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Japan's post-Fukushima reconstruction: A case study for implementation of sustainable energy technologies

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HIGHLIGHTS

- We examine the energy challenges faced by Japan in the aftermath of Fukushima.
- We identify policy measures for the use of energy technologies applicable to disaster prone nations.
- We evaluate the potential for renewable energy to support reduced reliance on nuclear energy in Japan.
- We model scenarios for eco-towns and smart-cities in post-disaster reconstruction.
- We assess the role of culture in formulating energy policy in post-disaster reconstruction.

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ABSTRACT

Following World War II, Japan miraculously developed into an economic powerhouse and a model of energy efficiency among developed countries. This lasted more than 65 years until the Northeastern Japan earthquake and tsunami induced nuclear crisis of March 2011 brought Japan to an existential crossroads. Instead of implementing its plans to increase nuclear power generation capacity from thirty percent to fifty percent, Japan shut-down all fifty-four nuclear reactors for safety checks and stress-checks (two have since been restarted), resulting in reduced power generation during the summer of 2012. The reconstruction of Northeastern Japan approaches at a time when the world is grappling with a transition to sustainable energy technologies—one that will require substantial investment but one that would result in fundamental changes in infrastructure and energy efficiency.

Certain reconstruction methods can be inappropriate in the social, cultural and climatic context of disaster affected areas. Thus, how can practitioners employ sustainable reconstructions which better respond to local housing needs and availability of natural energy resources without a framework in place? This paper aims at sensitizing policy-makers and stakeholders involved in post disaster reconstruction by recognizing advantages of deploying sustainable energy technologies, to reduce dependence of vulnerable communities on external markets.

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1. Introduction

Japan emerged from the Second World War over several decades as an economic powerhouse and a model of energy efficiency for developed nations. However, while Japan's rapid economic growth from the 1950s through the 1980s helped it become the world's second largest economy for a time, as well as one of the world's most industrialized states, several periods of low GDP growth, which averaged 1.3% annually between 2000 and 2008 (slightly below the average for OECD countries) have challenged its public finances and economic wherewithal. Japan's debt-to-GDP ratio projected to reach the highest level in the developed world, 240%, by 2014. Despite remarkable gains in energy efficiency Japan is resource poor, especially in fossil fuels. The country in 2012 therefore relied on resource imports for an astonishing 84% of its total energy use of 500 million tons of oil equivalent (Mtoe) (EIA, 2012b). Japan is the world's largest importer of liquefied natural gas (LNG), coal and the second largest net importer of petroleum (IEEJ Asia World Energy Outlook, 2012). In 2010, Japan relied on imported crude oil to meet 42% of its energy demand and LNG imports for virtually all of its natural gas needs. Much of the energy that Japan did procure domestically was nuclear, and until early 2011, Japan was the world's third largest producer of nuclear power.

However, Japan's energy balance fundamentally shifted on March 11, 2011, when a 9.0 magnitude earthquake and subsequent

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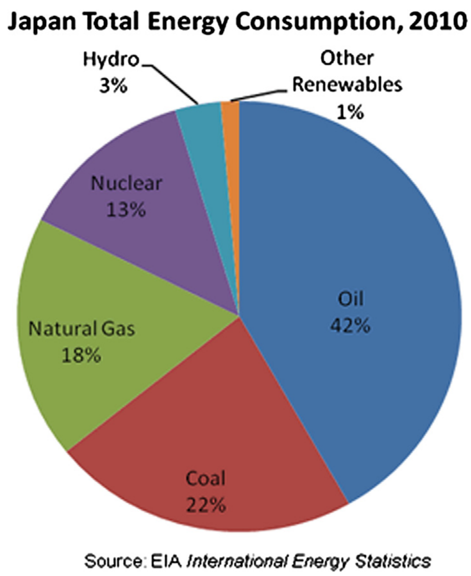


Fig. 1. Japan's energy consumption, 2010 (EIA International Energy Statistics).

tsunami hit Japan's North-East Pacific coast. In addition to causing horrendous physical destruction and loss of life, these natural disasters precipitated the loss of electrical power and the subsequent meltdown of three reactors at the Fukushima Daiichi nuclear power plant. Faced with its greatest reconstruction challenge since World War II, Japan is contemplating both the future of its energy supply as well as what sort of society should emerge in tsunami-damaged communities (Fig. 1)

For the past year, reconstruction efforts have focused on establishing temporary housing, on the restoration of damaged infrastructure, and on clearing millions of tons of related debris. However, current estimates suggest that it could take ten years to fully restore damaged areas, and in the coming decade Japan will need to choose a sustainable reconstruction framework which balances residents' needs with the nation's unique energy challenges (Fig. 2).

This paper aims to assist policymakers in Japan, as well as outside analysts, when considering Japan's reconstruction options from an energy context, because Japan's economic vitality will depend not only on its ability to rebuild bridges, roads, hospitals and homes, but on its capacity to make reasoned choices about the resources it uses to power that process. To that end, this paper first considers Japan's primary energy mix prior to the Fukushima disaster and the consequences of that event; second, it examines Japan's current options for energy investment; and finally, this report puts forward a possible reconstruction framework with existing concepts in line with Japan's unique circumstances.

2. Part 1: pre-March 2011 energy mix and consequences of Fukushima

Examining Japan's pre-crisis energy mix and the damage dealt by the Great Northeast Japan Earthquake and subsequent tsunami and nuclear disaster will define constraints and will help dictate a path forward for Japan to consider. This section will examine Japan's energy mix by individual resource and then by their role in Japan's important production and consumption sectors.

3. Resource-by-resource analysis

3.1. Nuclear

In 1966, the Tokai power station ushered in an era of electricity generation from nuclear plants in Japan. The expansion continued over the next four decades, such that Japan had 54 operating nuclear power plants in 2010. According to the U.S. Energy Information Agency (EIA) data, Japan produced 274 terawatt-hours (TWh) of nuclear-generated electricity, which accounted for 13% of Japan's total energy consumption in 2010. At that time, Japan's Ministry of Economy, Trade and Industry (METI) released a policy that set an ambitious goal for increasing nuclear power's share of the total electricity generation from 24% in 2008 to 40% by 2017 and to 50% by 2030. Progress was made and by 2009, nuclear accounted for 27% of electricity generation, according to the EIA. However, immediately after the March 2011 Fukushima nuclear plant accident, plans were put on hold and all of Japan's 50 remaining nuclear power reactors were shut down over the course of the next year. Though the government of Japan (GOJ) has managed to restart at least one reactor in recent months, the overall impact has been a significant reduction in Japanese domestic power generation capacity (Fig. 3).

3.2. Oil

According to the Energy Information Agency, "Japan has very limited domestic oil reserves, amounting to 44 million barrels," and the country relies heavily on imports. Japan produced 5000 barrels per day (bbl/d) and consumed 4.4 million bbl/d of oil in 2010, making it the world's third largest petroleum consumer, behind the United States and China. As an OECD country, Japan maintains required strategic oil stocks (596 million barrels in December 2010) to protect against supply interruptions (EIA, 2012b).

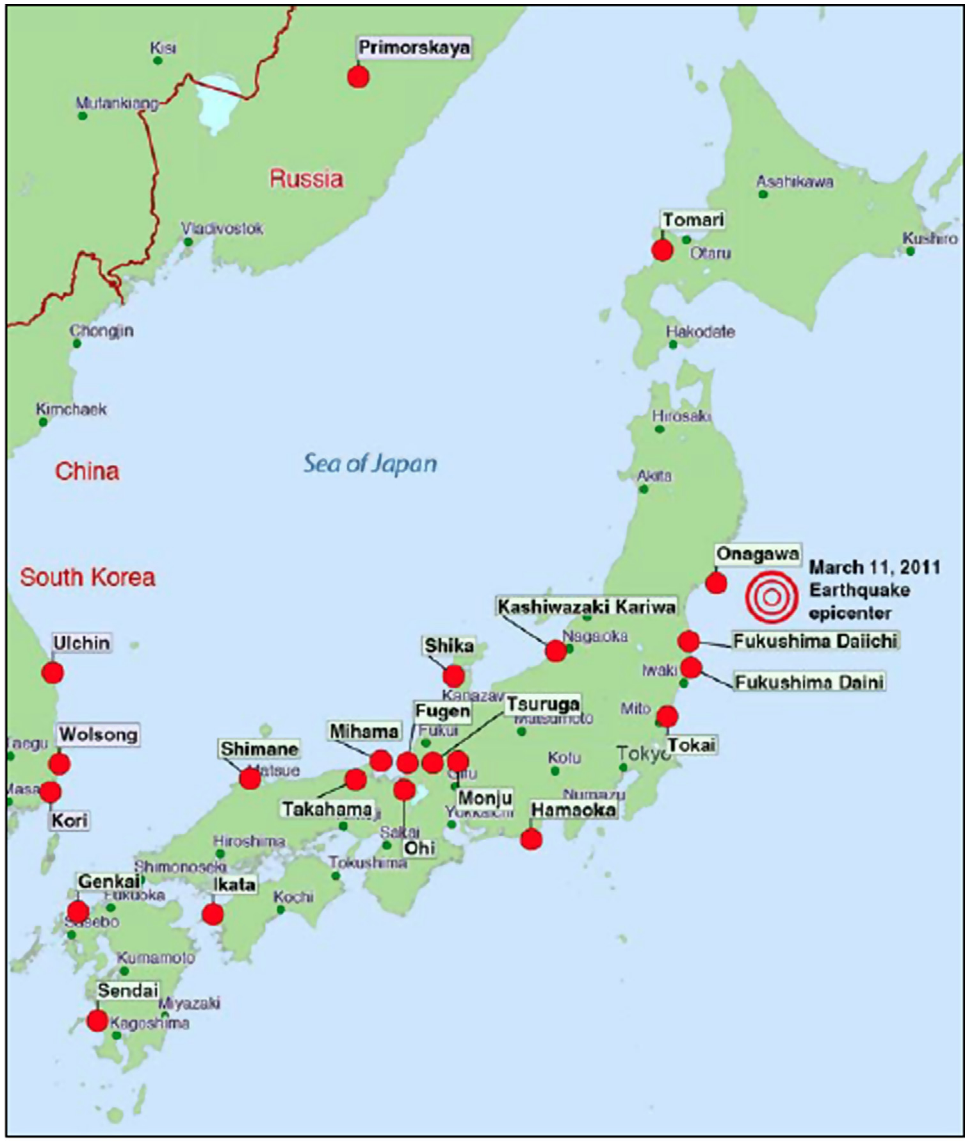
Oil demand in Japan has declined some 18% since 2000, though from 2009 to 2011 consumption was flat or slightly rising. As the EIA explains, this overall decline "stems from structural factors" that include "fuel substitution from oil to natural gas, an aging population, and government-mandated energy efficiency targets. In addition to a shift to natural gas in the industrial sector, fuel substitution is occurring in the residential sector as high prices have decreased demand for kerosene, a petroleum product, in home heating." However, in the absence of nuclear power, there is likely to be further upward pressure on oil consumption (EIA, 2012b).

3.3. Natural gas

Japan held 738 billon cubic feet (bcf) of proven natural gas reserves as of 2011, with its largest field at Minami-Nagaoka off the Western coast of Japan's main island of Honshu, accounting for about two fifths of Japan's domestic gas. In 2010, Japan consumed about 3.7 trillion cubic feet (tcf), of which over 3.4 tcf was imported, meaning that, much like in oil, Japan is virtually wholly dependent on foreign sources for its natural gas. Natural gas has grown as a share of Japan's total energy mix, and gas consumption increased by 25% between 2000 and 2009 (EIA, 2012b) (Fig. 4).

With imports in mind, Japan has 32 operating LNG import terminals with a total regasification capacity of 8.7 tcf per year (tcf/y), well in excess of typical demand in order to ensure flexibility. The EIA explains that

> "The majority of LNG terminals are located near the main population centers of Tokyo, Osaka, and Nagoya, as well as near major urban and manufacturing hubs, and are owned by local power companies, either alone or in partnership with gas companies. These same companies own much of Japan's LNG tanker fleet. Five new terminals are under construction and are anticipated to come online by 2015 and could add between 200 to 300 bcf/y of capacity" (EIA, 2012b).



Source: Nuclear Energy Institute, edited by CRS.

Fig. 2. Map of Japan's Nuclear Power Plants and March 2011 earthquake.

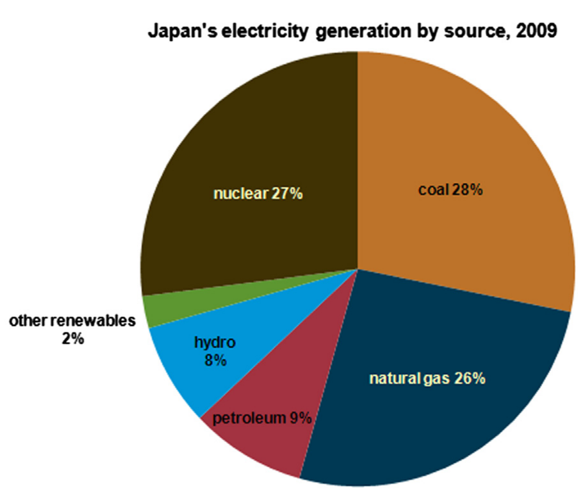


Fig. 3. Japan's electricity generation.
Source: 2009 (EIA).

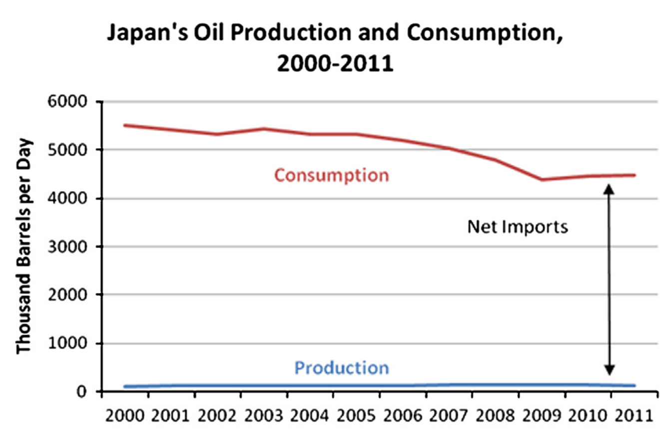


Fig. 4. Japan's oil production and consumption (EIA).

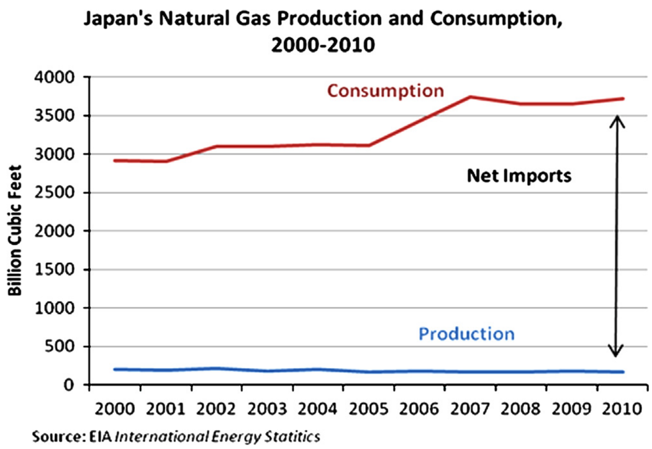


Fig. 5. Japan's natural gas production and consumption, 2000–2010 (EIA).

In large part because it over-invested in LNG import terminals, Japan has been able to leverage its overcapacity and partially rely on extra spot-market LNG purchases to compensate for lost nuclear capacity. LNG imports have grown as a result and higher levels of natural gas use are expected into the future; industry analysts project LNG imports to range from 4.1 bcf/y to 4.5 bcf/y in 2012, depending on whether more nuclear reactors return to operation (Fig. 5).

3.4. Coal

Coal, primarily used in the power sector, remains an important part of the Japanese energy mix, accounting for 22% of total energy consumption in 2010. However, domestic coal production came to an end in 2002, after a 50 year decline during which Japan struggled to compete with cheaper imports due to higher labor, transportation, and production costs. As a result, Japan imports 100% of its coal used, 207 million short tons in 2010, mainly from Australia (Global Methane Initiative, 2012).

3.5. Renewable resources

While Japan has supported five types of renewable resources in recent years—wind power, hydropower, solar energy, geothermal energy, and biomass—total renewables accounted for only 4% of the country's total energy production, of which hydropower provided 3%. Japan's hydroelectric generating capacity was 48 gigawatts (GW) in 2009, or about 16% of total electricity capacity, with another 5 GW scheduled to come online by 2020. Like nuclear power, hydropower supports Japan's base-load generation requirements because of low marginal costs and a stable supply of inputs. Hydroelectric generation was 73 TWh in 2010, making up about 7% of total net generation (EIA, 2012b).

In addition to supporting additional large-scale hydroelectric projects, the Japanese government has simplified regulatory procedures and provided subsidies to promote other sorts of renewable energy projects, such as small hydropower stations to serve local communities, as well as wind, solar, and tidal power projects; installed capacity from these three sources has increased in recent years to about 4.6 GW in 2009, up from 0.8 GW in 2004 (EIA, 2012b). As will be discussed in later sections of this paper, renewables have the potential to play an important role as Japan rebuilds its energy delivery capacity.

4. Sector-by-sector analysis

4.1. Power sector

According to the EIA, Japan had 282 GW of total installed electricity generating capacity in 2010, "the third largest in the world behind the United States and China." Of the around 1 Terawatt hour (TWh) of electric power that Japan produced in 2010, "63 percent came from conventional thermal fuels, 27 percent from nuclear sources, 7 percent from hydroelectric sources, and 3 percent from other renewable sources." However capacity fell to around 243 GW by mid-2011 due to facilities damage. Citing the International Energy Agency (IEA), EIA reports that the share of thermal generation rose to 186 TWh or 73% of total generation in the first quarter of 2012, the highest on record, as increased LNG and petroleum imports made up for lost nuclear power. In the case of crude oil, if no additional nuclear facilities are brought online in 2012, incremental oil demand in power generation could grow from 178,000 bbl/d in 2011 to over 250,000 bbl/d (EIA, 2012b).

According to the Japan Electric Power Information Center, there are currently 61 major thermal power plants, with six more under construction: three using natural gas and three using coal for generation. New coal-fired plants might suggest a greater reliance on that resource paralleling oil and gas, but the opposite appears to be true; because several coal-fired plants and import terminals in the Fukushima area took significant earthquake and tsunami-related damage in March 2011, coal use actually shrank during that year (EIA, 2012b).

Japan's nuclear-heavy energy input mix before 2011 explains only part of that nation's challenges; the country's unusual transmission network also shoulders some of the blame. Japan's transmission grid is divided in two, with eastern Japan transmitting at a frequency of at 50 Hz (Hz), and the western half running at 60 Hz. A quirk of history left over from Japan's initial forays into power generation in 1895–96, when the government procured mutually incompatible generators from two different manufacturers, this frequency difference partitions Japan's national grid, and power can only be moved between Japan's east and west using frequency converters. Gaps in Japan's anemic converter system contributed to poor electricity-sharing for affected areas after the Fukushima disaster, when electricity from Japan's unaffected west was unable to reach the benighted east (Fig. 6).

Currently, experts on the Energy and Environment Council, which the Japanese government set up to make recommendations on Japan's energy future to 2050, have proposed five nuclear fuel mix scenarios ranging from zero to 35% of production by 2030. The revised energy policy is slated to be adopted in the second half of 2012 after public comment. Regardless, Japan's use of LNG, oil, and renewable fuels is expected to grow following the government's assessment of energy security in the power sector (EIA, 2012b).

One possible bright spot for analysts, though, is that while Japan is the largest electricity consumer in OECD Asia, it has one of the region's lowest electricity demand growth rates, projected at an average of 0.7% from 2007 through 2018, according to the Federation of Electric Power Companies of Japan, meaning that the nation's primary concern will be to restore historic generation rates (total generation was over 1 Terawatt-hour for the past decade), not catching up with fast-growing demand (EIA, 2012b).

4.2. Transportation sector

As Phillip Lipscy and Lee Schipper point out in "Energy Efficiency in the Japanese Transport Sector," "Transport energy use in Japan grew at a very high rate in the 1970s, averaging about 7.8 percent, but growth slowed down in subsequent decades and turned negative in 2000–2008. Japan is fairly exceptional in this

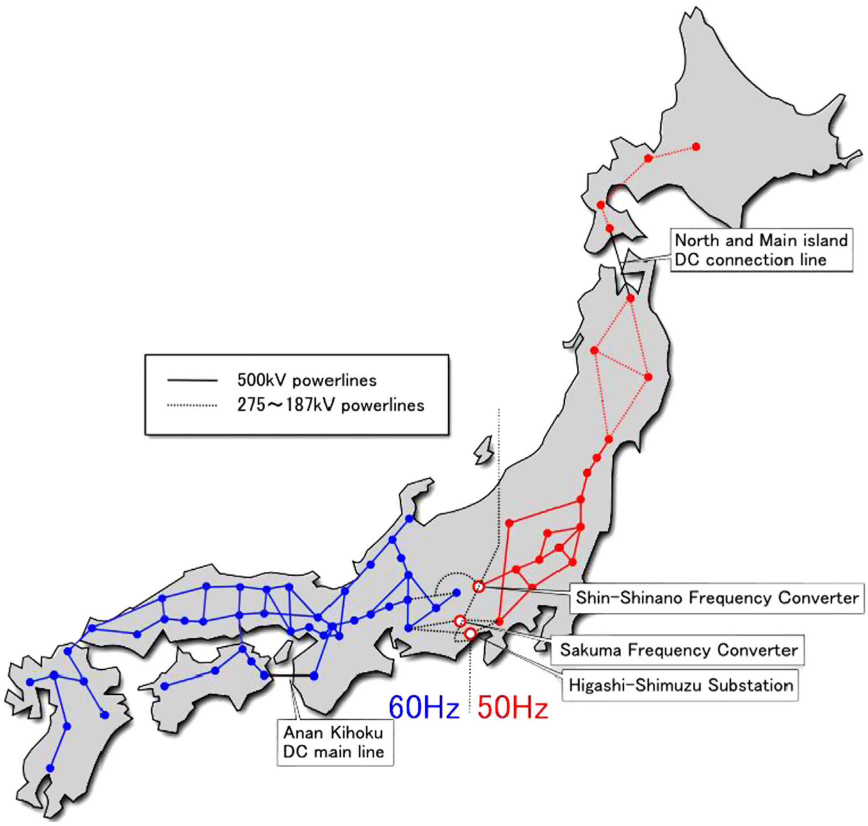


Fig. 6. Map of Japan's power grids (METI).

regard—of six developed countries analyzed by Millard-Ball and Schipper (2011), the only other country to record a decline in passenger transport energy use in recent years is the United Kingdom." The decline in Japan occurred "both because of a flattening in total travel, most markedly in car use," as well as because cars became more energy efficient (Lipscy and Schipper, 2012).

This has not meant that individuals are using less energy than before, however; the authors explain that, while Japan's population increased by 14% from 1975 to 2008, its transportation energy consumption increased 126%. Therefore, energy consumption per capita grew by 97% from 9.0 gigajoules (GJ) per capita in 1975 to 17.7 GJ per capita in 2008 (Lipscy and Schipper, 2012).

A primary focus of Japanese efficiency policy in the transportation sector has been automobile fuel economy standards. "Increasing fuel economy is viewed as the most effective way to reduce emissions from cars. Japan adopted stringent fuel economy standards very early, in 1979—the E.U. only adopted fuel economy standards in 2005 and made them mandatory in 2008, and although U.S. CAFE standards have been in place for a comparable period, they have been considerably less stringent" (Lipscy and Schipper, 2012).

Japan has already achieved relatively high levels of overall energy efficiency in the transportation sector, so "incremental improvement is expensive and sometimes impractical", as Lipscy points out in another paper (Lipscy, 2011). Lipscy and Schipper argue that "Japan will likely continue to pursue aggressive improvement of automobile fuel economy through regulation and tax incentives".

4.3. Industrial sector

Japan's industrial sector is enormous, and consumes the largest share of Japan's energy production, at around 38%, followed by transport (24%) and other sectors (37%), according to 2009 data from the International Energy Agency (IEA, 2010). The industrial sector has shown impressive gains in efficiency. According to the EIA's "International Energy Outlook, 2011," energy intensity in manufacturing dropped by a remarkable 50% over the three decades since the oil crisis of 1973. Japan achieved efficiency gains by shifting from heavy to light industries (EIA, 2011). Though Japanese industry is seen by some as "hollowing out" in the face of foreign competition (see McLannahan, 2012), in the short to medium term, industry will likely continue to be an important energy consumer.

5. Part 2: Japan's post-Fukushima energy options

5.1. Policy considerations

As previously discussed, Japan is chronically dependent on imports to meet its energy needs. Comparing self-sufficiency ratios among OECD countries in 2010 shows an OECD average (excluding Japan) of 71%, as opposed to only 18% for Japan. To confront this challenge Japan unveiled its Basic Energy Plan in June 2010 based on a best mix of three Es': Energy Security, Economic Efficiency and Environmental Preservation. The plan aimed to improve Japan's self-sufficiency rate from 18% to 40% while reducing CO_2 emissions by 30% by 2030. However, the plan included building additional nuclear reactors to eventually increase nuclear power's share of total energy consumption to 50% (METI, 2010). The March 2011 disasters, however, upended this plan.

This paper will examine whether Japan can rebalance its energy mix based on revised recommendations made by the Basic Energy Plan Committee after the disaster in the context of demographic realities, fiscal constraints, and commitments to improving energy efficiency and reducing carbon emissions. As the Institute for Defense Studies and Analysis study reveals in "Japan's Nuclear Energy Debate: A Year after the Fukushima Nuclear Crisis," these recommendations include: "Accelerated development and use of renewable energies[;] Environmentally-friendly use of fossil fuels, beginning with a shift to natural gas….; and [reduced] dependency on nuclear power, wherever possible." (Khan, 2012) However, this paper will also assess policies, such as supply-side as well as demand-side efficiency improvements, as well as electricity market reforms, which may help to define elements of Japan's reconstruction efforts in coming years.

6. Prospects for renewables to replace nuclear in Japan

Japan produced 1041 TWh or 5.2% of the world's electricity in 2009, making it the third largest producer of electricity. To determine Japan's capacity to displace nuclear energy production with renewable energy, this paper will first consider a baseline scenario in which Japan restarts its nuclear reactors in 2013 and nuclear power's share of electricity generation returns to its pre-Fukushima level of about 33%, and slowly transitions to renewables. This was a target of nuclear energy in the Basic Energy Plan of 2010 (METI, 2010).

6.1. Renewables in Japan

Japan has a total of 324 GW of achievable renewable energy potential (Sovacool, 2011). Of this, onshore and offshore wind energy is 222 GW, geothermal power is 70 GW, additional hydroelectric capacity is 26.5 GW, solar is 4.8 GW and biomass (agricultural residue) is 1.1 GW. Japan produced about 1.6% of its energy from renewables in 2011, the smallest portion among Group of Seven (G-7) countries after Canada (Watanabe, Bloomberg, 6/18/2012). Japan announced a program to boost renewables in June 2012, calling for utilities to buy solar, biomass, wind, geothermal and hydropower energy and to pass on their costs to consumers in the form of surcharges, estimated at 87 yen a month per household (Watanabe, Bloomberg, 6/18/2012).

6.2. Solar

Japan ranked sixth worldwide by new installations in 2010, when it added 1.3 gigawatts (GW) of solar to bring its installed base to 5 GW (Watanabe, Bloomberg, 6/18/2012). Next year builders will erect roughly triple that level, or another 3.2 to 4.7 GW, New Energy Finance forecasts. A GW is enough to supply about 243,000 homes in Japan.

This is made possible by the recent aggressive market intervention by Japan to expand solar. The government has set tariffs on solar electricity artificially high to triple what industrial users now pay for conventional power. Utilities will pay 42 yen ($0.53 cents) per kilowatt-hour (kWh) for 20 years to solar power (units bigger than 10 kW) producers, almost twice the rate in Germany, the world's biggest market by installations. That may spur at least $9.6 billion in new installations with 3.2 GW of capacity, Bloomberg New Energy Finance forecasts. That total is approximately equal to the output of three atomic reactors.

Japan is one of the highest price solar markets dominated by a few large installers. Residential solar units are currently sold in Japan for $6.28/watt, more than double the $2.70/watt price in Germany. Kyocera Corp. and IHI Corp. are considering a 70-MW station in Kagoshima, which would be the largest in Japan when completed. West Holdings now plans to start making modules with Taiwanese company Evrsol Corp. A unit of Showa Shell Sekiyu K.K. will offer more advanced technology that uses non-silicon thin-film modules using copper–indium–gallium–selenide (CIGS). The policy shift toward solar reflects concern that the cost of imported fossil fuels will rise in the coming decades. On the flip side, the environmental policy bureau of Keidanren, Japan's most powerful business lobby, contends that the clean power aid will raise bills and slow Japan's economic recovery, according to Bloomberg (Watanabe, 2012).

6.3. Geothermal

Danielle Demetriou notes in a 2011 article in The Telegraph, Japan is "located above the world's third largest reserve of geothermal resources (after the United States and Indonesia)…. More than 28,000 hot springs," or 'onsen,' "span the nation's mountainous landscape, with government regulations protecting developments in such regions rigorously controlled." Geothermal is a steady source of power and, unlike solar or wind, is unaffected by unpredictable weather patterns. Japan has a 70% global market share in geothermal technology, led by Toshiba, Mitsubishi, and Fuji Electric, which makes geothermal "ready-to-deploy" technology. There are currently fewer than 20 geothermal plants in the country, and geothermal currently accounts for less than 1% of Japan's energy output (Demetriou, 2011).

Recently, the Government of Japan has relaxed regulations, and is allocating funds for the survey for geothermal development surveys (Nagano, 2012). One challenge for wider geothermal use is high upfront investment costs that would require government support one MW of geothermal energy requires an investment of about $3.5 million, "some three times the cost of developing coal energy," according to Renewable Energy Magazine (Price, 2012). The gestation period from discovery to commercial operation period is another issue- typically 5–7 years, compared to a wind or solar farm can be up and running from scratch in 12–18 months. The potential rewards could be high, however—Japan has an estimated 23.5 gigawatts (GW) in geothermal potential, which could replace roughly half of current nuclear capacity (Nagano, 2012).

6.4. Wind

In 2010, installed capacity was 2.5 GW. The most recent feed-in-tariffs are 23 yen ($0.28/kWh for units greater than 20 kW) (Bloomberg New Energy Finance, 2012). However, an additional 100 MW will come on-line bringing the total to 2.6 GW in 2013. Additionally, Japan began formulating plans for floating wind farm technology in September 2011, according to Bloomberg New Energy Finance, and plans to build pilot floating wind farms, with six 2 MW turbines, off the Fukushima coast. After the evaluation phase is complete in 2016, the plan is to build up to 80 floating wind turbines off Fukushima by 2020.

6.5. Hydro

In 2008, Japan produced 83 TWh of hydropower with 47 GW capacity and ranked 9th in the world, producing 2.5% of the world's total hydro electricity. However, hydro made up only 7.7% of Japan's electricity (IEA, 2010).

6.6. Biofuels

A 2012 Global Agriculture Information Network (GAIN) report by the U.S. Foreign Agricultural Service, entitled "Japan Focuses on Next Generation Biofuels," reviews Japan's biofuels policy:

> "Japan's first biomass plan, "Biomass Nippon Strategy," was unveiled in 2002. That Strategy was updated in 2008, and the

Japanese government's current thinking, given the country's limited land resources, is to focus on cellulosic biofuel as the future for Japan's biofuel production. It was the "food versus fuel" debate that inspired the Japan to include food prices and food security in the G-8 Summit agenda held in July 2008 in Hokkaido, Japan. In February 2007, the Executive Committee on Biomass Nippon Strategy released a report titled "Boosting the Production of Biofuels in Japan." It sets a target of producing 50,000 kl of biofuels from molasses and off-spec rice, and 10,000 kl of biofuels from construction waste by 2011. In addition, the report sets a goal of producing 6 million kl (estimation by MAFF) of biofuels per year, 10 percent of domestic fuel consumption, from cellulosic materials such as rice straw, thinned wood and resource crops such as sugar cane, sugar beet by around 2030. This ambitious target is based on the estimation that Japan has unused biomass resources (non-edible portions of farm crops and forestry residues) equivalent to 14 million kl of oil, and that it could produce resource crops equivalent to 6.2 million kl of oil by fully utilizing the abandoned arable land, which is estimated at 386,000 ha" (USDA, 2012a).

The report also points to a number of government incentives for biofuels production, including a policy, in place until March 31, 2013, to provide tax breaks for fuels containing 3% bioethanol, lowering the usual gas tax of ¥53.8 by ¥1.6 per liter (USDA, 2012a).

The GAIN Report also points out that in 2010, the U.S. and Japanese governments agreed to start joint research on "new production methods of biofuels to contribute to the reduction of greenhouse gas emissions." The two nations will spend a total of 1 billion yen over three years for the program which includes a study on effective methods to produce fuel from algae that Japan believes can fulfill up to 20% of its transportation fuel needs by 2020. The following in-place efforts will help Japan achieve its goals: (1) Japanese companies are setting-up joint ventures with Brazilian companies to achieve the set-forth goal of bringing 1.9 billion liters to the Japanese market, of which 0.9 million kl will be imports from Brazil, (2) Japan has a 3% blending limit but new cars can run on E-10, and (3) there are 1717 bio-gasoline filling stations worldwide (USDA, 2012a).

6.7. Tidal and wave power

Thousands of miles of coastline provide ample opportunity for Japan to develop tidal and wave power technologies. However, there are a few experimental projects worldwide. For example, Sweden and Ireland are aggressively pursuing these options. This set of technologies may have to wait a few more years before they can be applied commercially (Renewable Energy Policy Network, 2011).

6.8. Economic realities and social constraints

Japan's GDP has continued to grow at a decreasing rate for the last several decades, in line with sustainable low-growth model for developed countries. Nevertheless as Japan attends to the fiscal constraints of growing public debt and a stagnating economy, where nominal GDP (NGDP) fell to an average of −0.07% in 2011 and 2012 (The Economist, 2013), supporting renewable energy technologies that will pay dividends in the short to medium term is paramount as Japan designs its renewable energy outlook, and selects the renewable sources to which it devotes both subsidies and resources for R&D.

Population trends in Japan highlight social considerations which further complicate the feasibility of Japan's renewable energy investments policies.

While Japan remains the world's 10th most populous country, after peaking in 2006, Japan's population is declining very slowly, especially in rural areas. In 2012 the Japanese Government reported that the proportion of citizens 65 and over will reach 40% by 2060. As the taxable population decreases, the burden to the welfare system is compounded by reduced sources of income to fund entitlements, especially as funding required to support the aging population rises. At the same time, despite overall flat population growth, in the 2000s the number of overall households grew in Japan, with distinct impacts on Japanese energy and resource use (OECD, 2011); while industry continues to account for the largest part of Japan's Total Final Consumption (TFC), at slightly more than 25%, growing electricity consumption in the residential and commercial sectors is of concern for GHG reduction goals. Moreover, because there is large variation in population density across regions, with incredibly high average population density concentrated in urban areas, designing a 'Goldilocks solution' for renewable energy use in disaster prone regions is unlikely.

As Japan considers the menu of renewable energy alternatives, policymakers will have to consider which options maximize investments for society, the environment and economy, investing in technologies which are not only accessible and scalable, but also those in which Japan can be a market leader (e.g. Geothermal) spurring the economy and greening economic growth.

6.9. Summary

Given Japan's current energy needs, its current renewables generation capacity, future capacity timelines, and economic and social constraints coupled with the comparative high cost required to bring renewables to market, it remains unclear whether renewables will be able to effectively displace nuclear power in the years to come without further structural reforms (this is before taking into account possible differences in alternative energy resources' resiliencies in the face of natural disasters and other threats, not analyzed here). However, given Japan's environmental commitments as well as the geopolitical ramifications of further oil and gas imports to replace nuclear power, Japan may conclude that renewable energies remain worth their significant cost and will invest the needed money to develop them which in the long term would enhance its energy security.

7. Part 3: sustainable, energy efficient reconstruction models for Japan

Having discussed Japan's energy resource challenges and the possibility for renewable energy substitution over time, this paper will conclude by examining the kinds of policy options Japan has at its disposal that go beyond energy production, but extend to other important issues like sustainable reconstruction. For example, as a result of investments in energy efficiency devices, changes in lifestyles and conservation measures, Japan has actually lowered its net peak summer demand energy usage per capita from 2011 to 2012 (Schuetze, 2012) beyond what is expected simply due to a mild summer. Given this scenario, energy efficiency gain can now be considered as an energy resource in and of itself with these issues applying to both supply and demand-side efficiency improvements in the energy sector. In addition, energy efficiency will also be incorporated in the reconstruction models, such as eco-towns and smart cities, that Japan can put in place to leverage these existing gains. The below is not meant as an exhaustive list of reforms or models, but rather as a starting framework from which analysts and policymakers can begin further work towards a specifically Japanese model of sustainable reconstruction.

District heating and cooling systems (DHS) and combined heat and power (CHP) systems, especially centrally provisioned heat, may provide another option for disaster-prone regions. By increasing energy efficiency and making renewable energy sources more accessible to end-users, the IEA notes that DHS has great potential to support sustainable development 'by facilitating productive use of waste heat from industrial processes, electricity generation, waste incineration or renewable energy sources' (IEA.org, District Heating and Cooling). Despite the proven and potential dividends to such systems, which continue to be a focus of research for developed countries including the United States, Republic of Korea, Finland and Sweden, which jointly fund and coordinate DHS/CHP research, Japanese households reveal a preference for single-room heating with movable appliances because it is understood that CHP/DHS will not withstand earthquakes. Furthermore, employing a '*kotatsu*'[1], whereby heat can be confined to one's local vicinity when energy costs are high, certain Japanese households find space heaters and kotatsu-like devises the most economical approach to residential heating. However, the drawbacks to single room kerosene or space heater type appliances for home heating —inefficient, expensive, and dangerous if left unattended—do not appear unambiguously superior to exploring a distinct form of centralized or district heating. Certain research indicates DHS have proven robust, even during disaster. In a reconstruction scenario, uniting mature DHS with superior building technology could prove preferable when economic, environmental, and social considerations are collectively considered, and thorough energy-use planning (including contingencies) is applied.

Finally if kerosene prices remain high—as they were in January and March 2013—there will be greater incentive to explore economical and energy efficient systems for home heating akin to DHS/CHP. Since such systems require a candidate population and commercial facilities be located within suppliable distance of heat, a technical analysis of population density required to centrally source heat is necessary before further considering such systems for certain disaster prone regions, especially rural, However, the Roppongi Hills buildings in Tokyo has such a system and supplied electricity for Tokyo Electric Power Company after Fukushima.

Once such independent power producers have fair access to grid, it may encourage competition among all the electricity producers. One of the original objectives of "setsuden" in the last summer was to cut or shift peak electricity demand in the summer afternoon for lighting and air-conditioning. Storage (battery) can be used for supplying peak demand by storing surplus electricity off-peak.

For disaster-prone region, it appears attractive to install enough batteries. It can be used off-grid during emergency like a blackout or any other disaster. And batteries can also be used to balance electricity demand with supply that has high ingredients of unstable renewable energy even for normal, on-grid situation. A smart grid system will recognize such balance. The main challenge of installing storage is cost.

7.1. Supply-side efficiency

To date, Japan's predominant energy efficiency focus has been on the demand side of energy conservation. Since 30% of Japan's primary energy consumption occurs in the energy sector, however, supply-side efficiency gains will need to compliment demand-side improvements to enhance Japan's energy security.

Research and development on power generation capability with higher energy efficiencies has been on-going to develop new materials for the high temperature and high pressure compatible piping that would allow for generation efficiencies exceeding 50% in all Japanese thermal power stations by 2020 (Sano, 2010). Japan as a nation has the highest thermal electrical power generation efficiency in the world.

In addition, the potential for system-wide efficiency gains beyond progress in specific technologies and market segments on the supply and demand sides is an exciting one. As the European Movement for Efficient Energy (EME[2]) points out in its report "Perspectives on the European Energy Efficiency Directive, "The larger energy system is typically divided into individual subsystems based on end-use sectors…or energy carriers…. This is necessary at times to address specific problems, but often overlooks the interfaces between the energy systems that could be leveraged to increase efficiency and reduce losses. In the future, with a largely enabled system-wide uptake of digital information and smart grid technologies, efficiency gains anywhere in the system trigger efficiency gains everywhere." To achieve such a goal, Japan must begin on the supply side with "efficient energy"—what the organization calls "producing and delivering more energy for final consumption from less primary energy and other natural resources" (EME[2], 2011).

7.2. Demand-side efficiency

Improved efficiency of energy use on the demand side is also important. As the Open University points out, "Improving the sustainability of energy use by applying demand-side measures involves two distinct approaches, one technological, the other social. The technological approach means installing improved energy conversion (or distribution) technologies that require less input energy to achieve a given level of useful energy output or energy service. The social approach means re-arranging lifestyles, individually and collectively, in minor or sometimes major ways, in order to ensure that the energy required to perform a given service is reduced in comparison with other ways of supplying that service," a perspective to be described in further detail later (Open University, 2012).

7.3. Market reforms

Discussing demand and supply-side energy efficiency gains, important as these issues are, all the same risks ignoring an important fact that Japan has as of yet been unwilling to confront, which is that the country's current utility structure disincentivizes cost-effective and energy-efficient approaches to power generation. Before Japan can make the necessary steps to increase system-wide efficiency, it will need to seriously consider unbundling power generation from transmission and distribution, putting in place independent power grid operators akin to American Independent System Operators (ISO) and Regional Transmission Organizations (RTO), and introducing market forces into power generation so that there can be a 'market price' for electricity. The introduction of a market price will help to incentivize supply-side as well as further demand-side energy efficiency gains. One of the lessons Japan learned from the electricity crisis in California in the early 2000s was that a deregulation might harmfully impact energy users. Unbundling, strict environmental regulation and high LNG price caused electricity producers in California to become reluctant to invest in sufficient capacity and it resulted in power failures. It will be beneficial for Japan to learn in detail from the problems experienced byelectrical power deregulation in the United States.

[1] A kotatsu is a low table with a heat source, often electric, stored underneath or built into the table.

7.4. Sustainable reconstruction

Japan's energy security can be enhanced if the government, in designing its urban spaces in the future, takes energy efficiency and sustainability into account, a policy choice which could significantly impact how Japanese live into the coming decades. Possible reconstruction models, not only for Tohoku but for all of Japan, include eco-towns, transition cities, and smart cities. The events of March 11, 2011 have been described as an unprecedented mega-disaster and one that is likely to strike again. Japan was well prepared, and was still devastated. Future threats require sustainable development that is equipped for the worst. Japan must be prepared to harness new innovation to meet future challenges, which will undoubtedly arise.

7.5. Eco-towns

Japan can choose to follow the "Eco-town" model, a European-born urban design concept that focuses on the "four Cs"—climate, connectivity, community, and character. Brendan Barrett explains that "Climate" focuses on climate-proofing communities to ensure they can cope with and adapt to the impacts of climate change, while minimizing their carbon footprint. "Connectivity" leverages technology and public transportation to enable access to employment opportunities. "Community" promotes a balanced social mix, ensuring inclusion of the most vulnerable, such as the elderly (in 2011, 22.9% of Japan's population of 126.45 million was over 65). Finally, "Character" advocates rigorous new design standards and creating a unique sense of place. Good examples of European ecotowns or eco-cities include Amersfoort in The Netherlands, Freiburg in Germany, and Zaragoza in Spain. These cities seek to reduce waste, conserve energy, make use of natural spaces, and enhance walkability while discouraging car use (Barrett, 2012).

Japan designated 23 urban areas as eco-towns by 2005 but, unlike their European counterparts, "these towns focused on developing industrial parks, introducing earth-friendly technologies, and promoting environmental methods such as integrated waste management, the three Rs—reduce, reuse, and recycle—green consumerism, and energy conservation" (Barrett, 2012). Japan has launched "Future City Initiative" after the earthquake. Eleven towns were selected including five from earthquake and tsunami damaged areas. Rikuzentakata is one of the designated cities under this initiative also called Kankyo Mirai Toshi which means environment future city. This initiative aims to develop a city designed not only for environmentally friendliness (low carbon, recycle, and biodiversity) but also for improving quality of life (disaster control, care for elder people) and vitalize local economy with growing industries (healthcare, energy, and environment). Furthermore, before Fukushima, the government also launched the concept of "Eco-model cities for low carbon society." 13 cities were designated (Japan's Regional Revitalization Office, 2012).

7.6. Transition towns

Given Japan's natural resource as well as geographic vulnerabilities, the experience of the Transition Movement—what Barrett describes as "an international network of cities and communities working to build resilience in the face of climate change and peak oil"—could be another way to guide reconstruction efforts. Whether or not the government of Japan subscribes to ideas of peak oil, the Transition approach can be "particularly instructive in demonstrating how to rebuild with a bottom-up approach" rather than the top-down methods "characteristic of most Japanese eco-towns" (Barrett, 2012).

This type of transition movement promotes progress at the local governance level and can encourage communities to draw on their own creativity, building on existing regional resources and modern energy services. For example, one of the first transition towns, Totnes in the United Kingdom, has developed its own Energy Descent Acton Plan to try to reduce local dependence on fossil fuels. In the case of rebuilding after the Japanese tsunami, the central government–led response initially made it difficult for the communities affected to participate in and influence the reconstruction effort. However, following instead the example of the "Transition Movement might empower communities to develop their own vision of the future" (Barrett, 2012). In fact, across northeastern Japan, the Japanese are increasingly involved in the planning and implementation of reconstruction efforts. It may be a slow, lengthy process replete with bureaucracy, but local buy-in for green reconstruction is taking hold.

Barrett points out that in Japan's 24 Transition Towns, residents "have followed Transition principles" in responding to energy challenges, such as in Fujino in Kanagawa Prefecture where residents petitioned to start a local power company after the tsunami. Places like Fujino are following in the footsteps of other transition towns. One town, Kuzumaki in Iwate Prefecture, "With a population of only 7000… set up the Green Power Kuzumaki Company in 2001. The project developed 12 wind turbines with a capacity of 1750 kW each." The operational rate of wind turbine is said to be about 20%. A 1750 kW—wind turbine is assumed to generate 350 kW. A Japanese average household needs 4 kW. So a 1750 kW wind turbine is for about 90 households. 12 wind turbines can supply 1080 households. Kuzumaki has slightly less than 3000 households according to the data from the municipal government. Rural areas like Kuzumaki may be able to rely a big part of its electricity on renewables, but populated cities may need a different strategy like Smart Cities for securing electricity. Places like Fujino and Kuzumaki succeed as transition towns in part because of a growing awareness of the need to reduce reliance on fossil fuels and nuclear power, and also due to a resurgence of local action stemming from a growing distrust of central government (Barrett, 2012).

7.7. Smart cities

A major characteristic of smart cities is the smart grid, a power generation network. It integrates electric power infrastructures to streamline and conserving energy. Smart grids enable the stable inclusion of renewable energy, where output, especially in solar and wind, can be unstable. Through integration, the grid brings new services and new values by also improving the environment. It requires collaboration between government, public utilities and related industries and consumers, as well as an already advanced energy infrastructure.

Japan has helped to export smart city ideas overseas, coordinating with the Indian government and respective businesses on smart transport schemes, and Japan's Hitachi Corporation has emerged as a leader in the development of the smart city concept. Cities devastated by the tsunami in Northeastern Japan like Rikuzentakata and Ishinomaki are considering smart city models in their reconstruction (Alabaster, 2012).

7.7.1. The effects of Japanese culture and reconstruction

Underlying all of Japan's technical and policy challenges is perhaps an even bigger obstacle to change—the role of culture. During the Fukushima nuclear disaster, human pride and the instinct to save face were reinforced by the communal mindset of Japanese bureaucracy in which the first duty of a civil servant is to uphold, support, and protect the organization and provide unfailing loyalty to the leadership of the organization. A final report by the Fukushima Nuclear Accident Independent Investigation Commission (NAIIC) identified a culture of reflexive obedience; the reluctance to question authority; a devotion to conform; “groupism” and insularity that were the root of the problems on March 11, 2011 (National Diet of Japan, 2012). This mindset also stands to affect the reconstruction effort.

Traditional Japanese society and culture stress the values of balance, consensus decision-making and social conformity. Work is where employees live in a sense. There is a strong sense of attachment to one's employer—part of what is described as “Japanese group mentality” that lies somewhere near to the heart of the Japanese economy. This “groupism” is commonly accepted. There is an ordered courtesy to human relations or harmony that does not exist in the West. The Japanese call it “amae”, a deep-seated need to be dependent upon a group, a company, or even a state. According to the NAIIC report, decision by consensus hampered a crisis response that included a lack of accountability by TEPCO and senior government officials. The current reconstruction effort has been negatively impacted by a mercurial political system that soon resumed a normal pace of daily activity in Tokyo and has been slow and bureaucratic in its overall response to the Tohoku crisis while local leaders plead for speedier assistance. On the issue of nuclear power, the government's move toward zero nuclear is another example of preserving cultural harmony. According to recent polls, 80% of the population is anti-nuclear in sentiment although intellectually most citizens understand the need for nuclear power for the health of the economy (Asahi, 2012). Japan's well known historical experience with the risks associated with nuclear technology dating back to World War II now bookended by the Fukushima man-made disaster of 2011, have created an anti-nuclear culture and politics that defy practical approaches to economic and energy policy. It is in a sense a cultural response to a technology that worked well under normal conditions but did not have a failure-safe capability in a disaster scenario which created this anomaly.

8. Conclusion

Japan has a history of being a leader in high-technology innovation and implementation. The Government of Japan (GOJ) released a Cabinet Decision on September 19, 2012 that will “implement future policies on energy and the environment, taking into account the Innovative Strategy on Energy and the Environment” (METI, 2012). This strategy, released several days prior to the Cabinet Decision, advocates for the phase out of nuclear energy by 2030 (with flexibility). Much of the replacement power generation capacity is believed to derive from renewable energy—the strategy calls for the construction of 300 billion kWh of capacity by 2030 (30% of generation). The rapid integration of such extensive capacity necessitates massive investment and a restructuring of Japan's energy mix and regulatory structure during this crossroads where Japan must not only find a way to meet its rising energy needs but also seriously consider reconstruction in a sustainable energy framework. Post-disaster reconstruction is an opportunity and a challenge for the promotion of safe and efficient energy technologies integrated with environmentally sustainable, renewable energy sources. Such a concept has its unique significance in a country like Japan, faced in an energy crossroads where nuclear is planned to be phased out completely and where cultural measures can offset progress.

Japan's energy security future will be predicated on the country's leaders balancing a commitment to lowering Japan's resource dependence and designing a framework for post-disaster reconstruction that stresses efficiency and sustainability with economic and social considerations. Namely, the Government will have to employ policies that are economically feasible across various time-scales and will withstand changes in the composition of Japan's population and urban/rural divide. While Japan's demography, public finances, and slow overall economic growth place a significant strain on meeting GHG emission reduction and sustainable development goals, as a leader in energy intensity operating in a post-Fukushima political economy, there are politically viable solutions to the constraints inhibiting advances in green tech.

This paper has explored Japan's primary energy mix, its post-disaster energy options, as well as various reconstruction frameworks considering political, bureaucratic, and cultural constraints. In light of recent political debates about phasing out nuclear power by 2030, now more than ever, Japan needs a reliable and diverse energy mix driven by sustainable technologies that leverage Japan's obtainable resources with limited environmental impact and optimize economic utility of renewable energy investments. Japan is well positioned, economically as well as technologically, to become a leader and model in sustainable energy technology and, if it takes advantages of these strengths in reforming its domestic energy policy, it may stand to profit from exporting these ideas and innovations to other, disaster prone regions and nations.

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