Japan, as one being of the highly developed nations. In terms of geothermal energy generation, there might be more room to adopt and develop in comparison to hydro, however this study does not consider it. However, the scenario considers the additional energy demand created by implementation of the next generation vehicles in addition to the normal demands. The graphs in Fig. 4 and Fig. 5 show energy generation prediction for the year 2050. As it can be seen in the figures, the increase in renewable energy, particularly solar, has been exponential compare to the fossil fuels.

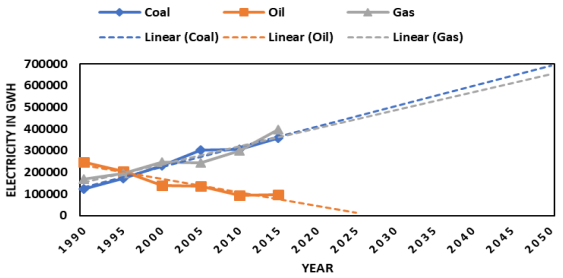



Fig. 4. Prediction of electricity generation from fossil fuels by 2050

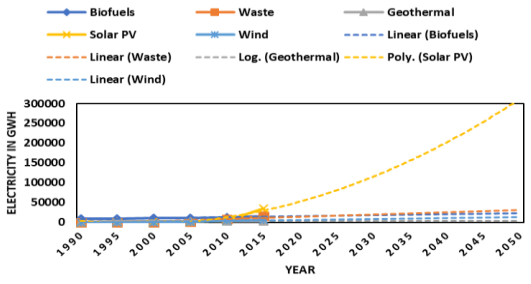



Fig. 5. Prediction of electricity generation form renewable sources by 2050

The energy consumption by a next generation vehicle for all scenarios is assumed to be 1722 kWh for an average of 10,000 km driven per year [12]. The excess requirement caused by the decrease in fossil fuel dependency is compensated by the nuclear power source. According to METI, 20% of the total energy generation will come from nuclear sources. The total share of energy generated from nuclear source in scenario 1 does not exceeds 15%, as shown in Fig.6. However, the solar energy jumped to about 26%.

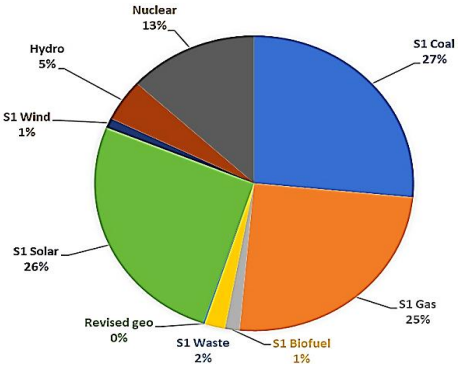



Fig. 6.Scenario 1 predicted electricity generation by fuel by 2050

### *3.2. Scenario 2*

Scenario 2 focuses on increasing the share of solar power in the total energy generation, limiting the fossil fuel share to 50% in combination with nuclear power. The percentages of coal and gas reduction in this scenario are reduced to about 40% from the predicted value. The nuclear power was limited to 10%. The solar energy source is increased to 32%, with wind energy at 7% (Fig. 7). In this scenario the coal and gas contribution in the energy generation has been substantially cut by a half in comparison with the scenario 1. The solar power generation has been increased by almost three quarters than the scenario 1, to accommodate the fossil fuels and nuclear power reductions.

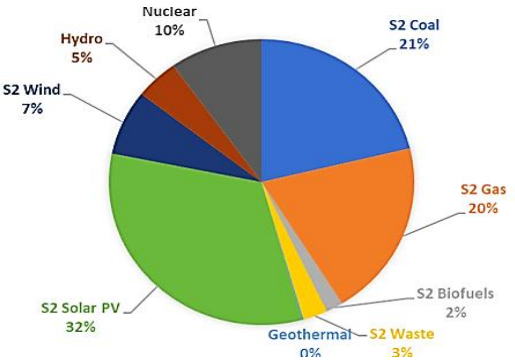



Fig 7. Scenario 2 predicted electricity generation by fuel by 2050

### *3.3. Scenario 3*

Scenario 3 is more ambitious and sustainable than others. It considers the elimination of nuclear power source all together, similar to Germany, in the light of public sentiment in Japan, after the Fukushima Daichi nuclear disaster. This elimination is mainly compensated by remarkable increase in wind energy generation. Wind energy contributes to 28%, which is the main objective for scenario 3. The total share of energy coming from renewable energy sources constitutes to 79%. The solar and wind contributing the most at 41% and 28% respectively. The hydro and biofuels contributing at 10% level and the fossil fuels, coal and gas marginalized at 11% and 10%, respectively. Thus, accomplishing the goal of minimizing the dependency on fossil fuels (Fig. 8).

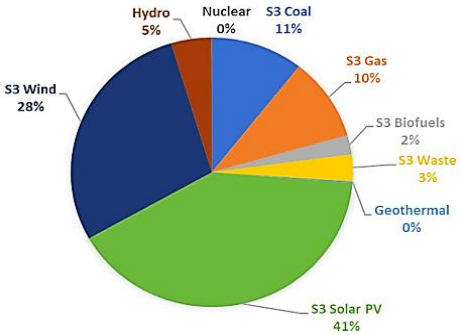



Fig. 8. Scenario 3 predicted electricity generation by fuel by 2050

## 4. Solar and Wind Power Generation

The current energy generation sources in Japan rely on coal and natural gas whose combined share is more than 85% of the entire energy generation sources [14]. Since METI has plans to shift the energy generation from fossil fuels to renewable energy generation sources, the following results present a plausible case for induction of the solar and wind power generation in the mix. The parameters for solar power generation is based on Japan's biggest solar power plant, the Oita solar power plant [24]. The solar panels considered for these predictions are 300W panels and could generate 1400 MWh per year for a capacity of 1 MW power plant. The cost of installation is approx. $1.06/watt considered.

The Tables 1, 2 and 3 present the solar power installation requirement in the three scenarios respectively. The solar installation capacity in the scenario 3 is the largest at 550 TW by 2050, whereas in the scenarios 2 and 3 are at 432 and 339 TW capacities respectively. It is a vast increase in the current level of solar installation in Japan, therefore the government needs to promote and implement attractive programs in the energy sectors in the coming years. The cost to the solar is currently at par with the conventional power generation plant and it is expected to be even cheaper in future as the research and development for more efficient solar panels and manufacturing cost optimization will be fruitful.

Table 1. Predicted solar power generation for scenario 1.

| Year | Capacity in GW | Electricity in GWh | No. of panels | Area (sq. mile) | Cost in million dollars |
|---|---|---|---|---|---|
| 2020 | 10.92 | 15296 | 37634000 | 35.26 | 11581.56 |
| 2030 | 120.12 | 168256 | 413971000 | 387.86 | 98077.56 |
| 2040 | 229.32 | 321216 | 790314000 | 740.46 | 184573.56 |
| 2050 | 338.52 | 474176 | 1166654000 | 1093.06 | 271069.56 |

Table 2. Predicted solar power generation for scenario 2.

| Year | Capacity in GW | Electricity in GWh | No. of panels | Area (sq. mile) | Cost in million dollars |
|---|---|---|---|---|---|
| 2020 | 13.95 | 19537 | 48067222 | 45 | 14792.3 |
| 2030 | 153.45 | 214907 | 528739442 | 495 | 162715.3 |
| 2040 | 292.95 | 410277 | 1009411662 | 945 | 310638.3 |
| 2050 | 432.45 | 605647 | 1490083882 | 1395 | 458561.3 |

Table 3. Predicted solar power generation for scenario 3.

| Year | Capacity in GW | Electricity in GWh | No. of panels | Area (sq. mile) | Cost in million dollars |
|---|---|---|---|---|---|
| 2020 | 17.74 | 24838 | 6110788 | 57.26 | 18805.46 |
| 2030 | 195.14 | 273218 | 617189668 | 629.86 | 206860.1 |
| 2040 | 372.54 | 521598 | 1228268548 | 1202.46 | 394914.7 |
| 2050 | 549.94 | 769978 | 1839347428 | 1775.06 | 582969.3 |

The Tables 4, 5 and 6 present the capacity of wind energy installation requirement in the three scenarios, respectively. The capacity of wind turbine considered for the calculations is 2.5 MW, according to the European Wind Energy Association (EWEA) which can generate 6 GWh of electricity per year. The area required is approx. 10MW/sq. mile and according to (IRENA) [25] and the cost of installation is $1470/kW. The following tables gives a detailed explanation about the three scenarios for

wind energy generation.

Table 4. Predicted wind power generation for scenario 1.

| Year | Capacity in GW | Electricity in GWh | No. of turbines | Area (sq. mile) | Cost in million dollars |
|---|---|---|---|---|---|
| 2020 | 0.21 | 6000 | 84 | 21 | 308.7 |
| 2030 | 2.31 | 11040 | 924 | 231 | 3395.7 |
| 2040 | 4.41 | 16080 | 1764 | 441 | 6482.7 |
| 2050 | 6.51 | 21120 | 2604 | 651 | 9569.7 |

Table 5. Predicted wind power generation for scenario 2.

| Year | Capacity in GW | Electricity in GWh | No. of turbines | Area (sq. mile) | Cost in million dollars |
|---|---|---|---|---|---|
| 2020 | 1.925 | 6000 | 770 | 192.5 | 2829.75 |
| 2030 | 21.175 | 52200 | 8470 | 2117.5 | 31127.25 |
| 2040 | 40.425 | 98400 | 16170 | 4042.5 | 59424.75 |
| 2050 | 59.675 | 144600 | 23870 | 5967.5 | 87722.25 |

Table 6. Predicted wind power generation for scenario 3.

| Year | Capacity in GW | Electricity in GWh | No. of turbines | Area (sq. mile) | Cost in million dollars |
|---|---|---|---|---|---|
| 2020 | 7.675 | 6000 | 3070 | 767.5 | 11282.25 |
| 2030 | 84.425 | 190200 | 337700 | 8442.5 | 124104.8 |
| 2040 | 161.175 | 374400 | 64470 | 16117.5 | 236727.3 |
| 2050 | 237.925 | 558600 | 95170 | 23792.5 | 349749.8 |

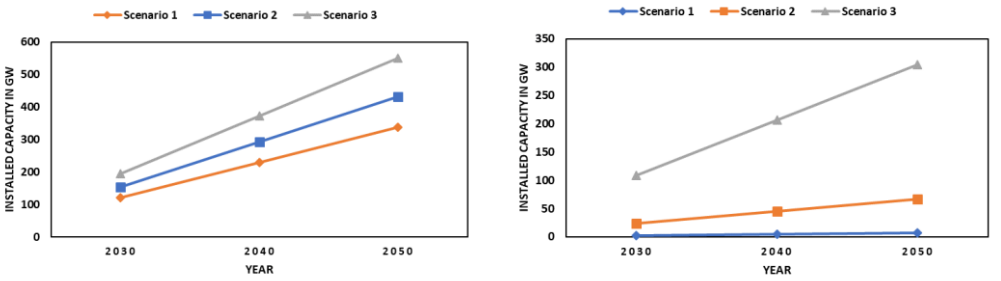
The wind energy installation capacity in the scenario 3 is the largest at 238 GW by 2050, whereas in the scenarios 2 and 1 are at 60 and 6.5 GW capacities respectively. It is an unprecedented increase in comparison to the current level of wind energy installation in Japan. Japan has so far, the lowest level of wind energy generation in comparison to Europe and USA. Therefore, the government of Japan must come up with a special program to promote the wind energy sector in the coming years. The cost of the wind energy generation is sliding downward for many years and currently it is at par with the conventional power generation plant. It is expected that the cost will be even cheaper in future as the research and development on efficiency improvement and reduction of manufacturing cost by optimization will become fruitful

The solar and wind are the two major portions of the renewable energy generation sources. The scenario 2 is intensely focused on solar sector and the scenario 3 eliminates nuclear sector from the share and increases wind generation sector significantly. Scenario 1 focuses on limiting the combined power generation by fossil fuels to around 50% by year 2050. Nuclear and solar power generation helps to do so (table 1). The total wind power generation for scenario 1 is 21,120 GWh per year by 2050 (Table 4). To achieve the above targets, scenario 2 will need approx. 432 GW and 60 GW of installed solar and wind capacity by 2050 (Table 2 and 5).

For the total elimination of nuclear power source, scenario 3 will require 769,978 GWh of electricity generated per year by 2050 from solar power generation sources (Table 3). Scenario 3 mainly emphasizes on wind power generation, boosting it to more than 25% of the total power generation by the year 2050. Wind power will produce approx. 558,600 GWh of electricity per year by 2050 with help of 95,170 turbines. (Table 6).

## 5. Scenario Analysis

The graph in Fig. 9 shows the trend of solar and wind power generation for these three presented scenarios. Scenario 1 and Scenario 2 deal with reduction of fossil fuel dependency and increase in the share of energy generated from solar. Scenario 2 deals with 40% reduction in consumption of coal and natural gas which will result in savings of 112 million tons of coal and 7377 million cubic meters of gas. Scenario 3 presents remarkable increase in wind power generation, which supports to reduce the coal and gas consumption by 70% each. This will save 197 million tons of coal and 12 billion cubic meters of natural gas. All this will save approx. 7.8 billion tons of $CO_2$ emissions by 2050. The scenario 3 also eliminates the nuclear power sources all together, making Japan, a nuclear energy free developed country like Germany.




(a) Solar power scenarios (b) Wind power scenarios

Fig. 9. Solar and wind power generation for different scenarios.

## 6. Conclusion

The three different scenarios considered dealt with the increasing demand in energy for the next 30 years due to the transition from conventional vehicles to zero emission next generation vehicles. The above scenarios strengthen the renewable power generation sector of Japan by reducing the dependency on fossil fuel and going nuclear free in the country's energy generation mix. The study predicts that solar and wind sectors will be the two major sources contributing to more than 50% of the total energy generation of the country by 2050. This transition will assist Japan to reduce the $CO_2$ emissions by a significant amount and aid to mitigate the current global environmental crises. Further work is being continued as to where the solar farms and the wind farms are to be placed in order to establish an efficient power generation grid in the country. Improvised incentive schemes and tax reforms are being drafted for the smooth transition from conventional to clean and green energy generation.

## Conflict of Interest

The authors declare no conflict of interest.

## Author Contributions

Vaibhav Pujari and Bade Shrestha conceived the presented research idea. Vaibhav Pujari conducted the research and analyzed the data. Bade Shrestha encouraged Vaibhav Pujari to investigate into energy policies of Japan and helped supervise the research. Vaibhav Pujari wrote the paper, Bade Shrestha helped in revision, proof reading and manuscript correction of the paper. Both the authors have approved the final version.

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