* 30 uses of the word "model"
* 50 uses of the word "technogies"

Overall, there are many long/run-on sentences. Consider as a general rule giving sentences one point, as you elaborate often and the main point can get buried

The role of current and emerging technologies in meeting mid to long term carbon reduction goals for Japan

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Abstract

ABSTRACT

Keywords: insert keywords here

1. Introduction

Only use with sizes

Is "buildings" a sector?

In order to mitigate climate change, and to improve environmental outcomes, many nations are actively seeking to reduce carbon emissions. They ~~and have~~ formalized this goal through the Paris Agreements (UNFCCC, 2015). The largest contribution to global greenhouse gas (GHG) emissions, some 73%, comes from energy consumption, consisting mainly of the transportation, electricity and heat, buildings, manufacturing, and construction sectors (WRI, 2020). For developed eco~~nomy~~ nations rich in natural resources, switching to natural gas or implementing carbon capture and storage (CCS) on fossil fuel plants is one option to reduce GHG emissions. However for developing nations, these options are economically unfavored, ~~not always economically feasible~~, leading to increased emissions (through greater coal use) for rapidly developing nations (IEA, 2019). For Japan, a developed economy nation without ~~with no~~ fossil fuel resources, the challenge to reduce GHG emissions is likely to follow a different path, already proven ~~evidenced~~ by the restart of nuclear reactors and a shift toward large scale renewable energy deployment (IEA, 2019).

Although influenced by the Paris Agreements, Japanese energy policy is governed by the Basic Energy Plan, recently updated to the 5th edition and approved by the Cabinet in July of 2018 (METI, 2018). The Basic Energy Plan outlines national policy toward a new energy system for the years 2030 and 2050, cognizant of limited indigenous resources, the impact of the Fukushima incident, and external pressures on energy supplies (ANRE, 2018). The Plan reaffirms the Japanese benchmarks for evaluating the energy system ~~as~~, first and foremost, within the context of energy security, followed by economic efficiency, safety, and a consideration of the environment (summarized as '3E+S'; ibid). Although there are some parallels between the 3E+S goals and the Paris Agreement

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☆ fails to include
~~lacks~~ or ↑

targets agreed to by Japan, the plan ~~does not set out in detail~~ how the 2050 emission reduction target of 80% is to be met. This may be due to the lack of evidence for the economically feasible reduction of GHG emissions in each sector, and it has been suggested that electrification of a number of sectors will be required to achieve the ambitious 2050 target, underpinned by electricity generated from low-carbon technologies (Matsuo et al., 2018). For the power sector to achieve such a target, near-zero emissions are required, and early action utilizing existing technologies is preferable to delaying action ~~in preference~~ for future technologies (Ashina et al., 2012). It is likely that a mixture of current and emerging technologies will be employed to achieve carbon reduction targets in Japan. The current candidates include a reinvigoration of the nuclear contribution to final energy demand, deploying CCS to fossil fuel power plants, and the ushering in of the hydrogen economy, underpinned by renewable energy deployment as well as hydrogen imports from abroad (Ashina et al., 2012; Matsuo et al., 2018; METI, 2017).

does candidates = technologies?

The aim of this research is to investigate the likely suite of electricity generation and storage technologies ~~and~~ as well as their feasibility in meeting Japan's carbon reduction goals, cognizant of energy policy, resource limitations, demand growth, emerging technologies, and economic constraints ☆ using the TIMES framework. Our dynamic simulations of transition scenarios, ~~by focusing~~ focused on minimizing ~~the~~ cost ~~of the transition~~ while satisfying CO2 emission constraints, suggest potential economically feasible decarbonization pathways ~~while meeting~~ that meet the increasing near-term electricity demand. Additionally, the significance of key economic parameters of emerging technologies is assessed through sensitivity analysis This is done in order to highlight the most impactful parameters of each technology and ~~hence~~ guide research and development efforts focused on these technologies.

See line 117: Maybe; "... constraints, assisted by models from The Integrated..."

2. Background and literature review

The Paris Agreement commits individual nations to significant carbon reduction over time through the Intended Nationally Determined Contribution (INDC) mechanism (UNFCCC, 2019). Japan, as a signatory to the Paris Agreements, has submitted an INDC with the following goals and timelines: by 2030, ~~to~~ reduce GHG emissions by 26% compared ~~to~~ with 2013 levels; and by 2050, ~~to~~ reduce overall GHG emissions by 80% or more through the "development and diffusion of low-carbon technologies and transition to a low-carbon socio-economic structure" (UNFCCC, 2015). Cognizant of these targets, a number of authors have evaluated Japan's future energy system using a variety of modeling approaches. Using the MARKAL model, considering the uncertainties of technology development, Ozawa et al., found that hydrogen will play a major role in the future energy system, reliant on both nuclear power and carbon ~~capture and storage~~ (CCS) to reduce electricity sector emissions to nearly zero by 2050 (2018). Recognizing the benefits that renewable energy will play in reducing carbon emissions and the issues of intermittency, Li et al. explored the role of hydrogen as a storage medium through power to gas (P2G) approaches in Kyushu, Japan. Their study

Define acronym

You defined this on line 7 already

is hydrogen or the energy sys. reliant?

What is 2018 referring to?

ignore; keep comma →

~~Very~~ long sentence; consider trimming

identified that P2G can increase the effective utilization rate of renewable energy and the use of hydrogen in the gas network, effectively pairing the electricity and gas networks, overcoming ~~overcomes~~ current renewable electricity curtailment issues (2019). Cognizant of the Japanese government's strategic approach to carbon reduction out to 2050 via energy system reform, Chapman and Pambudi also identify a strong role for nuclear, renewables, and hydrogen under a carbon constrained, optimal cost MARKAL/TIMES simulation approach (2018). Considering economic conditions and demographic trends such as Japan's moderate GDP growth and rapid aging ~~which are occurring in Japan~~, Kuriyama et al. suggest that 2030 targets can be met or exceeded (i.e. up to 42% GHG reduction) with limited renewable energy growth ~~at a 15% contribution from nuclear, or even without nuclear~~, under a renewable growth scenario (2019). ~~It appears that~~ these trends and energy system changes will be insufficient to meet the more ambitious 2050 targets. Taking a more holistic view, in line with the Japanese government's 3E+S targets, ambitious research and development to enable high levels of renewable deployment appears to ~~be necessary to not only~~ meet deep emission reduction goals, ~~but to~~ ~~and~~ while ~~also reduce~~ reducing Japanese dependence on imported fuels, cognizant of both CCS and nuclear deployment rates into the future. Consensus on policy options and priorities also ~~have a~~ ~~large~~ influence ~~on~~ modeling outcomes for the Low Carbon Navigator, which assesses ~~assessing~~ Japanese energy and emission options out to 2050 (Moinuddin & Kuriyama, 2019). A seminal work by Sugiyama et al. brings together a number of modeling approaches for Japan's long term (i.e. to the year 2050) climate change mitigation options, utilizing national and global general and partial equilibrium models (2019). Model results are contrasted under six scenarios which incorporate a baseline, ~~and~~ a range of emissions reductions (50-80%), and regional obligations for global models (ibid.). under the Paris Agreement target of an 80% reduction. Each ~~each~~ of the models assessed recognize the importance of renewable energy deployment by 2050 (notably hydro, solar, and wind) with varying contributions from nuclear energy and fossil fuels (predominantly natural gas). Additionally, ~~for Japan, the~~ Japan's option ~~for~~ to import ~~of~~ carbon-free hydrogen was identified as potentially playing a critical role (Sato, 2005; Akimoto et al., 2010; Matsuo et al., 2013; Fujii and Komiyama, 2015; Oshiro & Masui, 2015; Sugiyama et al., 2019). Many studies consider hydrogen a critical part of Japan's low-carbon energy transition. ~~It is effective~~ ~~because~~ It improves ~~specifically toward improving~~ energy security, ~~and~~ can ~~its ability to~~ be produced from multiple sources, and lacks ~~of~~ emissions when combusted (Iida & Sakata, 2019). Global modelling efforts consider the incorporation of long-distance international transport of hydrogen. Ideal ~~with~~ end uses are dominated by fuel cell ~~passenger and freight~~ vehicles and power generation via ~~both~~ mixed and direct combustion. Electricity from hydrogen is estimated to emerge in Japan from 2030 onwards, as nuclear and coal fired power generation reduces toward 2050 (Ishimoto et al., 2017). From a policy standpoint, Japan has committed to achieving a hydrogen society, ~~with~~ the primary goal is ~~of~~ cost parity of hydrogen with competing fuels, requiring a three-fold reduction in cost by 2030, and further reductions into the future (Nagashima, 2018). Under the Basic Hydrogen Strategy, the Japanese government aims to realize low cost hydrogen use in ~~power generation, mobility and industry~~ the power generation, mobility, and industry sectors, develop international

What papers are (2018) and (2019) referring to?

Sounds redundant

Why? Based on the previous statistic?

instead, say why it's necessary, which you do ✓

only use w/ sizes

Only use "when" while referring to time; try "if"

choose one; for Japan they're kinda the same supply chains to ensure stable supply, expand renewable deployment, ~~and~~ revitalize regional areas, and develop hydrogen related technologies (METI, 2017). The strategy aims to account for both economic and geopolitical impacts and the need to prioritize research and development to overcome the economic and technical challenges (Nagashima, 2018). is A common thread across previous research ~~is that~~ the uncertainty surrounding CCS? carbon capture and storage (particularly with regard to scaling up and public acceptance issues) and the role that nuclear energy will play, largely due to policy reform which occurred in response to the nuclear accident in 2011, (Oshiro et al., 2019). only use w/ sizes

The model and approach proposed in this research ~~is~~ are unique, as ~~it builds~~ they build on the works and modeling consensus outlined in the literature review and expand ~~the consideration of technologies beyond conventional and recent technologies to also~~ technological options to include emerging and disruptive technologies post-2050. This work leverages the dynamic simulation capabilities of TIMES (Loulou et al., 2005) by incorporating learning curves for parameters such as investment, ~~and~~ Operation and Maintenance ~~Cost~~ (O&M) costs, efficiency, and emission coefficients. Our model also incorporates life-cycle emissions of all conventional and emerging technologies, which are typically neglected externalities considering the highly globalized manufacture and supply chain of existing and emerging technologies. ~~This~~ Including all technologies accounts for a more meaningful analysis of the global warming potential of emerging technologies, as life-cycle emissions become significant when ~~considering deep emission reductions of the order of 80% from recent emission levels~~ ~~80% reductions of~~ reducing emissions by 80%. By modeling the Japanese electricity supply system out to the year 2100, our aim is to detail the mid and long-term impacts of technological development and market penetration, ~~and to identify~~ while identifying the suite of technologies which could underpin the successful achievement of carbon reduction.

only use "when" with time; try "while"

3. Methodology

TIMES

3.1. TIMES Model Description

move to 37 (first usage of TIMES)

weird

The The Integrated MARKAL-EFOM System (TIMES) ~~model generator~~ ~~is designed to~~ models dynamic energy systems and simulates transition scenarios as a mixed-integer linear optimization problem that is subject to a primary objective function and additional constraints. The generation, trade, refinement, storage, and supply of energy commodities across multiple sectors and multiple regions ~~is~~ are modeled using a wide variety of in-built commodity and process types. Emissions can be associated with energy commodities or processes as emission coefficient per unit commodity produced or consumed.

The objective function in our single-region model is the overall cost of the transition. The major constrains in our simulations are the demand for electricity (see Table 1 table 1), emission constraints based on Japan's Intended Nationally Determined Contribution (INDC) (see Table 2 table 2), and feasible nameplate capacity deployment limits (see Table A.7 table A.7). Miscellaneous assumptions are summarized in table A.9. Table A.9 Hence each simulation is focused on minimizing the transition cost, ~~while attempting to~~

Keep comma

meeting ~~meet~~ the increasing electricity demand, and achieving the required emission cuts using a combination of generation and storage technologies.

While electricity demand in the near future is expected to grow, long term electricity demand in Japan is expected to plateau, or even decrease, due to Japan's aging population. However, precisely quantifying this rate of decrease is challenging as there is potential for increased electrification of transportation and industrial sectors. Hence, post-2030, we have assumed a demand curve based on the likelihood of increased electrification, with ~~but~~ the demand gradually Plateauing ~~plateaus~~ due to the aging population. The unique initial condition of the post-Fukushima Japanese electricity supply system is captured using The Energy Data and Modelling Centre ~~(EDMC)~~ ~~data from 2013-2016.~~ Long term impacts of factors such as the retirement of the existing nuclear reactor fleet, and the deployment of emerging technology is assessed by simulating the system until 2100. The carbon cost of each technology is accounted for using an emission coefficient that incorporates both direct emissions and life cycle emissions (averaged over the entire operating lifetime) for every technology, as applicable. The daily and seasonal variability of renewables is incorporated using TIMES day-night and seasonal time periods (cite Loulou)?. The availability of renewables varies during these time periods based on the annually averaged capacity factors of renewables in Japan.

'2013-2016' Data from''

This is the only use of EDMC; acronym not necessary

~~[illegible]~~ Consider removing the parentheses; that could be useful info

Table 1: Demand increase over time.

Year	Annual demand increase
2017-2030	1.7 %
2031-2050	1.0 %
2051-2070	0.5 %
2070-2100	0.0 %

Table 2: CO_2 constraints.

Year	Emission limit	Base Year	Reduction from base year
2030	438 Mt CO_2-eq.	2013	26 %
2050	75 Mt CO_2-eq.	1990	80 %
2100	75 Mt CO_2-eq.	2050	0 %

Already defined GHG

To explore possible pathways, to curbing greenhouse gas (GHG) emissions, we simulated different transition scenarios with different try "various" combinations of technologies enabled for deployment. The first ~~set~~ combination ~~of technologies~~ includes conventional technologies such as Ultra Supercritical Coal (USC), Liquified Natural Gas (LNG), solar photovoltaic, wind energy (with onshore, offshore-fixed, and offshore-floating considered separately) and utility-scale lithium-ion battery storage. New deployments of oil-fuelled power plants are neglected ~~not considered~~ due to the declining use of oil for electricity generation in Japan due to Japan's goal ~~of energy security and independence~~ as per the Basic Energy Plan. The

space

Combination

second ~~set of technologies considered~~ includes emerging carbon-neutral technologies that are already commercialized or close to commercialization, namely emerging solar photovoltaic (representative of technologies such as perovskites, CdTe), Carbon Capture and Sequestration (CCS), and utility-scale hydrogen power. ~~For hydrogen power,~~ steam reforming, steam reforming with CCS, Alkaline Electrolyser Cell (AEC)s, Polymer Electrolyte Membrane Electrolyser Cell (PEMEC)s, Polymer Electrolyte Membrane Fuel Cell (PEMFC)s, and Solid Oxide Fuel Cell (SOFC)s were Simulated ~~selected~~ for hydrogen Power ~~simulation~~ based on their technological. ?? Along with these two technology groups, ~~it is also important to consider~~ the impact of nuclear energy due to its ~~extremely~~ long operational lifetimes, ~~and~~ consequently ~~extremely~~ low life-cycle emissions, and ~~a~~ high capacity factor. should be considered These factors grant nuclear power significant advantages over renewables. However, nuclear power faces extremely low public acceptance in Japan after the Fukushima Daiichi accident, and its future in Japan is highly uncertain. Hence, transition scenarios with and without new nuclear reactor deployment must be juxtaposed to assess the importance of the role of nuclear in emission reduction. Finally, the long-term impact of nascent hydrogen technologies on the hydrogen economy is assessed in an additional scenario. Additionally, ~~In this scenario,~~ the potential commercialization of Solid Oxide Electrolyser Cell (SOEC) and Photochemical Water Splitting (PWS) post-2050 is explored. ~~Thus,~~ a total of five transition scenarios of varying likelihood are simulated, and these are detailed in table 3. → Table 3

You have two CCS acronyms

Exogenous variables such as economic data, emission coefficients, nameplate capacity limits, and growth rates ~~incorporated in the model~~ are detailed in tables A.6, A.7, and A.8, respectively. Prices and projections for fossil fuels and nuclear fuel were incorporated (add references). Learning curves for costs and life-cycle emissions are compiled from existing data based on scaling of manufacturing, availability of manufacturing materials, and the use of clean energy for manufacturing energy system components. These learning curves are modelled as linear functions interpolated between the data values used, with the curve plateauing at the latest value for a given parameter, as detailed in table A.6. Capacity limits of renewables and PWS are based on their land-use requirements. The maximum annual capacity growth rates for existing technologies are held constant. The growth rate of nuclear power is based on historic trends and current pressure vessel manufacturing limitations. The reactor size assumed in this study is 1165 MWe. Why? Due to a projected increase in the share of renewables, nuclear power plants must be able to load follow, which is simulated in our model based on French reactors' range of capacity factors. The growth rates of all emerging technologies are modeled on the ~~growth~~ rates observed for solar photovoltaic technology, with rapid initial growth plateauing at a moderate ~~growth~~ rate. One notable exception is the maximum growth rate of emerging solar technologies, which we have assumed to be the same as that of existing solar photovoltaic technologies. We believe that these technologies, some of which are already commercialized or close to commercialization, will benefit immensely from the already streamlined solar photovoltaic manufacturing and supply chain. Therfore, ~~Hence~~ they could be deployed as rapidly as conventional solar photovoltaic.

What reinforced these decisions?

You use "hence" often

All hydrogen storage devices are operated with a maximum availability factor of 90%, making them extremely flexible for load following. Long-term storage of hydrogen is also available using hydrogen tanks with appropriate loss factors (cite IEA). For hydrogen electrolyzers and fuel cells, life-cycle emissions from just the stack are considered, as balance of plant (~~BOP~~) emissions from utility scale hydrogen depend strongly on the type of plant and the source of energy used for electrolysis. Our assumptions about the reduction in the investment costs and life-cycle emissions of batteries are conservative due to the rising cost of cobalt and nickel and ~~the manufacture of~~ manufacturing lithium-ion batteries in high GHG emission countries, respectively.

What stack?

Only usage of BOP ⇒ unnecessary acronym

Table 3: Scenario definition.

Scenario	Emerging tech. enabled	New nuclear enabled	Nascent tech. enabled
1	No	No	No
2	No	Yes	No
3	Yes	No	No
4	Yes	Yes	No
5	Yes	Yes	Yes

3.2. Sensitivity analysis

4. Results

4.1. Transition Scenarios

The results of each scenario from table 3 Table 3 are reported as annually aggregated plots of (i) the electricity that is directly supplied to the end user, (ii) the active nameplate capacities of generation and storage technologies, and (iii) the resulting emissions from each technology. Due to natural variations in renewables' output, the ability of some electricity sources to load-follow, and the increasing deployment of storage, the first plot shows a large degree of variation, as generated electricity is diverted from multiple sources to storage technologies, instead of being supplied directly to the end user. The second plot describes the transitions in terms of capacities, and highlights the effect of the capacity factor of intermittent versus base-load technologies. The third plot details the sources of direct and averaged life-cycle emissions from each source.

~~only w/ sizes~~ I think this is an acceptable use of large

In scenario 1 (~~fig. 1~~ Fig. 1), the model is able to meet 2030 emission goals but fails to meet 2050 emission goals by a margin of 25 Mt. Emissions continue to increase by another 25 Mt by 2100, primarily due to life cycle emissions from lithium-ion storage. As in all other scenarios, coal and oil must be retired by 2030. Natural gas sees rapid growth in the near-term, and complete retirement by 2055. Once deep emission cuts have been achieved, new natural gas is deployed again from 2071 onwards due to its load-following capabilities. All existing nuclear power plants must "be"? restarted by 2022 at

* 8 uses of "The amount of..."; please change some

"Will aid in decarbonization efforts"

full operating capacity. With renewable energy as the only option for decarbonization, significant investments in solar, onshore wind, offshore wind (both fixed-bottom and floating), and lithium-ion storage ~~are necessary~~ Vague wording. The presence of a large share of renewables results in significant overgeneration of electricity during some years. The amount 1 of electricity diverted to storage technologies over the entire simulation time frame is 46,342 TWh, primarily from solar (36%), onshore wind (22%), fixed-bottom offshore wind (22%), and Space floating offshore wind (12%). The total cost of this transition is **3,513,941 MUSD** (in 2015 USD).

"availability of" vs. "available"

With the availability new nuclear reactors in Scenario 2 (~~fig. 2~~ Fig. 2), both 2030 and 2050 emission targets are achieved, and a further emission reduction of 12 Mt occurs by 2100. The model chooses to rapidly deploy nuclear power plants at the maximum allowed growth rate despite the high investment cost of nuclear due to its low life-cycle emissions. Due to the reduction in emissions caused by nuclear power, natural gas power plants can continue to operate until 2100. The amount 2 of renewables required for decarbonization ~~is reduced~~ reduces dramatically. This, combined with the load following capabilities of natural gas plants and nuclear reactors, drastically reduces the amount 3 of lithium-ion storage deployed. The amount 4 of electricity diverted to storage technologies is 12,220 TWh, primarily from nuclear (46%), solar (41%), and onshore wind (8%). The total transition cost of this scenario is the lowest, at **2,664,207 MUSD.** Fig. 3

Using emerging technologies without new nuclear power (fig. 3), the model is able to meet both the 2030 and 2050 emission reduction goals, but no further decarbonization occurs after 2050. The results highlight the need to restart Japan's existing nuclear power plants at full capacity by 2030 in such a scenario. The deep emission cuts achieved through renewables, hydrogen, and CCS leave room for emissions from LNG; hence, natural gas plants continue to operate until 2100. Expansion of solar and onshore wind, along with a modest deployment of lithium-ion batteries and natural gas with CCS, helps the model meet 2030 emission goals. After that, the model relies primarily on renewables and hydrogen to curb emissions ~~and~~ keep this ~~while supplying~~ power. Significant investment in hydrogen from 2034 onwards allows effective utilization of renewables and precludes investment in offshore floating wind power. LNG-based CCS plays a modest role as an intermediate technology before the model can complete the transition to utility scale hydrogen. Between 2032-2077, the model generates 2,328 TWh of electricity from CCS technology, which is 2% of the electricity generated over the entire simulation time-frame. This results in 872 Mt of CO_2 being captured, which is well within the estimated 156 Gt CO_2 reservoir limit for Japan (cite Kato 2016). As the existing photovoltaic technology approaches the end of its lifetime and emerging solar technologies become cheaper and more efficient, they rapidly replace current solar power, benefiting from the existing solar manufacture and supply chains. The amount 5 of electricity diverted to storage technologies is 43,879 TWh, primarily from solar and emerging solar technologies (48%), fixed bottom offshore wind (28%), and Space onshore wind (20%). The amount 6 of hydrogen generated is 35,478 TWh, initially ~~from~~ using alkaline electrolysis(1%), but rapidly transitioning to PEM electrolysis(99%). The cost of this

What does "they" refer to?

Compared to ⇒ similarities
compared with ⇒ differences

Can you clarify what you mean by this? Is it based on how many new reactors there should be?

transition is **3,187,940 MUSD**.

Using both emerging technologies with new nuclear reactors (fig. 4) results in rapid decarbonization. Both 2030 and 2050 emission targets are met and an additional emissions reduction of 32 Mt occurs by 2100. The deployment of around 50 MW nuclear obviates the need to invest in offshore wind, lithium-ion storage, and CCS. Hydrogen plays a significant role in decarbonization, but it is deployed slightly later compared ~~to~~ with scenario 3, from 2037 instead. The amount of electricity diverted to storage technologies is 29,733 TWh, primarily from solar and emerging solar technologies(62%), onshore wind (20%), and nuclear (13%). The amount of hydrogen generated is 24,264 TWh, produced entirely from PEM electrolysis. The cost of this transition is **2,804,753 MUSD**.

4.2. Sensitivity analysis