The Case Against Placing All the Commonwealth's Eggs in the Rooftop Solar Basket (5/19/25)

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This brief paper reviews and challenges the widely publicized study estimate that Massachusetts has 40 GW[1] 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[2,3] 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 critical today as Mass. is increasingly challenged on its path toward the 2050 target of 23.4 GW[4] 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[5] of offshore wind operating or under development that is relatively safe from the above efforts to stymie it. Challenges to wind energy project development pre-dating the Trump administration include: cost increases associated with supply chain bottlenecks, the elevated cost of capital, inter-connection delays and extraordinary costs of legal challenges. 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, the prospects for solar deployment in Massachusetts are 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 vs 40 GW. As a result, there is little margin for error or slack (i.e., failing to install +1GW/year from 2023 on) in targeting the next 15-20 GW of solar deployment.

b) A state policy to develop all or most of that as 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. And it 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 those potential cost savings toward permanently protecting the NWL deemed so essential by state environmental agencies and private environmental organizations.[6]

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.

From Nut Shell to Tree:

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

(Read before continuing: While critical to the argument of this paper, section "**a)**" is relatively 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 - Mass. Roof Area Available and Required to Meet State Solar Targets.** The step-by-step logic and math of this review of technical roof-top solar potential (#1-9 below) can be followed in **Table 2 – Meeting the 2050 CECP Roof-Top Solar Goals: Capacity, Generation and Roof Area Needs.**

1. The 2023 MTPS study determined that the available Mass. rooftop area for locating solar PV equals 482.3 mil. m^2 – based on the MassGIS Building Layer.
2. Based on two similar estimates for rooftop area lost to solar deployment due to the anticipated implementation of the national fire regulations covering solar installations[7], this analysis deducts 25% of the 482.3 mil. m^2 with the resulting value of 362 mil. m^2 now maximally available for solar installations.
3. The MTPS relied on the National Renewable Energy Labs (NREL 2016) study *Rooftop Solar Photovoltaic Technical Potential in the United States* – specifically for its estimate of how much solar power capacity could be installed per unit of roof area (MW/km^2, or kW/m^2) - the packing factor or PF. [8]
4. The MTPS derived an average PF of 117 MWdc/km^2 (or 83 MWac/km^2) and applied it the MassGIS Building Layer figure of 482,229,000 m^2 for a result of 40 MWac (56 MWdc) of rooftop solar potential.
5. The NREL 2016 study assumed a 16% module efficiency, but the NREL has recently updated the module efficiency level to 20% for 2023.[9] This 25% increase means that 123.8 mil. m^2 of Mass. rooftops will be required to host 16 MWac/22.5 MWdc/26 TWh/yr instead of the original 165 mil. m^2 estimated in 2016. This 26 TWh is 18 TWh lower than the total annual 44 TWh projected by the Mass CECP for 2050. [10]
6. The dedication of 123.8 mil. m^2 of Mass rooftop with a projected capacity of 22.5 MWdc leaves a total of 238 mil. m^2 of rooftop with which to attempt to locate solar capacity capable of supplying the additional 18 TWh needed.
7. The question becomes – What quantity of solar capacity is required to generate the required 18 TWh, and how much of Mass. remaining rooftop area will be needed to support that generation? The NREL study estimated an average capacity factor (CF)[11] for Massachusetts of 13.1% after eliminating solar placement on roof areas oriented north/northeast/northwest 135 degrees (of the 360 degree compass), eliminating roofs with 60% or greater slope; adjusting for shading from roof obstructions, trees and nearby buildings and ensuring that any shaded roof area included would allow the panel to achieve at least 80% of the efficiency it would achieve with unimpeded solar radiation.

The problem is that the 13% capacity factor cannot apply to the remaining NREL' defined unsuitable or less suitable rooftops including those falling between 292.5-67.5 degrees (northeast/north/northwest azimuths) of the compass, or south/west/east oriented rooftops which were rejected as unsuitable due to excessive tilt, shading or other obstructions. Multiple technical sources suggest a 30% capacity factor penalty for these roof areas. Deducting 30% from the NREL' 13% capacity factor[12] for suitable roof area results in a 9% capacity factor. Working backwards from the TWh requirement, 22.5 GWdc of additional solar capacity, with a 9% capacity factor applied, will supply the needed 18 TWh/yr. The roof area required to locate this additional 22.5 GWdc of solar is equal to the roof area for the first 22.5 GWdc tranche of solar located on "suitable" roof areas – 123.8 mil. m^2.

8. Adding the original NREL 22.5 GWdc and 26 TWh/yr. estimates to the Pepi estimates of 22.5 GWdc and 18 TWh/yr, gives the total of 45 GWdc and 44 TWh/yr. The value of 44Twh/yr., once again, is the Mass. CECP total solar generation target for 2050.

9. The combined Mass. roof area requirements for the two estimates (NREL for the first - 22.5 GWdc and Pepi for the additional - 22.5 GWdc) is 248 mil. m^2. As shown in **Table 1**, this represents 51% of all technically available Mass rooftop area and 69% of the technically available roof top after accounting for fire code implementation impact .

Table 1 - Massachusetts Rooftop Area Available and Required to Meet State Solar Targets	
Rooftop Area m^2	
482,229,000	State Total from MassGIS building Layer
361,671,750	State Total from MassGIS Building Layer Minus 25% for Fire Code Restrictions
248,000,000	State Solar Rooftop Area Required to Meet Mass. Net-Zero 2050 Plan Target
165,000,000	National Renewable Energy Lab (NREL) 2016 Estimate of Suitable Mass. Rooftop Area
69%	Rooftop Area Required for Solar Over Total Mass *Available* Rooftop Area (with fire code restrictions)
51%	Rooftop Area Required for Solar Over Total MassGIS Rooftop Area (no fire code restrictions)
34%	Rooftop Area Classified "Suitable" by NREL Over Total Mass Available Rooftop Area

This emerging picture of the possible extent of roof coverage by solar appears wildly optimistic when roof age, roofing material, building tenure, owner priorities, competition for roof space and, finally, owner financing and payback considerations are addressed. These are all limiting factors for likely ultimate roof-top solar deployment which were noted in the MTPS but for which no adjustment to the 40GW technical potential estimate was provided.[13]

Table 2 - Meeting CECP 2050 Rooftop Solar Goal: Capacity, Generation and Roof Area Needs						
Row/	Source/Estimate Type	Col. 1 Capacity GW-ac	Col. 2 Capacity GW-dc	Col. 3 Capacity TWh	Col. 4 Mass. Roof Area Million M^2	Col. 5 Roof Area % Over MassGIS
A	MTPS Estimates(2023)	40	56	46	482	100%
B	Pepi - NREL/PVSquared Estimated - Fire Code Roof Area Loss of 25%	n.a.	n.a.	n.a.	362	75%
C	CECP 2050 Required(2022)	27	38	44	n.a.	n.a.
D	NREL TPRS-US (2016)	16	23	26	165	n.a.
E	Pepi-Update NREL: 25% increase in Panel Efficiency (2016-2023)	16	23	26	124	n.a.
F	Pepi-Net of NREL Estimate (Row C - Row D)	11	16	18	238	n.a.
G	Pepi-Net 18 TWh @ 30% Lower Capacity Factor	16	23	18	124	n.a.
H	Pepi-Totals to Achieve CECP 2050	**32**	**45**	**44**	**248**	**69%**
I	Remaining Roof Area After Meeting CECP 2050	n.a.	n.a.	n.a.	114	32%

b) Costs Matter – Including Opportunity Costs.

(From this point forward - all GW or kW references below are in AC unless specifically noted as DC.)

Should the state move to restrict and disincentivize forest for solar deployment, the cost premium paid by Mass. taxpayers and ratepayers amounts to potentially $ 17.3 billion dollars. Table 3 values for Cost$/Wattdc were derived from Mass. Production Tracking System data for solar installed between 2018-2024.[14] Table 3 shows the cost of two possible mixes of solar placement - each of which meets the CECP 2050 requirement of 44 TWh (Table 1 – Row H). The two options vary the proportion of large/utility ground mounted, rooftop/canopy and small ground mount solar in the total mix. The first option **(highlighted in green)** tallies the costs emphasizing rooftop and canopy solar (16 GW) over large utility scale solar (8 GW) – a scenario that reflects the public statements of the Healey administration and several Massachusetts environmental groups. The second option (**highlighted in blue**) reflects the Mass. 2050 Decarbonization Roadmap (Energy Pathways Rpt.)[15] with its emphasis on large ground mounted solar (16 GW) versus rooftop solar (8 GW).

Table 3 - Cost Premium For Roof-top Solar Priority Over Utility Scale Solar Priority				
	GWac	GWdc	$ Cost/Watt	Total $ Cost
Emphasis on Roof-top and Small Scale Solar				
Roof-top and Canopy	16	22.4	$3.75	$83,812,500,000
Small Ground Mount solar (GMS)	8	11.3	$2.59	$29,189,300,000
Large GMW -Utility Scale	8	11.3	$2.19	$24,681,300,000
Totals	**32**	**44.9**		**$137,683,100,000**
Emphasis on Large GMS & Utility Scale Solar				
Roof-top and Canopy	8	11.3	$3.75	$42,262,500,000
Small Ground Mount solar (GMS)	8	11.3	$2.59	$29,189,300,000
Large GMW -Utility Scale	16	22.4	$2.19	$48,946,500,000
Totals	**32**	**44.9**		**$120,398,300,000**
Cost Premium for Roof-Top Solar Policy Priority				**$17,284,800,000**

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 5-10x advantage [16] of solar over forest in **offsetting** electric grid carbon emissions. They each offset emissions, solar by preventing emissions produced by fossil fuels and forest by sequestering emissions already released. Yes, the world should seek to not lose ground on natural carbon sequestration and storage capacity as well as to develop responsible forms of non-natural carbon sequestration and storage. Yet, given the unequal rate at which solar and other renewables close down the CO2e spigot relative to the rate at which forests can pull CO2e out of the atmosphere, we must look ahead to the net contribution of each over the next 25 years to the struggle to meet our 2050 carbon budget. [17]

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[18] whereas middle aged (mature) New England forests on average will sequester 60 MTCO2e/acre over the same 30 years.[19] Table 4 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</u>

burden.[20]

Table 4		Comparative Carbon Budget Impact of 1-150,000 Acres of Solar PV versus Forest					
Acres PV GMS		MTCO2e Mitigation (30 yrs)		MTCO2e Mitigation (30 yrs)		MTCO2e Mitigation (30 yrs)	
1		3,563 *Best		2,485 *Moderate		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 (over 30 yrs.)		MTCO2e	MTCO2e	MTCO2e	MTCO2e	MTCO2e	MTCO2e
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 Mass MTCO2e 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)

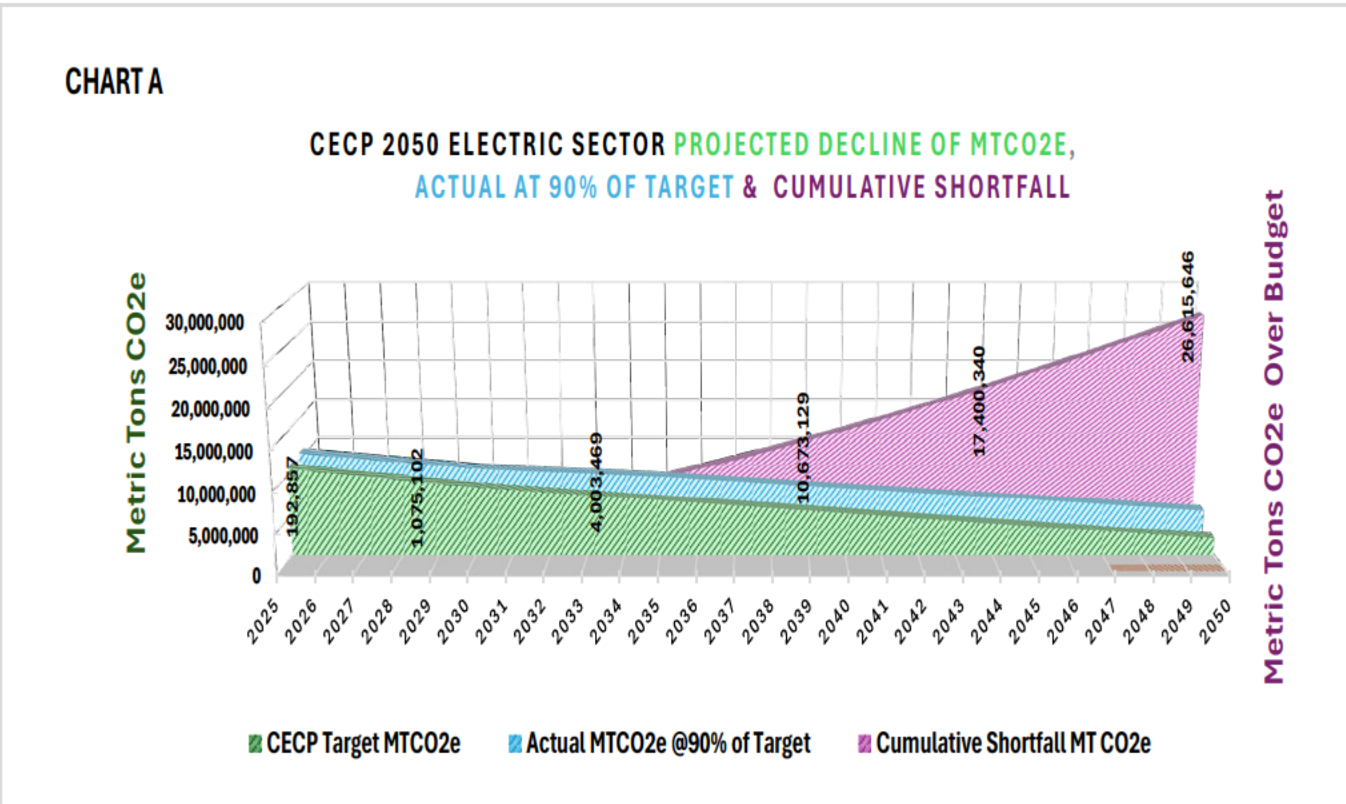
27.41% Best PV mitigation for 150,000 acres over Mass. 30 yrs. @ current GHG generation

19.1% Moderate Case Mitigation - 150,000 acres over all Mass CO2e emissions = 65 MMTCO2/yr

*From 50-150,00AcresComp tab in Google Drive file: UtilityScaleSolarVsForestLeftAloneDraftForReviewJohnPepi7-10-24

This approach to valuing the grid CO2e emissions offsets from solar energy is supported by the *Methodological Approach for the Common Default Grid Emission Factor Dataset* from the ***International Financial Institutions (IFI) Technical Working Group on Greenhouse Gas Accounting***[21] - a partner to the UN Framework Convention on Climate Change (UNFCCC). In estimating electric grid carbon emission factors, the IFI Greenhouse Gas Accounting Protocol methodology places the greatest weight on the highest cost/highest emitting, **marginal**, fossil fuel contributors to grid power rather than the **average** grid emissions value emphasized by the widely cited *Harvard Forest* (HF) Carbon Calculator.[22] 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 (900-1300/lb CO2e/MWh) fossil fuel power sources. The IFI common methodology is utilized worldwide by agreement of major international banks and finance agencies in the assessment of climate impacts for energy and other development projects. It employs a Combined Margin (CM) formula consisting of an Operating Margin made up of fossil fuel grid contributions (weighted 75% and typically in the range of 1,000-1,200 lbs/MWh) and a Build Margin made up of energy projects in development pipeline, 1- 8 years into the future (assigned 25% weight).

The current CM value for ISO N.E. computes to approximately 750 lbs. CO_2e/MWh based on a review of ISO-NE projects currently in the pipeline.[23] 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 respond over time with the changing inputs to the electric grid. However, since this 750 lb. CM grid emissions factor for Massachusetts already reflects future renewable energy 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 numerous possible causes Massachusetts should only achieve 90% of its additional solar deployment target annually, the resulting single year emissions surpluses might be unimpressive. Yet, such seemingly minor annual shortfalls - taken together over a 25-year period - contribute to a surprisingly outsized effect on Mass.'s 2020-2050 carbon budget. It is worth a reminder here, that adherence to the planned CO_2e budget for 2050 (regionally, nationally and world-wide) determines whether humankind slows the earth's rise in average temperature to 1.5 Celsius by the year 2050 and the degree of both weather extremes and unpredictability. While it is arguably a hypothetical and optimistic construct, it is nevertheless a necessary one in order for Massachusetts to quantify its societal obligation and to proceed in a good faith, coordinated approach with other state and international jurisdictions.

Chart A illustrates that if Massachusetts achieves only 90% of our annual electric sector CO_2e 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.[24]

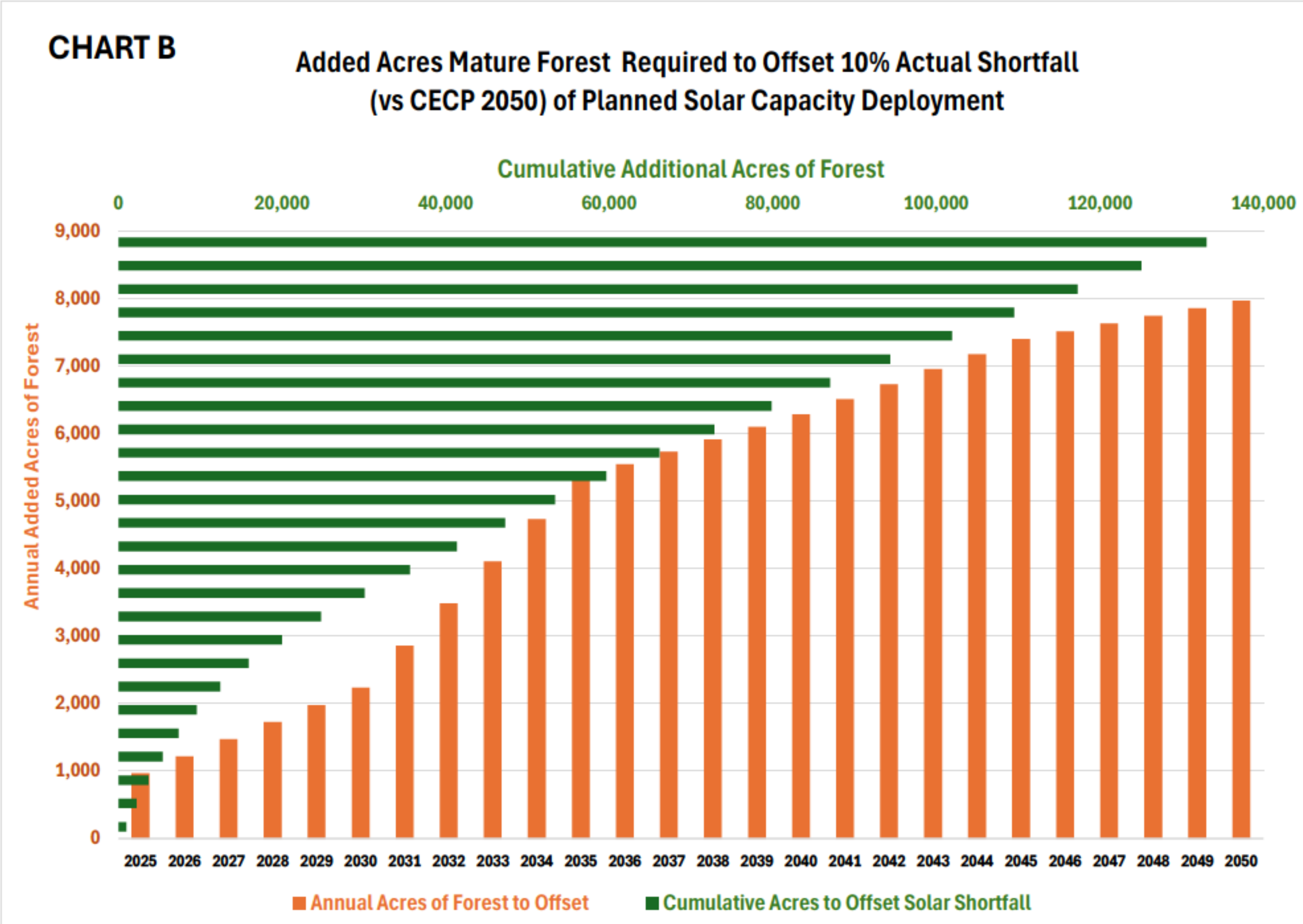
The 2023 MTPS study noted that Massachusetts needed to speed the annual rate of deployment of solar PV capacity from the recent plateau of 333 MW, to at least 1,000 MW. 2021 was the last year when Mass. deployed even 500 MW of solar capacity. The 2050 solar capacity target of 27-34 GW itself may need 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 state'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.[25] The overall net impact, i.e., the likelihood of these measures together boosting solar deployment to 1+GW annually – is yet to be seen. While several new provisions are designed to increase rooftop and small ground mounted solar deployment, there are also key provisions which are meant to disfavor or restrict (in certain cases -for 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 intentions of the state energy resource 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. Will this strategy keep Massachusetts within or even close to our 2025-2050 carbon budget? It has already been demonstrated 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 oft-cited concern of some 70% of the approximately 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, [26] was – "if the objective of installing solar farms in the first place is reduce the state's grid carbon emissions, how can Massachusetts cut down forest which is the only natural system available 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 our current forest inventory in netting Massachusetts carbon 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 in 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 considerably 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 basket. It can only be achieved, if at all, with a significant cost premium. The rollout of a rooftop only program will necessarily be slower than one relying on the large ground mount/utility scale option. And, finally, the rooftop strategy has and will continue to encounter substantial resistance or indifference within the property-owning population.

(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. He would be happy to clarify or elaborate for you at giannipepi@gmail.com).

End Notes:

[1] ***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

[2] ***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

[3] ***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)

[4] ***Massachusetts Workbook of Energy Modeling Results***: Tab 8. - Electrical Capacity New England https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2050?_gl=1*ozgc0w*_ga*NDI1MjQwNzI5LjE1OTY0MDg4Mzk.*_ga_MCLPEGW7WM*czE3NDcyMzY1NTMkbzEwJGcxJHQxNzQ3MjM2NzMwJGowJGwwJGgw

[5] 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

6 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

7 This loss of available roof-top area was acknowledged but not estimated in MTPS study. For estimates, see - **Western Mass Solar Forum – September 12, 2023** Presentation Notes – Josh Hilsdon, PV Squared, ***Challenges of Solar Development in the Built Environment*** "ii. Fire setbacks (New for 2023!) ~25% reduction in average residential solar array size, with smaller projects more dramatically impacted"; https://ag.umass.edu/clean-energy/solar-forum/session-2 ; 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

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.

8 **MTPS**, p17 at https://www.mass.gov/doc/technical-potential-of-solar-in-massachusetts-report/download, 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. And, packing factor (PF) "May refer to either the fraction of the total photovoltaic panel area occupied by a PV cell (for a solar panel), or the fraction of the actual building envelope or land area occupied by a solar array (for the whole solar system)." from - https://list.solar/guide/solar-glossary/packing-actor/

9 "These results are sensitive to assumptions about module performance, which is expected to continue improving over time. For example, this analysis assumed a module efficiency of 16% to represent a mixture of various technology types. If a module efficiency of 20% were assumed instead, which corresponds to current premium systems, each of the technical potential estimates would increase by about 25% above the values stated in this report." (p. VII), ***Rooftop Solar Photovoltaic Technical Potential in the United States*** (2016). Available at https://www.nrel.gov/docs/fy16osti/65298.pdf

10 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. See CECP 2050 - Additional Resources at: https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2050?_gl=1*aou8v3*_ga*NDI1MjQwNzI5LjE1OTY0MDg4Mzk.*_ga_MCLPEGW7WM*czE3NDcyNDM2NTUkbzExJGcwJHQxNzQ3MjQzNjU1JGowJGwwJGgw

11 "**Capacity factor:** The ratio of the electrical energy produced by a generating unit for the period of time considered to the electrical energy that could have been produced at continuous full power operation during the same period." Found at https://www.eia.gov/tools/glossary/index.php?id=Capacity_factor

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

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

13 Again, "technically available" as used in the MTPS study, versus economic potential. "It is important to note that the only suitability criterion applied to rooftop and canopy solar was electric infrastructure. There are several other key barriers to rooftop and canopy solar development that were not included in this analysis. Therefore, the estimated highly suitable potential of rooftop and canopy solar development is likely to be overestimated." p27 MTPS. And, "As previously mentioned, the Grid Infrastructure suitability category only considered proximity to substations and did not account for current hosting capacity. Therefore, the estimate of highly suitable rooftop solar potential is likely to be an overestimate based on current hosting capacity. P46, Footnote 64 - MTPS

When asked by ***The Energy Transition* Show** host Chris Nelder -
"is there any sort of like mental shortcut, mnemonic or rule of thumb that you bear in mind when you think about the difference between technical and economic potential?", Robert Margolis, lead author of the NREL 2016 study - ***Rooftop Solar Photovoltaic Technical Potential in the United States**, responded,*
"There's not a general rule of thumb. I think it would be on a case-by case basis. So, I would typically discount it somewhere between 50 to 80%. But that's a pretty big range.". (The Energy Transition Show podcast, Episode #229 – US Distributed Solar Potential -July 24, 2024)

14 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.

15 **Energy Pathways to Deep Decarbonization:** ***A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study (December 2020) p 54., Figure 23 - Massachusetts annual electricity supply by resource type for all pathways. Found at:*** *https://www.mass.gov/info-details/ma-decarbonization-roadmap#final-reports-*

[16] 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.

[17] 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)

[18] 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

[19] See ***ForestCO22Storage3Sources*** worksheet tab in file:
UtilityScaleSolarVsForestLeftAloneDraftforReviewJohnPepi
https://drive.google.com/drive/folders/1TKQAcmLxUbx2Zs13iljfYmPjd8bQWN6l

[20] ***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

[21] 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*

[22] 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/

[23] For the 5-16-2025 IOS-NE Queue Report see https://irtt.iso-ne.com/reports/external ; projects scheduled to come online between 2025 and 2032 are 99.9% renewable energy (excluding standalone battery plants). A typical mix of natural gas power plants, including combine-cycle, non-combined cycle and peaker plants warrant the application of 1,000 lbs/CO2e per MWh to the Operating Margin side of the Combined Margin formula.

[24] 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

25 "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."*

26 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