The Case Against Placing All the Commonwealth's Eggs in the Rooftop Solar Basket (2/8/25)

John Pepi

This brief paper reviews and challenges the widely publicized study estimate that Massachusetts has 40 GW[i] of technically feasible rooftop solar capacity, as well as the equally prevalent argument by those who would preserve all of Massachusetts's so-called Natural and Working Lands (NWL) at any cost – that Massachusetts can and should attempt to site and install the 27-34 GW[ii] solar required to meet our 2050 grid decarbonization goals almost exclusively on rooftops, canopies and previously disturbed lands.

The import of this latter approach is especially important today as Mass. is increasingly challenged on its path toward the 2050 target of 23.4 GW[iii] of offshore wind capacity by anti-wind NIMBYism among coastal communities and by Trump administration commitments to shutting down the offshore wind industry. Mass. currently has approximately 5 GW[iv] of offshore wind operating or under development that is relatively safe from the above efforts to stymie it. Challenges to wind energy project development which pre-date the Trump administration include: cost increases associated with supply chain bottlenecks, the elevated cost of capital, inter-connection delays and extraordinary legal expenses. Any wind powered zero carbon energy that isn't developed on time will almost certainly have to be offset by increased deployment of solar as well as battery storage.

At the same time, Massachusetts solar deployment prospects are themselves confronting the loss or rollback of federal tax incentives, potentially declining state incentives, and both increasing delays and expense for grid interconnection.

In a nutshell, the case made in this paper is as follows:

a) Even prior to factoring in an array of demonstrable physical and financial barriers to rooftop solar deployment, Massachusetts has far less rooftop solar potential than proposed by the Mass. Technical Potential of Solar study (MTPS -Synapse, 2023), likely between 20-30 GW. So, there is little margin for error or slack (i.e., failing to install +1GW/year from 2023) in targeting the next 15-20 GW of solar deployment.

b) A state policy to develop all or most of that rooftop capacity will cost many billions of dollars more than one that prioritizes large (1-5 MW) or utility scale (5-10 MW) ground mounted solar. This additional expense must be borne either by taxpayers or ratepayers. This can only be paid for at the expense of other more cost-effective measures to conserve energy and mitigate carbon emissions, or of wasted opportunities to direct some or all of those potential savings toward permanently preserving the NWL deemed so essential by state environmental agencies and private environmental organizations.[v]

c) The net carbon costs of a dedicated program of accelerated solar development in the most promising/least sensitive NWL – requiring no more than 5% of Mass. forest will: 1) far outperform the preservation of that 5% as forest in the race to meet the state's 2050 carbon budget, 2) leave significantly less residual carbon for the remaining 95% of NWL to sequester beginning in 2050, and, 3) save billions in taxpayer and ratepayer costs.

Nut Shell to Tree:

a) Massachusetts has far less rooftop potential than reported by the Massachusetts Technical Potential of Solar (MTPS) study

(Read before continuing: While critical to the argument of this paper, this section is fairly technical and may require the reader to explore notated source documents to fully comprehend. **The ultimate thrust of this section can be seen in Table 1.** Several quantitative analysis files by the author are cited with a google shared drive URL. Interested parties may need to email the author to gain access. I'd be happy to clarify or elaborate for you at giannipepi@gmail.com)

1. The MTPS study applies an appropriate NREL[vi] derived packing factor (PF - kW/m^2) to all roof area in the MassGIS Building layer. Leaving to one side the fact that a significant fraction of that roof area is technically/physically unsuitable for PV arrays, - all PV capacity is not created equal - especially between south facing roofs and north facing roofs.[vii]
2. This analysis takes the minimum 27 GW of solar capacity required in 2050 by the Mass. Decarbonization Roadmap and, applying the MTPS' inverter loading ratio (ILR) of 71/100 – (ac/dc) - arrives at a state 2050 target of 38 GWdc.
3. It then takes the NREL calculated Mass. solar PV capacity factor (CF)[viii] of 13.2% to quantify solar PV energy generation in 2050 based on that 38 GWdc of installed capacity. That result is 43.91 TWh. [ix]
4. Subtracting the estimated 26 TWh technical solar generation capacity for Mass. from NREL (2016) which was based on "suitable" Mass. roof area, there remains a deficit of 17.91 TWh which must be accounted for if we are to achieve our solar energy requirement for 2050 (43.91 TWh).
5. Working backward from the additional 17.91 TWh requirement - a 9.25% CF is then applied to account for the lower productivity of north facing (135 total compass degrees incorporating NE & NW aspects) roof area. The result is 22.14 GWdc. Taken together with the NREL estimated 22.5 GWdc, the new total for solar capacity needed in 2050 is 44.64 GWdc. This is considerably higher than the 38 GWdc derived above due to the fact that, given the less or unsuitable roofs/roof locations employed, more installed capacity is required to achieve the targeted energy output.
6. **Lastly and to the final point**, converting this power capacity to the additional roof area requirement (beyond the 165 mil. m^2 identified by NREL) results in an additional 162,400,177 m^2. Taken together with the NREL' estimated area this gives the sum of 327,400,177 m^2 roof area required to meet CECP solar energy requirements.

   Table 1 below indicates that 68% of all Massachusetts rooftop areas must be available and buildable (both physically and economically) for solar PV installations. If the estimated 25% loss of Mass. rooftop area for solar deployment due to the state implementation of the recent national fire code standards [x][xi] is accounted for, then the area needed to meet CECP 2050 targets represents 91% of total Mass. rooftop area.

Table 1	
Roof Top Area m^2	
482,229,000	Mass Total MassGIS Bldg. Layer
361,671,750	Mass Total MassGIS Bldg. Layer -Net of Fire Code Losses (-25%)
327,400,177	Needed to Meet CECP 2050 Target - 32 GW of Rooftop Solar
91%	Needed Over Available - Net of Fire code Losses
68%	Needed Over Total Mass Rooftop Area

b) Costs Matter – Including Opportunity Costs!

Should the state move to restrict and disincentivize forest for solar deployment, the cost premium paid by Mass. taxpayers and ratepayers amounts to potentially $15 bil. dollars. Table 2' values for Cost$/Wattdc were derived from Mass. Production Tracking System data for solar installed between 2018-2024.[xii] The table shows the cost of two possible mixes of solar placement - each of which meets the CECP 2050 requirement of 44 GW. The two options vary the proportion of large/utility ground mounted, rooftop/canopy and small ground mount solar. The first option **(highlighted in blue)** represents a mix reflective of the 2050 Decarbonization Roadmap (Energy Pathways Rpt.) emphasis on ground mounted solar (22 GWdc) versus rooftop solar (12 GWdc). The second option (**highlighted in brown)** reflects the public statements of the Healey administration and, importantly, the policy direction advocated by several Mass. environmental groups which are both very vocal and very active. This option shows the cost of emphasizing rooftop and canopy solar (22 GWdc) over large utility scale solar (12 GWdc).

Table 2					
Economic Impact of Rooftop Priority vs Utility Scale Priority Policy (*Watts are DC)					
Emphasis of large-utility scale solar		**GW**	**Wdc**	**Cost $/Watt**	**Total Cost $**
Large GMS -Utility Scale (.5MW-10MW)		**22**	22,000,000,000.00	$2.19	48,180,000,000.00
Small Ground Mount (<=500kW)		**10**	10,000,000,000.00	$2.59	25,900,000,000.00
Rooftop & Canopy (3-300kW)		**12**	12,000,000,000.00	$3.75	45,000,000,000.00
	Total	**44**	**44,000,000,000.00**		**119,080,000,000.00**
Emphasis on rooftop, Canopy & Small GMS		**GW**	**Wdc**	**Cost $/Watt**	**Total Cost $**
Large GMS -Utility Scale (.5MW-10MW)		**12**	12,000,000,000.00	$2.19	26,280,000,000.00
Small Ground Mount (<=500kW)		**10**	10,000,000,000.00	$2.59	25,900,000,000.00
Rooftop & Canopy (3-300kW)		**22**	22,000,000,000.00	$3.75	82,500,000,000.00
	Total	**44**	**44,000,000,000.00**		**134,680,000,000.00**
Additional Cost of Rooftop Priority Policy					**15,600,000,000.00**

c) The Decarbonization Irony (& loss) of Forcing Solar Out of the Forest

Incorporating the carbon free energy of solar PV into the electric grid – sooner rather than later – will play a significantly larger role in the timely achievement of Mass.'s Net- Zero Carbon 2050 objective than does the forest that it would displace.

The "anti-solar in forests" camp is unfailingly silent regarding the 5-10 times advantage [xiii] of solar over forest in offsetting electric grid carbon emissions. It **is** true that solar only replaces carbon emitting fuels powering the electric grid. Unlike forest, it cannot sequester carbon already in the atmosphere.[xiv] Yet, ton per ton of CO2, the impact of solar on Mass. achieving its net-zero carbon 2050 goal is equivalent – except to the extent that the net-zero plan assumes the existence of post-2050 residual carbon emissions which only forests (or CSS) can sequester.

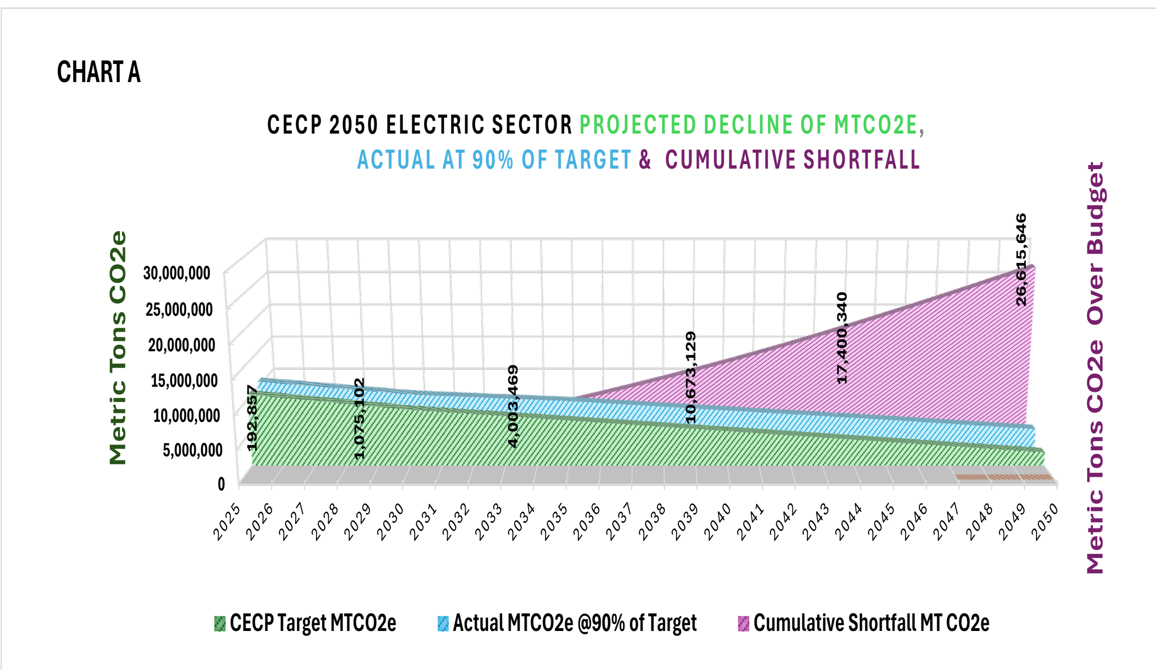
Solar farms are capable of offsetting 3,500 MTCO2e/acre over a 30-year lifetime – net of carbon releases from tree removal and the embodied carbon of solar and associated battery storage equipment[xv] whereas middle aged (mature) New England forests on average will sequester 60 MTCO2e/acre over the same 30 years.[xvi] Table 3 below shows that over 30 years, 5% of Mass.' approximately 2,900,000 acres of forest (150,000 acres) dedicated to solar PV would offset/mitigate 534,450,000 MTCO2e compared to 60,000,000 MTCO2e sequestered and stored by that same 5% of Mass forests. That difference equates to <u>8 years' worth of the entire present Mass. carbon burden</u>.[xvii]

Table 3	**Relative Carbon Impact of 150,000 Acres of Solar PV versus Forest**						
		MT CO2e		**MT CO2e**		**MT CO2e**	
Acres PV GMS		**Mitigation (30 yrs)**		**Mitigation (30 yrs)**		**Mitigation (30 yrs)**	
1		3,563	*Best	2,485	*Middle	130	*Very Worst
50,000		178,150,000		124,250,000		6,500,000	
100,000		356,300,000		248,500,000		13,000,000	
150,000		**534,450,000**		**372,750,000**		19,500,000	
		Store & Sequester	**Sequester Only**	**Store & Sequester**	**Sequester Only**	**Store & Sequester**	**Sequester Only**
Acres Forest (30 yrs.)		**MT CO2e S&S/ Acre**	**MT CO2e S&S/ Acre**	**MT CO2e S&S/ Acre**	**MT CO2e S&S/ Acre**	**MT CO2e S&S/ Acre**	**MT CO2e S&S/ Acre**
1		400	60	200	40	150	30
50,000		20,000,000	3,000,000	10,000,000	2,000,000	7,500,000	1,500,000
100,000		40,000,000	6,000,000	20,000,000	4,000,000	15,000,000	3,000,000
150,000	5.17%	**60,000,000**	9,000,000	**30,000,000**	6,000,000	22,500,000	4,500,000
2,900,000	100%	1,160,000,000	**174,000,000**	580,000,000	**116,000,000**	435,000,000	87,000,000
	Yrs	**All MT CO2e Annual 2025**					
2025	1	65,000,000					
2025-27	**3**	**195,000,000**					
2025-30	5	325,000,000					
2025-55	30	1,950,000,000					
	8.92%	Best forest sequestration for 2.9 mil acres over Mass. 30 yrs. @ current GHG generation (assume current 65 MMT CO2 x 30 yrs)					
	3.1%	Best forest sequestration for 150,000 acres over Mass. 30 yrs. @ current GHG generation (assume current 65 MMT CO2 x 30 yrs)					
	27.41%	Best PV mitigation for 150,000 acres over Mass. 30 yrs. @ current GHG generation					
	19.1%	Middle Case Mitigation - 150,000 acres over all Mass CO2e emissions = 65 MMTCO2/yr					
	*From 50-150,00AcresComp tab in UtilityScaleSolarVsForestLeftAloneDraftForReviewJohnPepi7-10-24						

This approach to valuing the grid CO2e emissions offsets from solar energy is supported by the <u>*Methodological Approach for the Common Default Grid Emission Factor Dataset*</u> from the ***International Financial Institutions (IFI) Technical Working Group on Greenhouse Gas***

Accounting[xviii] which places the greatest weight in its grid carbon emissions factor on the highest cost/highest emitting, **marginal**, gas and oil contributors to grid power rather than the **average** grid emissions value emphasized by the widely cited *Harvard Forest* (HF) Carbon Calculator.[xix] For the foreseeable future, solar and other renewables entering the electric grid can be assumed not to be displacing other renewable energy sources. Instead, they displace the firm, base load of dirty (1,000/lb CO2e/MWh) fossil fueled power sources. The IFI common methodology sponsored by the UNFCC and applied worldwide by agreement of major international banks and finance agencies to the assessment of climate impacts for energy and other development projects – develops a Combined Margin formula consisting of an Operating Margin made of fossil fuel grid contributions (weighted 75% and falling in the range of 1,000-1,200 lbs/MWh) and a Build Margin made up of energy projects in development 1- 8 years into the future (assigned 25% weight).

The current Combined Margin (CM) value for ISO N.E. is approximately 750 lbs. CO2e/MWh based on a review of ISO-NE projects in the pipeline. When one applies this value to the Harvard Forest Carbon calculator, a much different picture emerges than that presented by the authors in public presentations of its carbon calculator. The IFI methodology produces results which move over time with the changing inputs to the electric grid. However, since this 750 lb. CM for Massachusetts already reflects renewable energy future grid entrants almost exclusively, there is



little reason to think it will shrink until the last surviving gas power plant shutters or goes on standby.

If, due to any one of several possible causes, Massachusetts should only achieve 90% of its additional solar deployment target annually, these seemingly minor shortfalls - taken together over a 25-year period - contribute to a surprisingly outsized effect on Mass.'s 2020-2050 carbon budget. It is worth reminding ourselves that adherence to the planned CO2e budget for 2050 (regionally, nationally and world-wide) determines whether we keep the earth's rise in average temperature to

1.5 Celsius (above pre-industrial levels) in the year 2100 and the degree of both weather extremes and unpredictability. This is a problematic concept for sure, but a necessary one in order for our state to quantify its societal responsibility and to proceed in a good faith, coordinated approach with other state and international jurisdictions.

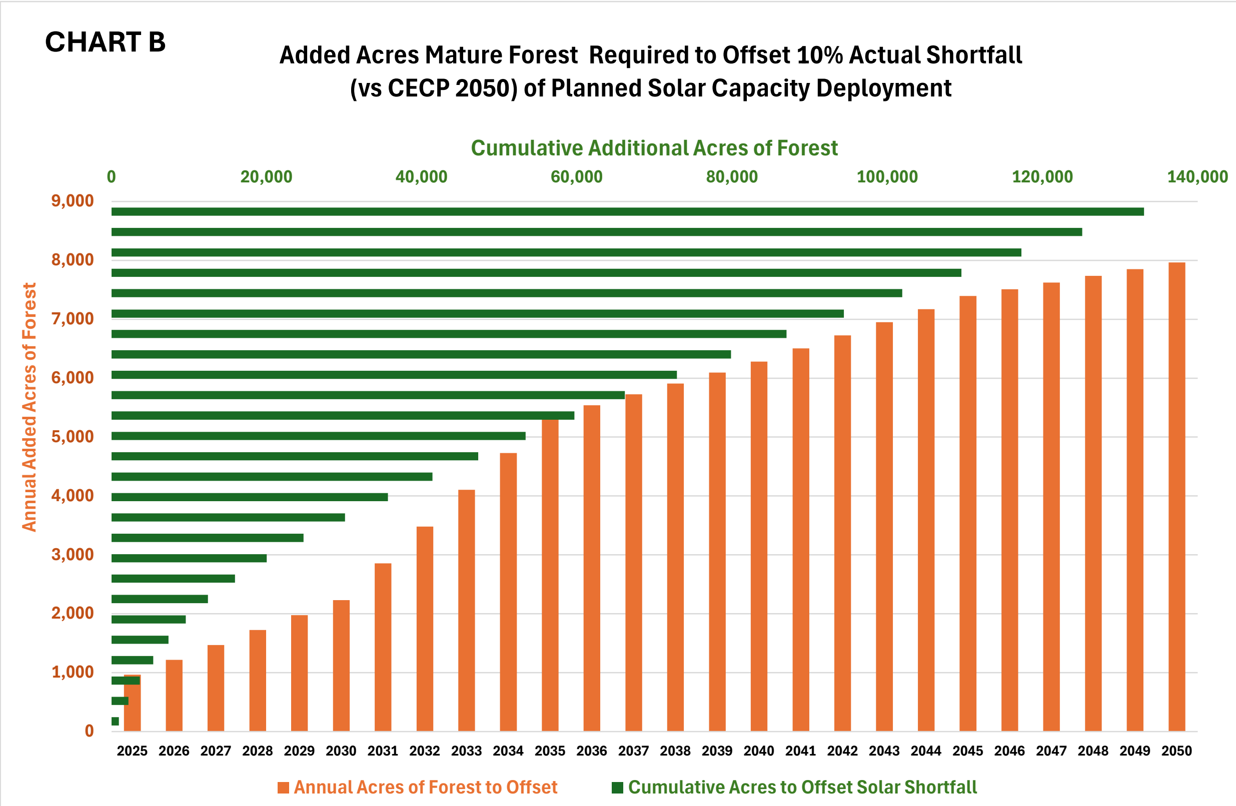
If we achieve only 90% of our annual electric sector GHG reduction targets over the next 25 years, Mass. will exceed its total electric sector budget by 26,615,646 MTCO2e – an amount 2.5 times the entire year 2025 electric sector carbon budget.[xx] The 2023 MTPS study noted that Mass.' needed to speed the annual rate of deployment of solar PV capacity from the recent plateau of 333 MW, to at least 1,000 MW. 2021 was the last year when Mass. deployed even 500 MW of solar capacity. The 2050 solar capacity target of 27-34 GW may also need to be significantly raised in the face of expected delays or termination of offshore wind development. While the state appears to be on target to meet or exceed the 3.7 GW wind target for 2030, the 2035 - 8 GW target is at serious risk given typical project development timelines and the likelihood that offshore leases and permits off the New England coast will be delayed at least until 2028.

The Mass. legislature and the Governor's climate/energy administration are in the process of designing and implementing a new regime of renewable energy infrastructure siting/permitting for mid-2026 and new solar generation incentive rules for later this year.[xxi] The overall net impact, i.e., the likelihood of these measures together boosting deployment to 1+GW annually – is yet to be seen. While a number of provisions are designed to increase rooftop and small ground mounted solar deployment, there are also key provisions which are meant to disfavor or restrict (for some valid purposes) large, or utility scale ground mounted solar. The big picture suggests that there is a considerable likelihood that Mass. will fall short of achieving its solar deployment targets in the years and decades ahead.

A reasonable follow-on question, then, is whether the intention of the state energy resources administration and its supporting cast of environmental organizations to prioritize and incentivize solar development on previously disturbed lands and buildings - at the expense of utility scale solar using 5% or less of Mass. forest lands - will get it right over the long run relative to staying within or even close to our 2025-2050 carbon budget. We've already shown how a minor 10% shortfall in achieving annual solar deployment targets through 2050 will blow the electric sector carbon budget cumulatively by 26,615,646 MTCO2e (17% above the 158 mil. MTCO2e 25-year budget).

The primary refrain of some 70% of those ~3,000 Mass. citizens who chose to respond to an online survey of public values and priorities as part of the state sponsored MTPS study (2023), [xxii] was – " if the objective of installing solar farms in the first place is to produce carbon free electrical energy, how can Mass. cut down forests which are the primary mechanism we have for sequestering and storing carbon?" A corollary question would be, what will be the demand for carbon sequestering forests in the year 2050 if Mass. falls 26,615,646 MTCO2e short on its target because it suffocates solar development in forests.

Chart B below illustrates the annual (begin 2025) and cumulative (end 2050) mature forest acreage that Mass. would need to "acquire" (add to its current forest inventory of 2.9 mil. acres) and protect for 30 years in order to offset the excess carbon emissions resulting from its falling short of solar deployment targets 10% each year to 2050. The total new forest acreage required - 133,000 – is not much less than the 150,000 acres proposed for dedication to utility scale solar development in the first place. The message**:** unless we are certain that solar deployment targets can and will be met with solar restricted to rooftops and previously disturbed land, we are at serious risk of jeopardizing the sufficiency of current forest inventory in netting Mass. carbon emissions at zero by 2050.



Conclusion:

According to the Massachusetts Audubon Society's webpage, "Climate change threatens every aspect of Mass Audubon's mission: the land we steward, the plants and animals we treasure, and the communities we serve." At the core of the Mass. 2050 Decarbonization Roadmap is the strategic proposition that – while the electric grid itself is currently the source of a significant share of the state's carbon emissions (~15%) – it can and must serve as the linchpin the Commonwealth's strategy to tame the dominant carbon spewing sectors - transportation and buildings. Electric vehicle deployment and building electrification on a mass scale will more than double electricity demand by 2050. Solar power along with wind power are the twin pillars of the state's grid decarbonization plan. Solar growth has stagnated over the past 5 years and wind targets are now at risk.

If we take to heart the Mass. Audubon case that climate change represents the single greatest threat to birds, and plant and animal habitat (not to mention human lives and well-being), we then need to maintain some perspective on what the battle to halt human-induced climate change will cost. What is it worth sacrificing to win this battle? This paper has made the case that we have the land (forest and other) necessary to deploy the required solar at pace – without sacrificing the strong overall position of forest lands in our state's ecosystems and public perception. To build our next 10-15 GW of solar, it will be both faster and much cheaper to contract with a few thousand willing landowners to site ground mounted solar than it will be to cajole and "incentivize" close to two million property owners into installing roof top solar. An honest accounting of the relative carbon fighting capabilities of solar farms based in forests - versus the forests left untouched - indicates sizable advantages for the former.

To identify and prioritize the protection of irreplaceable or highly sensitive lands, we can apply the collective knowledge of forest ecosystems represented by our state forestry experts, environmental scientists and landowners. This need not, and cannot, require a wholesale ban on solar development in some 2.5 million acres currently mapped as BioCore or Critical Natural Habitat land. By 2050, we require only 5% of our forests to achieve our solar goals – in tandem with quadrupling rooftop deployments. Over the coming 2-1/2 decades, a campaign to acquire and permanently preserve the additional 630,000 acres of NWL needed to meet the state's 40% protection goal might be financed via the savings to ratepayers, taxpayers and gov't. budgets which should occur if the state eschews a policy of forcing most solar onto rooftops and the built environment.

In the final analysis, there is insufficient desirable rooftop area to place all – or even the majority – of our eggs into the rooftop solar panacea basket; it can only be achieved, if at all, with a significant cost premium; it has and will continue to encounter substantial resistance or indifference within the property owning population; and, the rollout of rooftop will necessarily be slower than with the large ground mount/utility scale option.

End Notes: **(all GW or kW references in the body of paper or below are in AC unless specifically noted as DC.)**

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i ***Massachusetts Technical Potential of Solar (MTPS)*** study (Synapse Energy Economics, Inc. 2023) (Table 1, p. 5) https://www.mass.gov/doc/technical-potential-of-solar-in-massachusetts-report/download

ii ***Massachusetts Workbook of Energy Modeling Results*** – Tab 10, Electricity Generation New England - https://www.mass.gov/doc/massachusetts-workbook-of-energy-modeling-results/download
https://www.mass.gov/doc/appendices-to-the-clean-energy-and-climate-plan-for-2025-and-2030/download

iii ***Massachusetts Technical Potential of Solar*** study (Synapse Energy Economics, Inc. 2023) https://www.mass.gov/doc/technical-potential-of-solar-in-massachusetts-report/download (p. 27, footnote #27))

iv See https://www.canarymedia.com/articles/offshore-wind/scare-tactics-and-uncertainty-what-trumps-offshore-wind-order-means and,
https://www.permits.performance.gov/projects?title=&term_node_tid_depth=2941&term_node_tid_depth_1=2656&field_permitting_project_adpoint_administrative_area=MA&field_project_status_target_id=7011&field_project_category_target_id=All

v For example: MassSave's new 2025-2027 plan calls for approx. $5 bil. spending on home weatherization and energy efficiency programs - https://www.masssave.com/-/media/Files/PDFs/News/FINAL-MA-2025-2027-Plan-09_25_24-v2.pdf **or**, the recent sale of W.D. Cowls land to a New Hampshire timber company permanently preserves 2,400 acres in Franklin and Hampshire counties for a price of $20 mil. or $8,333.acre - https://www.kestreltrust.org/wp-content/uploads/2025/01/2025-1-8-Gazette-Lyme-Purchase.pdf

[vi] https://www.mass.gov/doc/technical-potential-of-solar-in-massachusetts-report/download, p17 and,
National Renewable Energy Laboratory. ***Rooftop Solar Photovoltaic Technical Potential in the United States*** (2016). Available at https://www.nrel.gov/docs/fy16osti/65298.pdf.

[vii] ***Massachusetts Technical Potential of Solar (MTPS)*** study (Synapse Energy Economics, Inc. 2023)
https://www.solarpowerworldonline.com/2016/06/much-less-efficient-north-facing-solar-modules/ or
https://www.solarreviews.com/blog/best-direction-orientation-solar-panels (-30% north facing panels)
https://www.sunrun.com/knowledge-center/best-direction-for-solar-panels another reference to 30% loss for north facing panels

Adjust Capacity Factor - Less Suitable Roof Area	
With "NREL" CF - 1.155kWh/kWdc or 13.2% CF	
Mass. TWh	26,000,000,000
Mass. GWdc	22,510,822,511
Mass. GWac	15,982,683,983
With CF - less 30% - .8103 kWh/kWdc or 9.25% CF	
Mass.TWh	17,910,000,000
Mass. GWdc	22,102,924,843
Mass. GWac	15,693,076,638

[viii] ***Massachusetts Technical Potential of Solar (MTPS)*** study (Synapse Energy Economics, Inc. 2023) -*Estimated Generation* p. 37 – Table 15) https://www.mass.gov/doc/technical-potential-of-solar-in-massachusetts-report/download

ix This 2050 TWh estimate diverges from the 2050 solar energy generation value of 46.83 TWh in the **Mass. Workbook of Energy Modeling Results** (Phased approach) due the Workbook's application of a 14.12% capacity factor versus the 13.2% NREL estimates for Massachusetts. I intend to rerun my calculations substituting 48.83 TWh for the 43.91 TWh used here, but this substitution will not diminish the points made both about the pace of capacity installation required to meet CECP 2050 goals or the share of total Mass rooftop required to meet solar generation targets.

[x] ***Massachusetts Technical Potential of Solar (MTPS)*** study (Synapse Energy Economics, Inc. 2023) -*Estimated Generation* p. 37 – Table 15) https://www.mass.gov/doc/technical-potential-of-solar-in-massachusetts-report/download

[xi] **Western Mass Solar Forum – September 12, 2023** Presentation Notes – Josh Hilsdon, PV Squared, ***Challenges of Solar Development in the Built Environment*** "~25% reduction in average residential solar array size, with smaller projects more dramatically impacted"; https://ag.umass.edu/clean-energy/solar-forum/session-2 and ***FINAL REPORT: LA100—The Los Angeles 100% Renewable Energy Study***, Chapter 4. Customer-Adopted Rooftop Solar and Storage (2021) Accounting for Effects of Fire Department Requirements. *The Los Angeles city fire department requires that permitted solar arrays installed in LADWP comply with Regulation 96, which specifies the minimum requirements for fire-compliant PV systems. In short, this regulation affects the configuration of a PV array on a rooftop for safe firefighting operation, typically, a 3-foot setback from the roof ridge and edges of the roof. These setbacks are intended to allow safe vertical ventilation techniques during a firefighting operation. Though NREL did not explicitly model the effect of this policy, NREL conducted a literature review and determined that the compliance with the policy is likely to reduce the amount of solar-developable roof area by 26%. Thus, a uniform derate fraction of 26% was applied to the developable area, generation potential, and capacity potential for all solar-suitable roofs. The derate factor was not applied to parking lot solar canopies.* https://www.nrel.gov/docs/fy21osti/79444-4.pdf.

527 CMR 1.00: Massachusetts Comprehensive Fire Safety Code. Available at https://www.mass.gov/doc/massachusetts-527-cmr-100-2021-edition-effective-february-3-2023/download

[xii] https://drive.google.com/drive/folders/1TKQAcmLxUbx2Zs13iljfYmPjd8bQWN6l; see filename: ***C-PTS-solar-pv-in-mass-as-of-feb-2024jpAnalysi.xlsx***, and tab named ***SumCostbySizeClass.*** This table is based on the sorting and tabulation of installation cost ($/watt) by kWac size range (1 worksheet tab each can be found in same file) for the period 2018-2024 as provided by the Mass. Production Tracking System database.

xiii Based on MTPS cited value of 69 MWAC per square kilometer or 3.6 acres/MWac. MTPS was citing Bolinger, M., and G. Bolinger. 2022. "***Land Requirements for Utility-Scale PV: An Empirical Update on Power and Energy Density***," in IEEE Journal of Photovoltaics, vol. 12, no. 2, pp. 589-594, doi: 10.1109/JPHOTOV.2021.3136805. See Figure 3 and Section IV.

xiv At the same time, the "forests are sacred and untouchable" camp fails to acknowledge that their rooftop first commitment necessarily involves massive tree removal or canopy pruning in order to make solar productive enough to become viable (i.e., economically competitive for the majority of income brackets) on the 60-90% of all Mass. rooftops where it will be need to be installed to site 32 GW and generate 44TWh called for by CECP 2050. A back of the envelope calculation for residential rooftops only: (2 mil. roof sites x aver. 1-2 trees/site = 2-4 mil. trees @ 300 trees/acre (aver. age/maturity forest) = 7,000-13,000 acres worth of trees. In New England, one cannot hold that trees and forests are sacred and indispensable and yet still maintain that solar is a pillar in the state's renewable energy strategy and that it will mostly have to be placed on rooftops. (MTPS, p27, Table 13 indicates 1,878,188 parcels with roofs)

xv See ***ModelBestCase*** worksheet tab in file: ***UtilityScaleSolarVsForestLeftAloneDraftforReviewJohnPepi -*** *the Cell e36' value of 3,639 MTCO2e/acre over 30 yr. lifetime is rounded down here to 3,500.* https://drive.google.com/drive/folders/1TKQAcmLxUbx2Zs13iljfYmPjd8bQWN6l

xvi See file: ***UtilityScaleSolarVsForestLeftAloneDraftforReviewJohnPepi*** and ***ForestCO22Storage3Sources*** worksheet tab. https://drive.google.com/drive/folders/1TKQAcmLxUbx2Zs13iljfYmPjd8bQWN6l

xvii ***Final 2050 CECP 12.21.22.0pdf , see Chap. 5C, Table 5C-1 Power Sector Sublimit for 2050*** at https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2050#2050-emissions-limit-and-sublimits Also see - ***CECPSolarShortfalltoMMTCO2e&ForestAcres7-29-24then12-27-24****, Column E,* for the annual interpolation and sum of the 2025 and 2050 electric sector sublimit values -157,950,000 MTCO2e. This is the Mass. electric sector carbon budget through 2050 at https://drive.google.com/drive/folders/1TKQAcmLxUbx2Zs13iljfYmPjd8bQWN6l

xviii https://unfccc.int/sites/default/files/resource/AHG-003_Guideline_on_GHG_Accounting_and_reporting_1Jun_.pdf
The IFI-TWG is affiliated with the UNFCC and consists of 26 international development banks including the World Bank, Inter-American Development Bank, European Investment Bank and the UNFCC Secretariat.
see ISO-NE-*QueueReport_20240502124047.xlsx*
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xix See: "***Answering an unnecessary question: What are the carbon tradeoffs between forest and solar?"*** Jonathan Thompson and Lucy Lee, Harvard Forest, at Western Mass. Solar Forum Session 2: Solar and Land Use in Ma., October 2023: https://ag.umass.edu/clean-energy/solar-forum/session-2 For the interactive carbon calculator, see https://harvard-forest.shinyapps.io/carbon-calculator/

xx see - *CECPSolarShortfalltoMMTCO2e&ForestAcres7-29-24then12-27-24, Column I, for annual budget exceedance in MTCO2e based on 10% shortfall in achieving CECP annual targets. This calculation applies the value 750lbs/MWh for a grid emissions factor.* https://drive.google.com/drive/folders/1TKQAcmLxUbx2Zs13iljfYmPjd8bQWN6l, https://www.canarymedia.com/articles/offshore-wind/scare-tactics-and-uncertainty-what-trumps-offshore-wind-order-means; https://www.permits.performance.gov/projects?title=&term_node_tid_depth=2941&term_node_tid_depth_1=2656&field_permitting_project_adpoint_administrative_area=MA&field_project_status_target_id=7011&field_project_category_target_id=All

xxi "An Act promoting a clean energy grid, advancing equity and protecting ratepayers" or the Renewable Energy Infrastructure Permitting & Siting law, which, at line 518, allows local gov't, to set fees for compensatory mitigation ..... and, at line 500, sets standards for applying site suitability guidance to evaluate social and environmental impacts –

which shall include a mitigation hierarchy. https://malegislature.gov/Bills/193/S2967_ and, the new proposed SMART rules found at: https://www.mass.gov/doc/2024-smart-straw-proposal/downloadt

see – *"Land Use Eligibility - Greenfield Subtractor:*

• Ground-mounted projects >250 kW AC on Important Agricultural Farmland or undeveloped land that do not qualify for a locational adder will receive the Greenfield Subtractor.

• All projects will receive a flat subtractor of $0.06/kWh plus an acreage-based subtractor of $0.004/acre impacted by the footprint of the project. – The acreage calculation will include the footprint of the solar panels and the footprint of land impacted by associated construction activities, such as clearing, grading, and shading prevention."

xxii Environmental activists, legislators, state planners and the media alike frequently place unwarranted confidence on the results of this online survey – one that was neither random nor representative. According to the Massachusetts Audubon Society:

> "Public opinion is clear: Massachusetts residents support a solar build-out that is balanced with nature and agriculture. A 2022 survey by the Massachusetts Division of Energy Resources (DOER) found that over 85% of residents believe that the state should strive to site solar on rooftops, parking lots, landfills, and other developed lands, rather than continuing to clear forests and convert productive farmland"

As to the survey's 3,000+ respondents, one can only wonder if their enthusiasm for the protection of natural and working lands at the expense of solar development would not have been tempered by access to some of the information and analysis presented above. If nothing else, the survey likely captured the outlooks of environmental and NIMBY activists, environmental organization membership and some industry participants.

The MTPS study itself acknowledges: –
"Although the survey was open to all residents of Massachusetts, the results of the survey are not scientific or representative of all residents. Instead, it is likely that the responses came from people interested in the development and siting of solar."
https://www.mass.gov/doc/technical-potential-of-solar-in-massachusetts-report/download see Appendix A