An Actor-Network Theory Analysis of Solar Panel Use in Singapore

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

The portion of the Sun's light energy that continuously hits the surface of the earth has been calculated at 173,000 terawatts. Capturing this would satisfy the world's current energy needs 10,000 times over (Chandler, 2011). This simple fact, taken along with the reality of climate change primarily due to the burning of fossil fuels, forces us to ask what obstacles are keeping the world from utilizing this virtually endless amount of renewable energy. The goal of this thesis paper is to explore how one nation has approached the problem of increasing their solar power capacity. Such analysis will allow developed countries to draw valuable conclusions about the benefits and limitations of this energy source.

The working principle behind solar photovoltaic (PV) cells can be explained by the photoelectric effect first described by Einstein. Essentially, when light hits a material containing electrons at low energies near their respective nuclei, the electrons absorb the light energy. This excites them, giving them the kinetic energy to make discrete "jumps" to higher energy levels within the atom. At certain frequencies of light, the electron can overcome the attractive forces of the nucleus and leave the atom (Kasap, 2018). The photovoltaic effect is similar to this in that light energy brings electrons to a higher energy state within the material, rather than entirely freeing the charge carriers. In semiconductors, the electron leaps from the valence band to the conduction band where it can be shared among the other units of the crystal lattice. The energy difference between the highest valence band and the lowest conduction band is called the band gap or energy gap (E_{gap}) of the material. Current solar photovoltaic cells use semiconductors, primarily made of silicon glass, fine-tuned to the sunlight induce the collective, unidirectional motion, or current, in the cell. This energy is desirable because it is freely available, it doesn't have to be mined, drilled, or refined.

Singapore, a nation, which lies only 1.35º of latitude above the equator is in an excellent position to receive direct sunlight for most of the year. It is considered an archetype among capitalist countries (Völgyi, 2019) for its policies which led to its rapid industrialization and development. Developed nations, which are primarily responsible for the increase in emissions, would do well to learn from how Singapore has taken on the implementation of solar power. Policymakers of developed capitalist societies (or the Global North) are the target audience due to their history promoting fossil fuels to revolutionize their industrial output. Studying Singapore's efforts to deploy solar will take into account key actors such as the government, technology companies, and citizens as well as the natural environment itself. In this thesis paper, I will argue that while expanding solar power output is a wise choice an Actor-Network Theory analysis shows that deeper economic work is necessary in truly reaching the Singapore's energy goals.

This can be successfully argued after looking through relevant literature regarding Singapore and current solar panel technology using secondary sources. The use of Actor-Network Theory will allow for a sociological analysis of the grand system that brings solar photovoltaic cells into the nation's energy sector. Lastly, an analysis section will bring together the technical and social research along with the conceptual framework.

Literature Review

According to the United States Energy Information Administration, "Singapore produced 53 billion kilowatt hours (kWh) of electricity in 2020," with natural gas accounted for around 96% of energy generated (2021). Even though fossil fuels are currently key to their energy capacity and economic development, the Singaporean government is committed to reducing their emissions as shown by policy initiatives such as the Carbon Pricing Act and Green Plan. The latter even includes the goal of having solar power capacity reach 2 gigawatts (GW) by the end of the decade (*International - U.S. Energy Information Administration (EIA)*, 2021).

In theory, what then is the limit to solar power in Singapore? The National Climate Change Secretariat reports that the island nation receives an "average annual solar irradiation of about 1,580 kWh/m^2" which is relatively high. In other words, due to its climate and position near the equator, the city, compared to other sovereign states, receives a large amount of energy per unit surface area. This makes solar power a viable option for them. A simple calculator using the total area of Singapore, 733.1 km^2, (*Singapore's Approach To Alternative Energy*, n.d.) and average efficiency of current technology, around 18% (Aggarwal, 2022), shows that if roughly a third of the total surface area was dedicated to solar photovoltaics, the nation's entire energy needs for could be met based on consumption in 2020. While this thought experiment is woefully impractical due to a litany of other considerations, it still helps us begin to understand the relationship between surface area, solar panel efficiency, and available power from the Sun that allow large solar projects to be undertaken.

Several solar projects have been proposed and/or implemented in recent years on the island. The International Trade Administration (Kei, 2021) reports that Singapore is deploying solar panels primarily in two ways involving roof tops and reservoirs. Rooftop solar panels are being installed on commercial, industrial, and residential buildings. Additionally, floating solar panel farms have been installed for offshore power generation. These solar farms make use of the unused surface area from the sea and can be rather expansive, with a potential 80 megawatt (MW) peak capacity (Kei, 2021). While these initiatives look promising, one megaproject recently failed due to funding concerns. The company, Sun Cable, originally had the goal of overcoming the surface area problem by importing energy from a 20 GW solar farm in Australia via an undersea cable. The two billionaires, Mike Cannon-Brookes and Andrew Forrest, were not able to reach an agreement on the direction of the project (Paul & Swaminathan, 2023).

Actor-Network Theory will be used as the conceptual framework in the social analysis of this problem. In short, it is "a powerful tool to destroy spheres and domains, to regain the sense of heterogeneity, and to bring interobjectivity back into the centre of attention" (Latour 1998). This framework has key strengths including its inclusion of nonhumans, emphasis on relationships rather than actors, and value equivalence of all actors in the network. One pioneer of ANT, Bruno Latour, wrote that this theory "starts from irreducible, incommensurable, unconnected localities which then, at a great price, sometimes end into provisionally commensurable connections" (Latour 1998). This is precisely how I plan to quantify and qualify the contributions of disparate actors in Singapore. Their effects appear as market forces which act on the common variables of energy or power supply. The network at play here includes but is not limited to the following actors: solar photovoltaic cells, the Sun, the natural environment, the Singaporean government, and solar PV companies.

New economic ideas will be utilized to address the larger systemic issues at play. The scholars Wahlund and Hansen (2022) have proposed a new style of governing the economy in which the foundational economy is prioritized and the "Doughnut economics" perspective of Kate Raworth is adopted. The foundational economy is "'part of the economy that creates and distributes goods and services consumed by all (regardless of income and status) because they support everyday life' (Bentham et al. 2013, 7 as cited in Wahlund & Hansen, 2022)." Such an economic system would prioritize sectors and social services that are essential to the well-being of all, rather than the growth of the biggest players. This would lead policymakers to prioritize "health and welfare services, education, transportation, food processing, and retailing." (Wahlund & Hansen, 2022). Raworth's work calls for an economy that operates within the sweet spot of our social and ecological limitations.

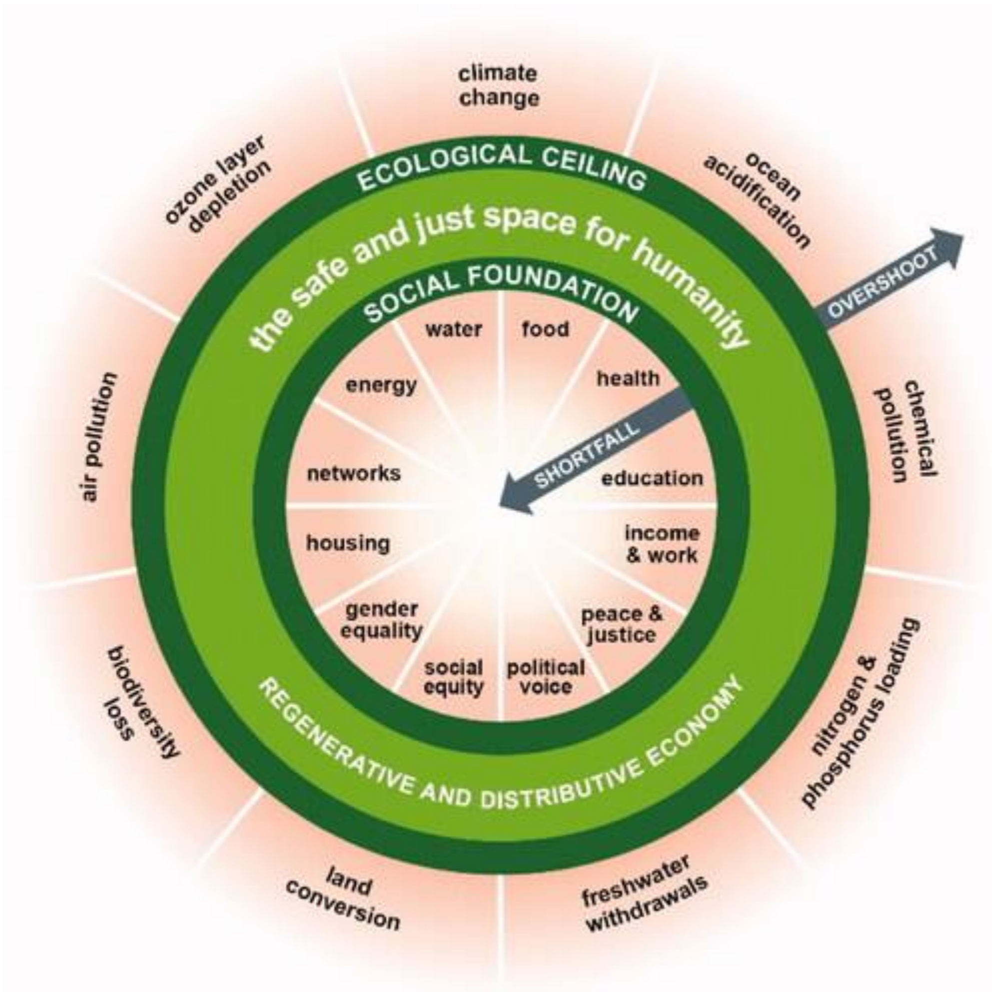


Figure 1. "The doughnut of social and planetary boundaries" (Wahlund & Hansen, 2022).

As Wahlund and Hansen summarize, "If we overshoot the ecological boundaries to maintain our social foundation, the planet will not be able to regenerate in the future. Therefore, to maintain our social foundation without breaking through the ecological ceiling of the planet, Raworth

(2017) contends that all economic activity should take place in the space right between – in 'the safe and just space for humanity.'" (2022). A visualization of this economic philosophy is illustrated in Figure 1.

Methods

In gathering data, I mainly used secondary sources, which focus on recent developments in Singapore's energy landscape and current technology. Media and journalistic accounts were particularly useful for their ability to summarize large sets of data and policy decisions. This method was helpful in drawing conclusions about a broad topic such as this. For example, an ethnographic study would have been too specific and would prevent me from presenting key findings to my target audience: the policymakers of developed nations. Some of my analysis will be dedicated to the crucial calculations that make solar power worthy of investment. The use of MATLAB two-dimensional and three-dimensional plotting will aid in bringing key equations to life. These visuals will give the reader deeper insight into the potential and limitations of solar PV array deployments. My code for these plots can be found in the Appendix. It was primarily obtained using a textbook from Jaffe (2018) and a research paper on optimizing tilt angles for solar cells (Khoo et al., 2014).

Furthermore, I limited my study to solar photovoltaic (PV) systems. Other renewable energy technologies, such as wind or solar thermal energy, could also be considered, however Singapore's geographic location places it at an advantage in terms of capturing the Sun's energy. Additionally, PV systems are unique in their lowering costs and increasing efficiencies which give them an economic advantage to other systems. Finally, energy and power, the time rate of change of energy, can be considered using many different units. For this paper, I will use or translate units into watt-hours (Wh) for energy and watts (W) for power.

Analysis

The key research question here is as follows: **What social, economic, or technical changes need to be made so that Singapore can sustainably reach its energy goals?** First off, it is worth noting that the government of Singapore has set the goal of reaching 3% of its power output being supplied by solar energy by 2030. Currently, that figure is less than 1% (Kei, 2021). At the same time, their total energy output in 2021 was 53.5 TWh (1 TWh = 10^9 kWh) an increase of 5.3% from 2020. This was in congruence with a 7.6% increase in Gross Domestic Product (Energy Market Authority, n.d.). As long as energy needs are increasing in this fashion, solar photovoltaics will have a difficult time catching up to the needs of the grid.

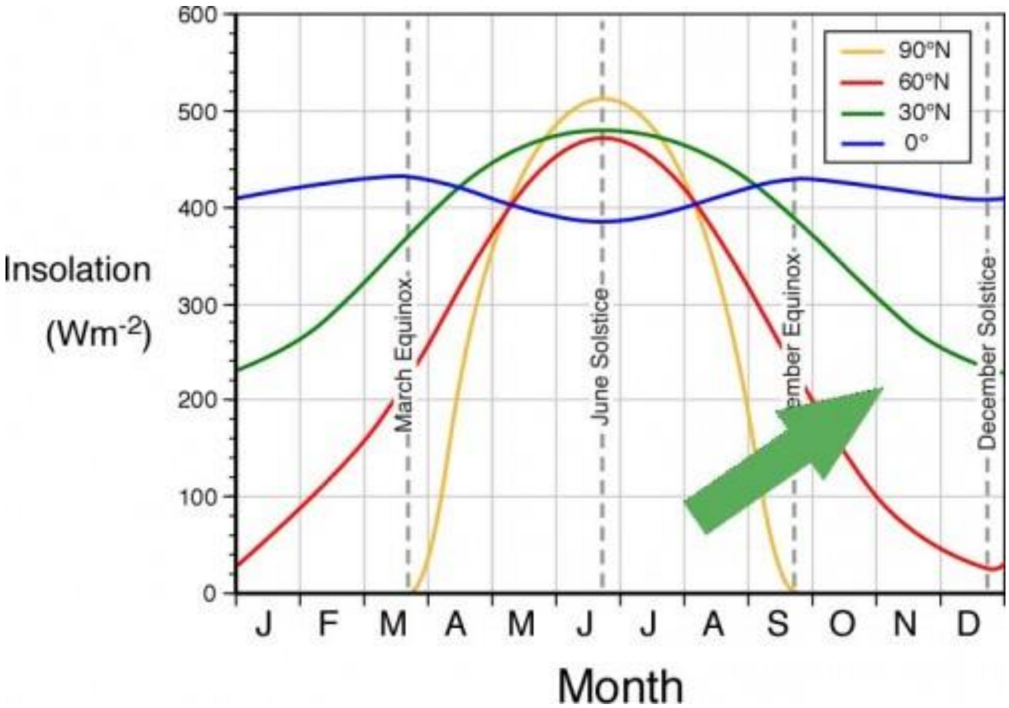
As a city practically lying on the equator, Singapore would be wise to fully utilize the solar power that is readily available to it. The relationship between a location's latitude, the solar radiation it receives, and the time of the year is given by the following equations from a text called the Physics of Energy (Jaffe, 2018).

$$I = I_0 \cos(\beta) \quad \textbf{(eq. 1)}$$

$$\cos(\beta) = \sin(\lambda)\sin(\delta) + \cos(\lambda)\cos(\delta)\cos(\omega t) \quad \textbf{(eq. 2)}$$

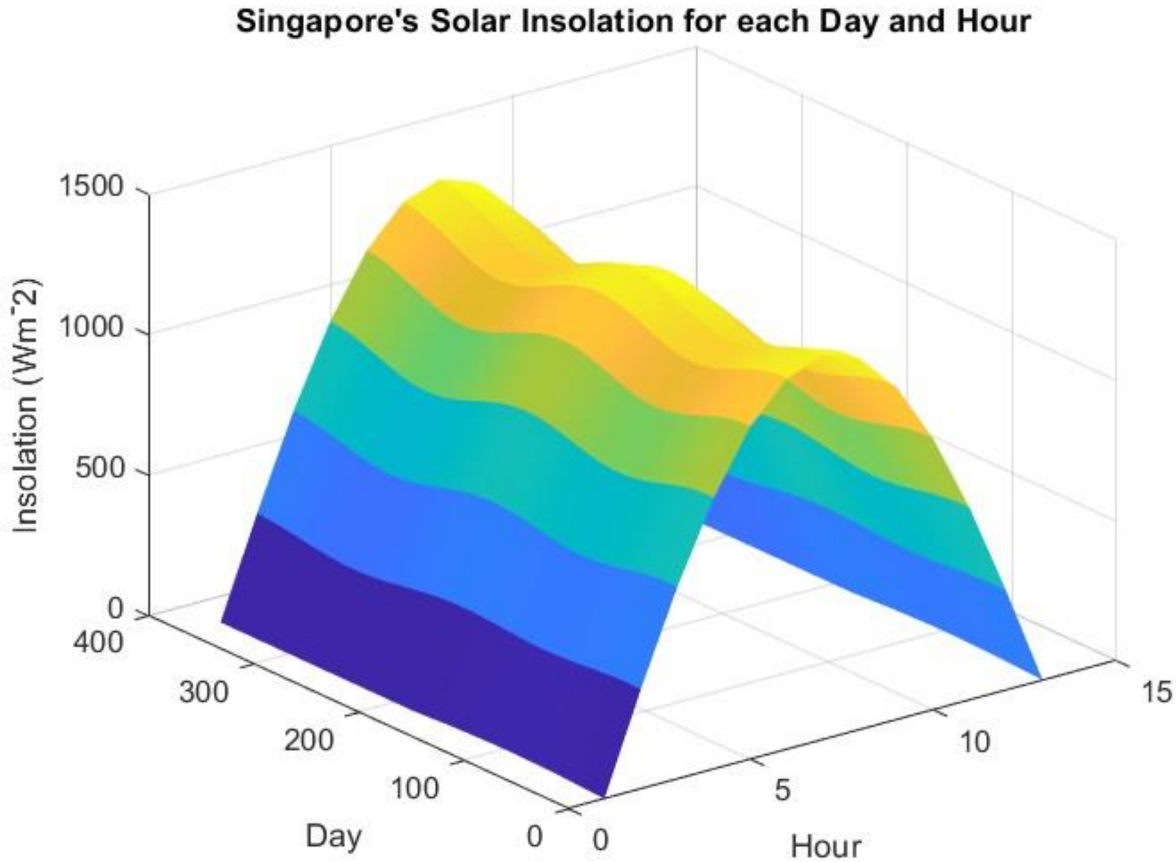
The first equation gives the amount of solar power directly striking one unit of earth's surface. This is called insolation (commonly measured in Watts per square meter). I_0 is the constant solar insolation the earth receives due to its distance from the Sun. (Its value is 1366 W/m^2.) Both eq.

1 and eq. 2 have a *cos(β)* term. This function accounts for the angle at which sunlight hits a surface and is dependent on the time of day, *t*, the location of interest's latitude, λ, and the declination, δ, which is the latitude at which the Sun is directly overhead on a given day (Jaffe, 2018). This value at a given time and place is influenced by many factors. One of which is the latitude of the given location, measured in degrees from the equator. Graph 1 (Lindeke, 2014) shows the relationship between insolation and latitude over a year.



Graph 1: Insolation throughout the year at given latitudes.

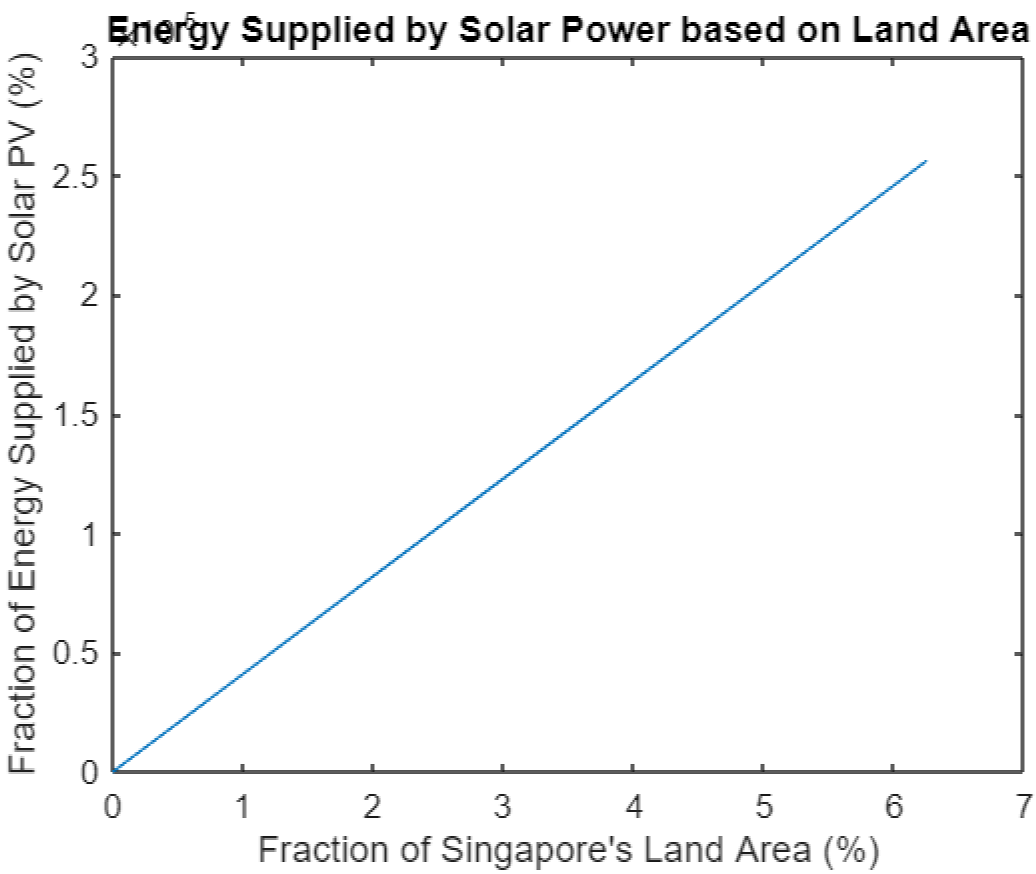
The blue line represents the equator. It can be concluded that nations on the equator should find solar energy desirable due to its relatively high and stable output. Further studies can improve upon this graph by including more factors. For example, below is a three-dimensional plot (Graph 2) I've produced which gives Singapore's insolation each day at each hour, made using Robert Jaffe's text on the Physics of Energy (2018).



Graph 2: Insolation (W/m^2) for each day at each hour for Singapore's latitude.

The peak ridge through the middle of the graph represents the maximum solar insolation, received at noon, for each day. Additionally, crests represent equinoxes while troughs represent solstices. Figures like this would allow designers and decision makers to know when panels would be operational and make accurate predictions for expected energy captured by panels for a given time. The maximum attainable solar energy per year for Singapore is both proportional to and limited by this curve. Integrating this curve over days and hours gives an annual irradiance of 3625.3 kWh/m^2 (see Appendix for calculations). Atmospheric conditions like cloud coverage and temperature, allow panels to receive 42% of this value (Khoo et al., 2014) at 1522.6 kWh/m^2.

The remaining unknown value is the total land area available for solar panels in Singapore. Unfortunately, there is a lack of recent data on this missing factor. One research team from 2013 considered the use of residential roof-tops, facades, infrastructure, islets, and inland waters, concluding that 45 km^2 of Singapore's 720 km^2 total area are available for solar arrays (Luther et al., 2013). This data only predicts a small fraction, roughly $2.5*10^{-5}$ %, of Singapore's total energy consumption can be supplied by solar energy. Graph 3 was made with this faulty data to show how solar energy targets and land use have a linear relationship. While more accurate data is missing, similar methods to those found in the Appendix can be used to generate better models.



Graph 3. Projected energy supplied by solar power based on land area.

Technical limitations aside, it is important to consider the actors within this network bringing about the implementation of solar power. The government acts on behalf of the public and uses policies and funding to set goals for businesses. Businesses design and innovate technological solutions while receiving funding from the government. In this case, these technologies include solar photovoltaic cells as well as tracking and projection products that have physical limitations from the natural environment (Kei, 2021). Nature limits this technology primarily due to cloud coverage and heat. In the same way, sunlight provides consistent power until obstructed by cloud coverage or the rotation of earth (nighttime). The need for lighting and A/C drives up the need for energy, which can contribute to more climate change due to the burning of fossil fuels. From this simple analysis we can see the interconnectedness of each actor. At the same time, this allows policymakers to see the other factors at play. Perhaps increasing energy production doesn't have to be the only solution to energy needs. One documentary proposes adjustments to the design of the city to increase shading to mitigate the urban heat island effect. Additionally, while asking individuals to reduce their energy consumption may not be the best solution, it can be helpful to make people aware of their usage (CNA Insider, 2021).

The bulk of green policy initiatives must be directed towards the industry and commerce sectors in Singapore. These sectors, as opposed to others such as households and transportation, are responsible for around 80% of electricity consumption in Singapore in 2022 (*Energy Consumption*, 2022). At the same time, these sectors have experienced mostly unimpeded as shown in Figure 2 below.

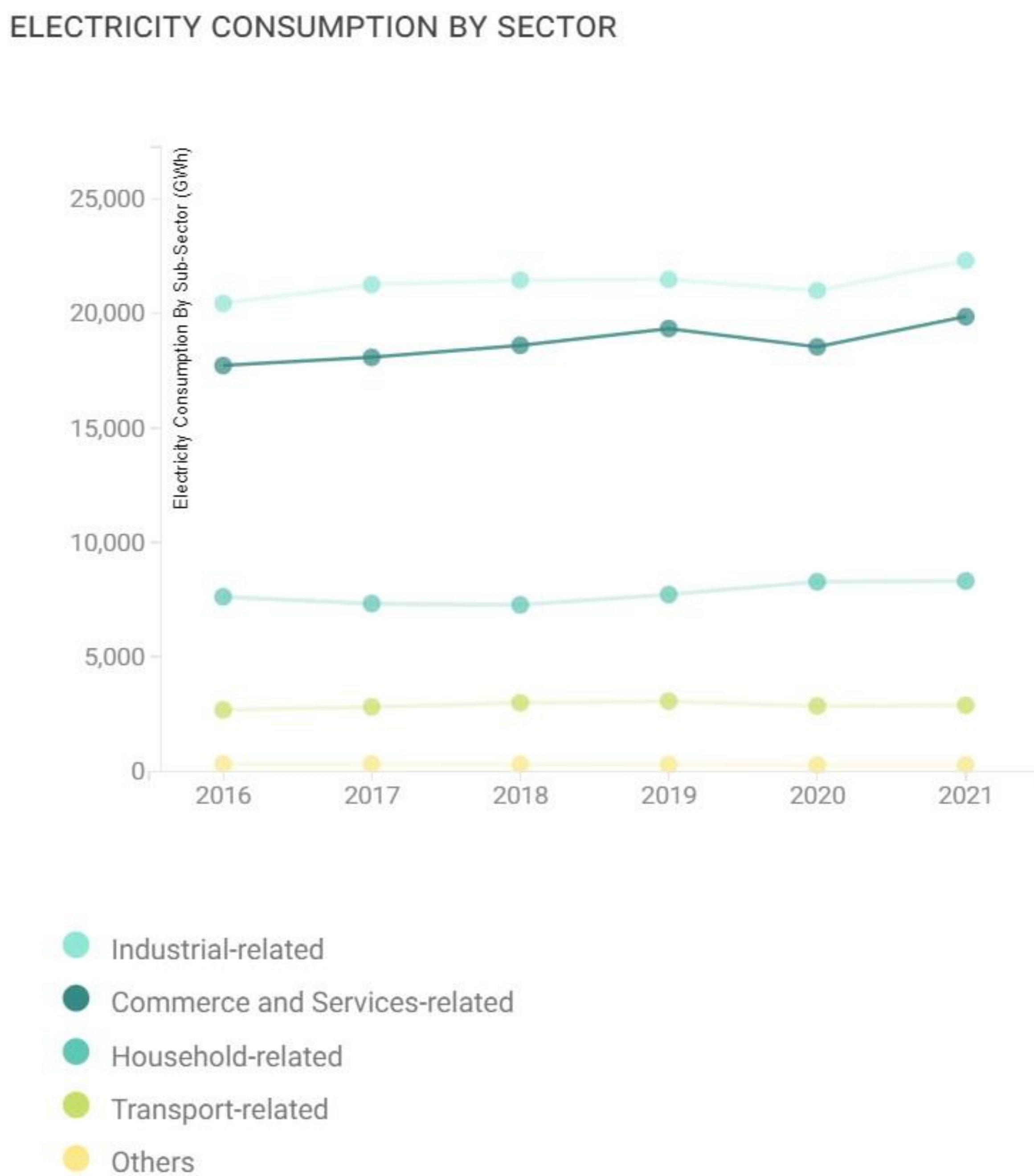


Fig. 2. From the Energy Market Authority illustrating electricity consumption by sector over time. Notice how the industry and commerce sectors stand out above the rest and continue to grow while other sectors remain stagnant.

The general public should not bear the brunt of the responsibility, through changes affecting their household expenses or travel, for the energy transition simply because they are not responsible for the majority of emissions.

Furthermore, ANT helps identify a glaring issue within any capitalist system that has pledged to rely more on renewables. This issue is as follows: the businesses and their shareholders contributing to the GDP have stronger ties to profit and economic growth than to renewable energy and net-zero goals. What will happen then if quarterly growth is opposed to sustainable development goals? In September of 2022, this was shown when the manufacturing sector, which makes up a quarter of Singapore's economy, was blamed for its deceleration affecting the rest of the city-state's GDP (Mapa, 2022). At the same time, the Energy Market Authority has identified the industrial sector as the largest consumer of both electricity and natural gas at 42% and 90%, respectively (2022). Lastly, the same authority reported that Singapore's electricity consumption rose alongside its GDP. This fuller picture reveals that the economic pressure to grow or else crash has put the nation's larger goals at odds with its environmental commitments. Unlimited growth has boosted the demand for electricity and natural gas over the years, creating a runaway energy consumption problem. How will solar installments catch up to an ever-increasing power demand?

What options do policymakers have to mitigate these effects? Firstly, it must be understood that renewable energy incentives (i.e., tax exemptions, subsidies, and easy access to credit) are necessary but not enough in themselves. Fossil fuels must be disincentivized as well. This can be done by "imposing environmental taxes and by withdrawing the incentives available to emission-led industries and sectors" (Kuşkaya et al., 2023). Taxes stand out among other initiatives as a key tool wielded by policymakers to push or pull the economy in the right direction.

Beyond taxes, more fundamental changes can and must be made as well. One group of researchers has suggested the “devolution of power to the local units” where environmental policies can then promote environmental quality (Shan et al., 2021). In this model, each locality sets their own goals under federal guidance. A more decentralized political structure in terms of environmental policy reflects one of the strengths of solar power. Panels can be placed in a variety of spaces based on the needs of the user or community (e.g., rooftop solar). Recently, Singapore has installed a floating solar farm for specifically powering their water reservoir systems. Municipalities seeking to adopt this form of energy policy devolution may seek the installment of micro-grids which allow two-way feedback between power sources and users at a local level.

Building on this, Singapore could implement foundational economy and Doughnut economics approach as described by Wahlund and Hansen (2022) through decentralization of power, prioritization of essential sectors, and the consideration of boundaries. First, the GDP must be dethroned as the chief economic metric in favor of new indices which describe whether the nation is within the “doughnut” of meeting social needs while not encroaching ecological boundaries. Further research is necessary in this area since it is a newer theory.

Conclusion

What do these findings mean for the world? First, an economic model of infinite growth in productivity will produce a runaway effect for energy. As one group of authors concluded, “ongoing efforts for the decarbonization of the environment are encouraging but inadequate to avoid climate disasters knocking down in near future. Thus economy-wide transformations are required to achieve zero carbon emissions in key sectors like energy, industry, agriculture, and transport” (Kuşkaya et al., 2023). This issue isn’t particular to Singapore, but to every developed nation that has been and continues to rely on fossil fuels.

Therefore, it must be recognized that developed nations should focus on decoupling their GDP from their energy consumption until abundant carbon-free energy is available. As this is being corrected, developed nations may look into a mixture of renewable energy resources to offset their emissions until they reach a net zero goal. Secondly, solar power generation is very useful in smaller-scale applications that are coupled to a specific need (e.g. lighting, water treatment). While this strength of solar energy should be promoted, developed nations may want to look at other renewable resources as well as battery technology to make up for the issues with solar deployment.

Further studies should be conducted on technological developments of solar panels. These can range from transparent panels to the commercialization of higher efficiency, perovskite solar cells. As stated earlier, any gains in efficiency reduce the proportional need for surface area coverage. With these in mind, policymakers should be confident in their decisions to balance the promotion of solar panels and other technologies along with making key economic changes for the good of their constituents and the physical environment we share.

Appendix – MATLAB CODE

Solar Insolation for Singapore

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5/11/2023

Available Power from the Sun

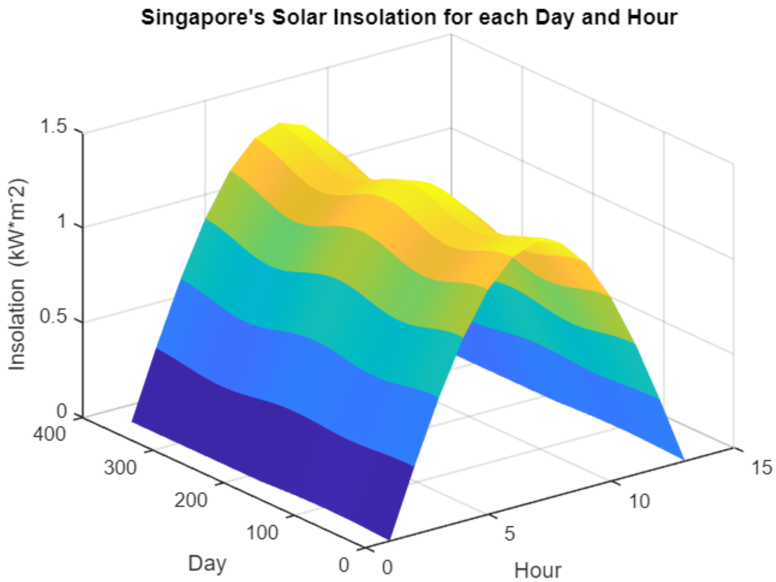
A three-dimensional graph showing the relationship between solar incoming power from the Sun, time of day (in hours), and time of year (in days)

```
I0 = 1.366; % solar constant --> power/area hitting earth (kW/m^2)
theta = 1.37; %latitude of Singapore (in degrees)

d = 0:1:365; % number of days since spring solstice
days = length(d);
t_rise = -6; %sunrise, hours before noon
t_set = 6; %sunset, hours after noon
t_hr = t_rise:1:t_set; % array of hours in a day (0 = noon)
hours = length(t_hr);

delta = asind(sind(23.44)*sin(2*pi*d/365)); % latitude at which sun is directly
overhead on a given day (degrees)
omega = 2*pi/24;

%beta = acosd(sind(theta).*sind(delta)+cosd(theta)*cosd(delta)*cos(omega*t_hr))
y1 = sind(theta).*sind(delta);
y1 = repmat(y1,hours,1)';
y2 = cosd(theta).*cosd(delta);
y2 = repmat(y2,hours,1)';
y3 = cos(omega*t_hr);
y3 = repmat(y3,days,1);
y4 = y2.*y3; %zeros(days,hours)
y5 = y1 + y4;
beta = acosd(y5); % angle of incoming solar radiation (in degrees)

disp('AVAILABLE POWER FROM THE SUN')
```

```
AVAILABLE POWER FROM THE SUN
```

```
I = I0*cosd(beta);
```

```
for i=1:days
    for j=1:hours
        if I(i,j) < 0
            I(i,j) = 0;
        end
    end
end

plot = surf(I); % plots power for each day at each hour
set(plot,'LineStyle','none')
title("Singapore's Solar Insolation for each Day and Hour")
xlabel('Hour')
ylabel('Day')
zlabel('Insolation (kW*m^-2)')
```




```
E_day = zeros(days,1); %Energy available
for i=1:days
    for j=1:hours
        E_day(i) = abs(trapz(I(i,:),t_hr)); %kWh/((m^2)*day)
    end
end
E_m2 = sum(E_day) %add energy from each day to get energy per year
[kWh/((m^2)*year])
```

```
E_m2 = 3.6253e+03
```

```
fprintf("Singapore's total energy received from the Sun in a year is %4.2f kWh/m^2", E_m2)
```

```
Singapore's total energy received from the Sun in a year is 3625.32 kWh/m^2
```

```
disp('Note: This value is only valid at the top of the atmosphere.')
```

```
Note: This value is only valid at the top of the atmosphere.
```

```
% E2 = zeros(days,1);
% for i =1:days
%     E2(i) = trapz(abs(trapz(I(i,:),t_hr)),d);
% end
% sum(E2)
disp('---------------------------------------')
```

```
---------------------------------------
```

Technical Limitations

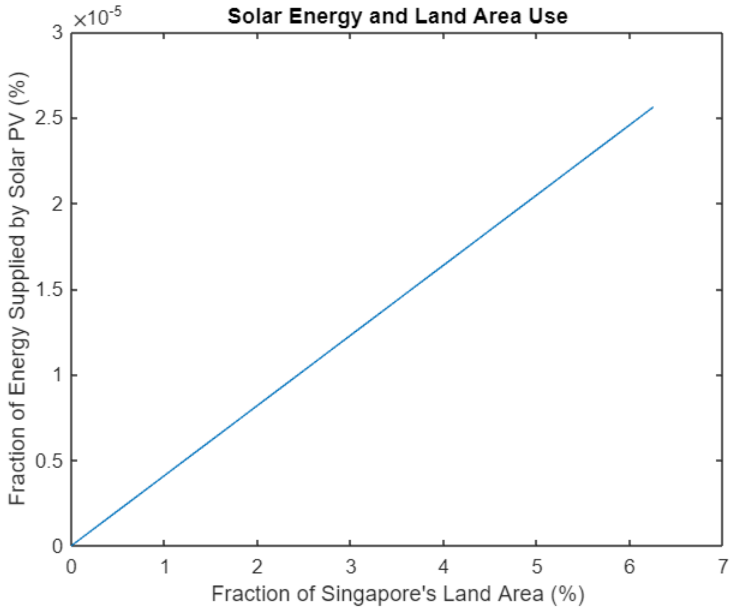
Incorporates efficiency of panels and area that can be potentially covered with solar PV cells.

```
disp('TECHNICAL LIMITATIONS')
```

```
TECHNICAL LIMITATIONS
```

```
eta = 0.2; %solar PV efficiency
pack_factor = 1; %accounts for packing distance b/w panels (1 = ideal)
atm_factor = 0.42; %accounts for atmospheric conditions (from Khoo et al)

A_total = 720; % Total land area of Singapore [km^2]
A_max_solar = 45; %Maximum land area available for solar panels [km^2] (from Luther et. al, 2013)
E_total = 53.5e9; %total energy consumed in 2021 [kWh]
%percent_goal = linspace(0,1,100);
A = linspace(0,A_max_solar,100); %array of land area used for panels
E_solar = E_m2.*A.*(eta*atm_factor*pack_factor); %Array of energy that can be supplied by solar PV with a given land area [kWh]
%A_need = pack_factor*(atm_factor^-1)*(E_solar/E_m2)*10^-6; %km^2
percent_land = (A./A_total)*100;
percent_Energy = (E_solar./E_total)*100;

clear plot
plot(percent_land,percent_Energy)
xlabel("Fraction of Singapore's Land Area (%)")
```

```
ylabel('Fraction of Energy Supplied by Solar PV (%)')
title("Solar Energy and Land Area Use")
```



Bibliography

Aggarwal, V. (2022, November 1). What is the Output of a Solar Panel? | EnergySage. *EnergySage Blog*. https://news.energysage.com/what-is-the-power-output-of-a-solar-panel/

Chandler, D. L. (2011, October 26). *Shining brightly*. MIT News | Massachusetts Institute of Technology. https://news.mit.edu/2011/energy-scale-part3-1026

CNA Insider (Director). (2021, March 19). *Singapore's Power Problem: Inside Our Immense Energy Consumption | Climate Change: A Wicked Problem*. https://www.youtube.com/watch?v=9UjnUjhEbW0

Energy Consumption. (2022). Energy Market Authority. https://www.ema.gov.sg/singapore-energy-statistics/Ch03/index3

Hickel, J., & Kallis, G. (2020). Is Green Growth Possible? *New Political Economy*, *25*(4), 469–486. https://doi.org/10.1080/13563467.2019.1598964

International—U.S. Energy Information Administration (EIA). (2021). Retrieved March 15, 2023, from https://www.eia.gov/international/analysis/country/SGP

Jaffe, R. L., & Taylor, W. I. (2018). *The Physics of Energy* (Brown Science and Engineering Stacks). Cambridge University Press.

Kasap, S. O. (2018). *Principles of electronic materials and devices* (Fourth edition). McGraw-Hill, a business unit of The McGraw-Hill Companies, Inc.

Kei, C. Y. (2021, September 12). *Singapore solar energy*. https://www.trade.gov/market-intelligence/singapore-solar-energy

Khoo, Y. S., Nobre, A., Malhotra, R., Yang, D., Rüther, R., Reindl, T., & ABERLE, A. (2014). Optimal Orientation and Tilt Angle for Maximizing in-Plane Solar Irradiation for PV

Applications in Singapore. *Photovoltaics, IEEE Journal Of*, *4*, 647–653. https://doi.org/10.1109/JPHOTOV.2013.2292743

Kuşkaya, S., Bilgili, F., Muğaloğlu, E., Khan, K., Hoque, M. E., & Toguç, N. (2023). The role of solar energy usage in environmental sustainability: Fresh evidence through time-frequency analyses. *Renewable Energy*, *206*, 858–871. https://doi.org/10.1016/j.renene.2023.02.063

Latour, B. (1996). On actor-network theory: A few clarifications. *Soziale Welt*, *47*(4), 369–381.

Luther, J., Reindl, T., Wang, D. K. S., Aberle, A., Walsh, W., Nobre, A., & Yao, G. G. (2013). Solar photovoltaic (PV) roadmap for Singapore (A summary). *Solar Energy Research Institute of Singapore (SERIS): Singapore*.

Mapa, N. (n.d.). *Singapore's economy is losing steam*. ING Think. Retrieved April 6, 2023, from https://think.ing.com/articles/singapores-economy-losing-steam/

MarketLine Industry Profile: Energy Consumption in Singapore. (2021). *Energy Consumption Industry Profile: Singapore*, 1–44.

Paul, S., & Swaminathan, H. (2023, January 11). Billionaires' squabble stalls Australia-to-Asia solar power project. *Reuters*. https://www.reuters.com/business/energy/singapores-sun-cable-collapses-appoints-administrators-2023-01-11/

Shan, S., Ahmad, M., Tan, Z., Adebayo, T. S., Man Li, R. Y., & Kirikkaleli, D. (2021). The role of energy prices and non-linear fiscal decentralization in limiting carbon emissions: Tracking environmental sustainability. *Energy*, *234*, 121243. https://doi.org/10.1016/j.energy.2021.121243

Singapore's Approach To Alternative Energy. (n.d.). Retrieved March 15, 2023, from https://www.nccs.gov.sg/singapores-climate-action/singapore-approach-to-alternative-energy/

Solar City: The surprising places you will find solar panels in Singapore | The Straits Times. (n.d.). *The Straits Times*. Retrieved March 15, 2023, from https://www.straitstimes.com/multimedia/graphics/2022/05/singapore-solar-power-panels/index.html?shell

Völgyi, K. (2019). A Successful Model of State Capitalism: Singapore. In M. Szanyi (Ed.), *Seeking the Best Master* (pp. 275–296). Central European University Press. https://www.jstor.org/stable/10.7829/j.ctv138wqt7.13

Wahlund, M., & Hansen, T. (2022a). Exploring alternative economic pathways: A comparison of foundational economy and Doughnut economics. *Sustainability: Science, Practice and Policy*, *18*(1), 171–186. https://doi.org/10.1080/15487733.2022.2030280

What Are the Advantages of Wind Energy and Solar Energy? (2022, November 23). INN. https://investingnews.com/daily/tech-investing/cleantech-investing/solar-energy-and-wind-energy/