Peer Review

Sharma, Kavya. 2025. “Costs, Efficiencies, and Carbon: Analyzing Solar Photovoltaics and the Smart Grid as Sustainable Energy Solutions.” *Journal of High School Science* 9 (2): 248–70.

1.you have used different time periods for calculating residential average use in Austin (A) (2000-2018) and Sammamish (S) (2023-2024). If you use the latest YTD data from 2018 March to 2019 March for A; that comes out to be 851 kWh, whereas the different time period for the same city A (2000-2018) calculates to 940 kWh. Should you not have used the most recent 1 year data from both cities to be comparable ? Since power consumption is expected to follow a long term change ? Please justify. What would be the implications to all your subsequent calculations if you used 851 kWh for A instead of 940 kWH ?
2.You state “….The energy consumption data was adjusted by subtracting the energy used by the EV charging station in the home to determine the average household energy usage……” Why was this done? This is still energy consumed by the household for their needs. Please justify. Was an analogous calculation performed for A ? Why not?
3.I am assuming that the size of the plant (solar farm?) in equation 1 is in sq.meters? That is the only way the dimensional analysis works out to be kWh. If in sq.meters, is there a linear relationship between the solarfarm square meter area and the power generation capacity? If not, then a straight multiplication will not work. Need reference.
4.you state “……So, Equation 1 was manipulated to find the best size of the solar photovoltaic plant, as shown in Equation 2. Then, the average of the twelve monthly plant sizes was calculated to find the best size for the photovoltaic plant to sufficiently meet the residential consumer’s energy demands…..” Again, I am assuming that the size is in sq.meters. Also, you would have needed to calculate the size of the plant during the winter months - because that is when the lowest irradiance occurs. Calculating the average is incorrect, since the solar farm will then not be able to supply during the winter months. Please justify.
5.In equation 5, the battery efficiency has nothing to do with grid efficiency or grid storage efficiency. Why was this boosted by 10% ? Please justify.
6.In equation 6, why are the units of hours chosen for time? Is the energy use also figures in hours? In your revised version of the manuscript, please provide units (dimensions) for ALL the equations so that I can check the dimensional analysis. Also provide representative numbers for these equations. Please check all the equations in the manuscript.
7.Please provide a raw data worksheet that you used (either excel or other) as a supplementary file so that readers may check the numbers and adapt to suit their own models. (I see that you have provided a link at the end of the manuscript).
8.You state “……The cost of constructing a battery storage is $781.97 per kWh which was multiplied by the total amount of excess energy stored in the battery….” Does this ‘excess energy’ lead to 100% battery capacity usage? Did you perform battery sizing calculations based on your other inputs/outputs? If not, how are you sure you are not underutilizing battery storage - and hence overestimating storage costs? Please explain in the manuscript.
9.Equation 10 cannot be checked for dimensional units. See point 6.
10.The content in the manuscript does not fall into relevant sections. For example, you state “……..The operation and maintenance costs per year will be $69,835.60 per substation, multiplied by an additional 700 substations to account for the nationwide implementation of solar photovoltaics, which is 67,150 substations………” some of this content should go into “Results”. I suggest that you structure your manuscript significantly better so that readers know beforehand (in a table) what assumptions you are making, what numbers are your fixed data. Then, present another table, showing what numbers are calculated and how they are calculated. Then present the results. Use tables extensively and less

verbiage so that readers do not have to go back and forth to find out how and why a certain number was derived or obtained or calculated. I look forward to reviewing a much better structured manuscript, with relevant content in relevant sections. You will also need to explain your plan better. What are these 'substations'? Do you want to put a lithium battery bank in each substation? How long can energy be stored in such a bank? ……..Where do you obtain the number of 67150 substations for the US?

11.see https://www.canarymedia.com/articles/transmission/lots-of-demand-too-little-grid-the-us-power-sector-in-2024, where the authors state that the problem is not so much in making the Grid 'smart' as in expanding it. Excerpt "…..Instead, the backlog of solar, wind, and battery projects now seeking to interconnect to U.S. grids has ballooned to nearly 2,600 gigawatts' worth of generation capacity. That's roughly twice the country's existing generation capacity, per data from the Department of Energy's Lawrence Berkeley National Laboratory. ….." In view of these statistics, is making the Grid Smart, really going to deliver enough power to US households? You can build out all the solar farms and battery banks you want (in fact, they have already been built and seek to be connected) but the existing grid is unable to handle the load. Please explain in detail in the manuscript and also discuss how this does not negate the premise of your manuscript.

12.Table 5 has no units. Please make sure to present units and dimensional analysis for all equations and calculations. Also see points 6 and 9.

13."……Utilities would have access to consumers' electricity usage and other information from their base locations, and they could then power down individual appliances during peak demand. ……" from https://www.americansecurityproject.org/can-the-smart-grid-solve-americas-forthcoming-electricity-problem/, does this imply that I cannot run my AC during the hottest part of the day? This is going to be a hard-sell with consumers. Please explain. Also see:"….. A virulent public reaction against dynamic pricing could impede the adoption of smart-grid technologies, delaying the many public benefits that the smart grid can bring….." from https://issues.org/levinson/. Even though policy is not the topic of your manuscript, your calculation of a 7.5% energy reduction from a smart grid no doubt involves dynamic pricing fully built in. This may not happen.

14. You have used different time periods for calculating residential average use in Austin (A) (2000-2018) and Sammamish (S) (2023-2024). If you use the latest YTD data from 2018 March to 2019 March for A; that comes out to be 851 kWh, whereas the different time period for the same city A (2000-2018) calculates to 940 kWh. Should you not have used the most recent 1 year data from both cities to be comparable? Since power consumption is expected to follow a long term change? Please justify. What would be the implications to all your subsequent calculations if you used 851 kWh for A instead of 940 kWh?

15. Added on Page 5 - "A dataset of this size was used to capture both older and newer energy trends to find a long-term average as energy consumption is expected to follow a gradual change, rather than just short-term trends."

16. Added on Page 5 - "As Sammamish lacked available long-term data, only a single year was used since it was the only data available."

17. Added on Page 13 - "The implications of using short-term trends is that the total estimated energy demand may not fully reflect long-term consumption patterns. This could influence the resulting calculations, such as the sizes of the solar PV systems, NGCC emissions, and other related factors in the long term."

18. You state "....The energy consumption data was adjusted by subtracting the energy used by the EV charging station in the home to determine the average household energy usage……" Why was this done? This is still energy consumed by the household for their needs. Please justify. Was an analogous calculation performed for A? Why not?

19. Added on Page 5 - "In King County, where Sammamish is located, there are about 1,832,000 cars, with only 3.74% being electric vehicles. By removing the energy used for EV charging, the adjusted data provided a more accurate representation of the average household energy consumption in Sammamish."

20.

21. I am assuming that the size of the plant (solar farm?) in equation 1 is in sq.meters? That is the only way the dimensional analysis works out to be kWh. If in sq.meters, is there a linear relationship between the solarfarm square meter area and the power generation capacity? If not, then a straight multiplication will not work. Need reference.

22.

23. An error was made while calculating the sizes of the solar photovoltaics without and with a smart grid as it should indeed be in square meters ($m^2$). The necessary revisions have been made throughout the paper to ensure consistency and correctness in the dimensional analysis of all equations and calculations.

24. you state "……So, Equation 1 was manipulated to find the best size of the solar photovoltaic plant, as shown in Equation 2. Then, the average of the twelve monthly plant sizes was calculated to find the best size for the photovoltaic plant to sufficiently meet the residential consumer's energy demands….." Again, I am assuming that the size is in sq.meters. Also, you would have needed to calculate the size of the plant during the winter months - because that is when the lowest irradiance occurs. Calculating the average is incorrect, since the solar farm will then not be able to supply during the winter months. Please justify.

25.

26. Added on Page 6 - "The average was used since, with the battery storage paired with the solar PV, any energy shortfalls in solar production can theoretically be compensated for by

the stored energy. This allows for the size of the solar PV not to be based solely on the worst case (e.g. winter months when there is less solar radiation), avoiding unwarranted oversizing."

27. Added on Page 13 - "The author suggests that in the first year of implementing the solar PV systems, NGCC plants can provide support. This way, all the excess energy created in the months of March, April, May, June, and July (which is the same for the solar PV with and without the smart grid seen in Figures 3 and 5), can be stored in the battery storage. By the following year, the battery storage will have enough energy to cover any deficits, as seen in Figures 4 and 6, allowing for NGCC plants to be phased out. Also, throughout this next year, energy will continue to be stored in high solar radiation months, keeping a steady and reliable supply. Additionally, as shown in Figures 4 and 6, at the bottom, Austin will still have leftover power that can be used for other things."
    28. In equation 5, the battery efficiency has nothing to do with grid efficiency or grid storage efficiency. Why was this boosted by 10% ? Please justify.
29.
30. The website https://dragonflyenergy.com/smart-grid-smart-battery-technology-future-energy-management/#:~:text=The%20coherent%20integration%20of%20smart,stable%20and%20reliable%20power%20supply states: "The coherent integration of smart batteries with smart grids enables more efficient and intelligent energy management. These batteries store energy, regulate frequency, and respond to demand to help smart grids optimize the use of clean energy. They also reduce wastage and help maintain a stable and reliable power supply" (This citation is added on page 7).
31.
32. It is important to note that the "smart batteries" that the article are referring to are conventional batteries that are operating within a smart grid system. Their efficiencies are being increased because of the smart grid mechanisms, so their energy losses are reduced by 10%.

33. In equation 6, why are the units of hours chosen for time? Is the energy use also figures in hours? In your revised version of the manuscript, please provide units (dimensions) for ALL the equations so that I can check the dimensional analysis. Also provide representative numbers for these equations. Please check all the equations in the manuscript.

34. The energy usage *is* in hours. I have added units for all equations in the manuscript, noting that for efficiencies and PR, they will always be a percentage.
35. Here are some representative numbers for equations (All fake numbers just to give an idea):
    36. Month's avg GHI – 4.8 $kWh/m^2/day$
    37. Days in month - 30
    38. PV efficiency – 20%
    39. T&d efficiency – 95%
    40. Battery efficiency – 80%
    41. PR – 60%
    42. Size of plant – 10,000,000 $m^2$
    43. Energy residents in the city used in a month – 164,160,000 kWh
    44. Total energy residents in the city used – 2,000,000,000 kWh
    45. Total energy produced by solar PV w/ smart grid – 1,500,000 kW
    46. Excess energy generated by solar PV w/ smart grid going into battery – 500,000,000 kWh
        47.
    48. Please provide a raw data worksheet that you used (either excel or other) as a supplementary file so that readers may check the numbers and adapt to suit their own models. (I see that you have provided a link at the end of the manuscript).
49.
50. Attached the excel spreadsheet as a supplementary file.
51.

52.You state "……The cost of constructing a battery storage is $781.97 per kWh which was multiplied by the total amount of excess energy stored in the battery…." Does this 'excess energy' lead to 100% battery capacity usage? Did you perform battery sizing calculations based on your other inputs/outputs? If not, how are you sure you are not underutilizing battery storage - and hence overestimating storage costs? Please explain in the manuscript.

53.Added on Page 8 - "The assumption made by doing this calculation is that during the first year of implementing the solar PV and battery storage, *all* excess energy generated by the solar PV will be stored in the battery storage, which be utilized in the following year. It is important to note that solar PV will not be the sole source of power generation during the first year, which will be further examined in the results section."

54.(This implies that the battery will reach 100% capacity by the end of the first year)

55.Equation 10 cannot be checked for dimensional units. See point 6.

56.Solar PV + Battery Storage Residential Bill = $\dfrac{20.09\text{¢ (per kWh)} \times \text{energy used in city (kWh)}}{\text{number of households}}$ 58.(10)

57.

59. $$\frac{\frac{cents}{kWh} \times kWh}{num\, of\, households} = \frac{cents}{num\, of\, households}$$

60.The content in the manuscript does not fall into relevant sections. For example, you state "……..The operation and maintenance costs per year will be $69,835.60 per substation, multiplied by an additional 700 substations to account for the nationwide implementation of solar photovoltaics, which is 67,150 substations………." some of this content should go into "Results". I suggest that you structure your manuscript significantly better so that readers know beforehand (in a table) what assumptions you are making, what numbers are your fixed data. Then, present another table, showing what numbers are calculated and how they are calculated. Then present the results. Use tables extensively and less verbiage so that readers do not have to go back and forth to find out how and why a certain number was derived or obtained or calculated. I look forward to reviewing a much better structured manuscript, with relevant content in relevant sections. You will also need to explain your plan better. What are these 'substations'? Do you want to put a lithium battery bank in each substation? How long can energy be stored in such a bank? ……..Where do you obtain the number of 67150 substations for the US?

61.A new table labeled "Assumptions" was added and referred to throughout the methodology to make it clearer where the numbers were found, so that readers know that the numbers are pre-computed and not found calculations.

62.Added information about the substations:

63.Added on Page 9 - "These substations will serve as critical infrastructure to accommodate the increasing load growth. They will help alleviate any backlog of energy and aid in expanding the grid's capacity and enhance transmission. The 66,450 substations are derived from the Electric Power Research Institute's report, *Estimating the Costs and Benefits of the Smart Grid*, which identified the necessary infrastructure needed to support the integration of a smart grid in the United States."

64.

65.Added on Page 10 - "These 700 additional substations are to ensure that the United States' electrical grid can handle the nationwide integration of solar photovoltaics."

66.

67.see https://www.canarymedia.com/articles/transmission/lots-of-demand-too-little-grid-the-us-power-sector-in-2024, where the authors state that the problem is not so much in making the Grid 'smart' as in expanding it. Excerpt In view of these statistics, is making the Grid

Smart, really going to deliver enough power to US households? You can build out all the solar farms and battery banks you want (in fact, they have already been built and seek to be connected) but the existing grid is unable to handle the load. Please explain in detail in the manuscript and also discuss how this does not negate the premise of your manuscript.

68. The substations mentioned in the manuscript are going to add to the existing grid and help address the need of the grid to be "rapidly reform its interconnection and transmission planning, permitting, and cost-allocation processes" that the author states in the article. However, as stated by the reviewer of this paper, the substations were not explained well, hence the confusion, and so, this article does not negate the premise of the manuscript.
69. Added on Page 9 - "These substations will serve as critical infrastructure to accommodate the increasing load growth. They will help alleviate any backlog of energy and aid in expanding the grid's capacity and enhance transmission. The 66,450 substations are derived from the Electric Power Research Institute's report, *Estimating the Costs and Benefits of the Smart Grid*, which identified the necessary infrastructure needed to support the integration of a smart grid in the United States."
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71. Added on Page 10 - "These 700 additional substations are to ensure that the United States' electrical grid can handle the nationwide integration of solar photovoltaics."
72.
73. Table 5 has no units. Please make sure to present units and dimensional analysis for all equations and calculations. Also see points 6 and 9.
74.
75. "2024 USD" unit was added to the table.
76.
77. "……Utilities would have access to consumers' electricity usage and other information from their base locations, and they could then power down individual appliances during peak demand. ……" from https://www.americansecurityproject.org/can-the-smart-grid-solve-americas-forthcoming-electricity-problem/, does this imply that I cannot run my AC during the hottest part of the day? This is going to be a hard-sell with consumers. Please explain. Also see:"….. A virulent public reaction against dynamic pricing could impede the adoption of smart-grid technologies, delaying the many public benefits that the smart grid can bring….." from https://issues.org/levinson/. Even though policy is not the topic of your manuscript, your calculation of a 7.5% energy reduction from a smart grid no doubt involves dynamic pricing fully built in. This may not happen.
78. Added on Page 3 - "While this mechanism could allow utilities to remotely manage certain appliances during peak demand, they would target non-essential devices rather than crucial systems such as air conditioning, and would require voluntary participation from residents for control over essential devices."
79. Added on Page 13 - "Another limitation is that the 7.5% reduction in household energy consumption assumes full consumer participation in smart grid mechanisms and programs. However, if there is public resistance to some features, then this could reduce the actual amount of energy being saved."

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check equation 1 again. If efficiency improves by 31% ,they PV efficiency was taken to be (20+(.31x20)) = 26.2, correct?

1.where does the battery improvement go in equations 1 or 2 ? You state after equation 5 that "….the best size for the solar PV system was calculated using Equations 1 and 2 with the recalculated variables from equations 3-5 ….." but there is no 'battery storage' variable in either equation 1 or in equation 2.

Also, did you plug in improvements or actual values ? for example, if the improvement in solar PV efficciency was to be 0.19 (for eg.), then, what value of solar PV efficiency would be substituted into equations 1 and 2 ? I am assuming you would substitute 1.19 (relative, not exact number) in equations 1 and 2, correct ?
2.Table 4, the four costs (from left to right, in billions of dollars) are 1.56, 538, 664 and 1163. Is a 2-order of magnitude difference between the NGCC and the other three modes of production valid? This does not seem correct. Please re-check the calculations. If this is due to comparing one city versus the country, please multiply 1.56 by the number of gas fired plants in the country to enable comparison. Put down an explanation below the table.
3.Similarly for yearly operations and maintenance, costs rise from 40 million to 4.6 billion for the last two categories (columns). This does not seem correct. Please recheck.
4.Between Table 4 and Table 5, why is there a large difference between NGCC costs (1.56 billion versus 0.09 billion)? why should it cost 16 times more to construct an NGCC plant in Austin? Does not seem correct. Please check.
5.same with yearly maintenance costs for the two scenarios in table 5. Check numbers. Justify.
6.Yearly carbon footprint for only NGCC for austin is 2.7 billion Kg, whereas it is 0.16 billion kg for Sammamish. Does not seem correct. Should be about the same since only NGCC is used. Check numbers.

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1. <u>check equation 1 again. If efficiency improves by 31% ,they PV efficiency was taken to be (20+ (.31x20)) = 26.2, correct?</u>
   Yes! 20% x 1.31 = 26.2% was the PV efficiency and was used in the calculations. I revised the wording in the paper to make it clearer:
   "To find PV efficiency, the base efficiency of crystalline silicon PV cells was adjusted using the enhancement provided by single-axis tracking technology, which is found in Table 1." (Fixed on Page 6)
2. <u>where does the battery improvement go in equations 1 or 2 ? You state after equation 5 that "….the best size for the solar PV system was calculated using Equations 1 and 2 with the recalculated variables from equations 3-5 ….." but there is no 'battery storage' variable in either equation 1 or in equation 2. Also, did you plug in improvements or actual values ? for example, if the improvement in solar PV efficciency was to be 0.19 (for eg.), then, what value of solar PV efficiency would be substituted into equations 1 and 2 ? I am assuming you would substitute 1.19 (relative, not exact number) in equations 1 and 2, correct ?</u>
   When I say "solar PV system" I mean just the solar photovoltaic, "system" (Fixed on Page 7 and I have checked & deleted it from anywhere else) has been removed from the sentence for clarity. The battery storage size in kWh would be the excess energy added up throughout the entire year (found here: 8), and in kW was just dividing the kWh by the number of hours in a year.
   The way I calculated the improvement of the efficiencies for Equations 3-5 was due to all efficiencies having a reduction in energy losses by 10%, for example, if the original solar PV efficiency was 20%, then this is 80% energy losses. Reduced by 10%, that is a 72% energy loss or a 28% energy efficiency. So, we see an increase in efficiency from 20% to 28%. This 28% was then called the Solar PV Improvement and was used as the new efficiency for the solar PV within a smart grid. However, I have changed the names of from ____ Improvement to ____ New Efficiency to help make it easier to understand.
3. <u>Table 4, the four costs (from left to right, in billions of dollars) are 1.56, 538, 664 and 1163. Is a 2-order of magnitude difference between the NGCC and the other three modes of production valid? This does not seem correct. Please re-check the calculations. If this is due to comparing one city</u>

versus the country, please multiply 1.56 by the number of gas fired plants in the country to enable comparison. Put down an explanation below the table.

Yes, this difference is due to the fact that I was comparing one city versus the country. However, to solve this problem, I decided to multiply the U.S. smart grid costs by "the percentage of all U.S. households that live in the chosen city, to estimate Austin's share of the cost" (Added on Page 9). This changed my results, as now for operation and maintenance costs, the smart grid is the cheapest, and so, the rest of the paper was reflected accordingly. One important thing to note is that for the operation and maintenance, the reason that we see a decrease in the smart grid o&m from NGCC o&m, but an increase in the solar PV + smart grid o&m is because for the solar PV + smart grid, that has to reflect many components such as the solar PV, smart grid costs, and also the battery storage (which has a high o&m). Also, the reason that the smart grid o&m decreased from the NGCC o&m is because the city uses less energy under the smart grid (same as before!).

4. Similarly for yearly operations and maintenance, costs rise from 40 million to 4.6 billion for the last two categories (columns). This does not seem correct. Please recheck.

   Check answer to question 3. All calculations have been checked and are completely accurate!

5. Between Table 4 and Table 5, why is there a large difference between NGCC costs (1.56 billion versus 0.09 billion)? why should it cost 16 times more to construct an NGCC plant in Austin? Does not seem correct. Please check.

   We are seeing this large difference in NGCC costs because of the fact that Austin's NGCC has to power significantly more households in comparison to Sammamish.

   "It is important to note that the reasoning for the difference in costs between Austin and Sammamish is due to Austin having to accommodate power for 20.7 times more households than Sammamish." (Added on Page 13).

   Austin has 458,505 households, and Sammamish has 22,146 households. So, Austin has 458,505/22,146 ≈ 20.70 times more households than Sammamish. This justifies the fact that it costs 16 times more to construct an NGCC plant in Austin because it needs to account for 20 times more households, and thereby needs to be bigger and cost much more.

6. same with yearly maintenance costs for the two scenarios in table 5. Check numbers. Justify.

   Once again, with the yearly maintenance costs for the two scenarios for the NGCC, we see that Austin's NGCC operation and maintenance cost is once again 38074820.82/2280607.80 ≈ 16.70 times Sammamish's NGCC operation and maintenance cost. This makes sense because, once again, the NGCC in Austin has to accommodate for 20.70 times more households.

7. Yearly carbon footprint for only NGCC for austin is 2.7 billion Kg, whereas it is 0.16 billion kg for Sammamish. Does not seem correct. Should be about the same since only NGCC is used. Check numbers.

   Once again, we see a 2.7/0.16 ≈ 16.875 times more kilograms being emitted by the NGCC in Austin in comparison to Sammamish because Austin has to power almost 20 times more households than Sammamish. So, Austin's NGCC is larger, and also generates more electricity for residents to use, thereby emitting much more carbon emissions than Sammamish.

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Thank you for addressing my comments. Accepted.