INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH
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GOLD ON THE ROOF:

THE ECONOMICS OF A NET-ZERO-ENERGY ROOFTOP SOLAR MANDATE FOR NEW RESIDENTIAL HOUSING IN MONTGOMERY COUNTY, MARYLAND

Arjun Makhijani, Ph.D.

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Contents

Preface and Acknowledgements

This report is a publication of the Solar Democracy and Equity Collaborative, funded by the Town Creek Foundation. It was prepared by the Institute for Energy and Environmental Research, which is a member of the Collaborative; its other members are Civic Works, Climate Access Fund, Earthjustice, Montgomery County Green Bank, and Solar United Neighbors.

The Collaborative "is committed to making decentralized solar energy generation a significant part of the future of the energy landscape in Maryland." Its objectives are to:

1. "Establish a durable policy framework for both single family and community solar."
2. "Create market-making pathways for urban rooftop solar installations for LMI [low- and moderate-income] households."
3. "Implement a replication infrastructure that focuses on extending the framework and pathways to the whole state."

The announcement in 2019 by Montgomery County Executive Marc Elrich of an intent to require rooftop solar on new residential construction provided the occasion for the analysis in this report, following as it did the county's declaration of a climate emergency in 2017. Examining whether rooftop solar is economical for new residential construction provides the policy and technical insights for making progress on all three objectives. Equitable access to solar by low- and moderate-income is a principal goal of the Collaborative; it is examined in the context of new construction in this report.

Overall, this report takes a rather conservative view in assessing the economics of a rooftop solar mandate. Certain costs, like the added costs of gas connections and internal piping for a gas-heated home are not included. The rapid decline of residential solar costs is not included. A sensitivity analysis is done to ensure that the conclusion is robust across a wide range of assumptions. This approach ensures that policies based on the analysis in this report will remain economically sound and contribute to the economy and health of the people of the county and to its climate goals.

I would like to thank my colleagues in the Collaborative and the reviewers of this report. A draft of this report has been discussed by Collaborative members. I would especially like to thank Corey Ramsden of Solar United Neighbors and Susan Miller of Earthjustice for their insights on policy and regulatory issues. A draft of this report was also reviewed by David Murray (MDVSEIA), by a builder in Montgomery County, as well as by Montgomery County staff members Adriana Hochberg, Stan Edwards, Brian Bomer, and George Muste. Their comments have helped make this a better report. As reviewers, they bear no responsibility for the report's contents, analysis, conclusions, and recommendations; they may or may not agree with them. The responsibility for this report in its entirety, including its assumptions, analysis, conclusions, recommendations, and any errors or problems that may remain, rests entirely with me, the author.

Finally, I am deeply grateful to the Town Creek Foundation, whose grant enabled this report. It was among the final grants made by the Foundation before it closed its doors at the end of 2019.

Cover photo: Courtesy of Solar United Neighbors

Arjun Makhijani
President, Institute for Energy and Environmental Research
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Executive Summary[1]

This report compares the economics of a solar rooftop mandate for new detached residential homes with a conventional home with gas heating and central air-conditioning. The home with rooftop solar is assumed to be an all-electric, net-zero-energy home that would generate as much solar electricity on its rooftop each year as it uses. The gas-heated home would be built to the same standard in all respects other than the gas space and water heating and gas cooking are replaced by efficient electric devices in the net-zero-energy home. The context is Montgomery County's 2017 ambitious climate emergency resolution and a more recent statement by County Executive Marc Elrich about the possibility of a rooftop solar mandate. The County's goal is to reduce greenhouse gas emissions by 80% by 2027 and achieve 100% elimination of emissions by 2035.

a. Main findings

- **New net-zero-energy detached homes would have lower energy costs than new gas-heated homes**: New net-zero-energy detached homes with rooftop solar have lower energy costs (including the costs of solar) than new gas-heated homes. Annual average savings over the life of a 30-year mortgage would be about $1,200 per year relative to a gas-heated house built to the same overall standards for a 3,500 square foot detached home and about $800 per year for a 2,400 square foot home. *A large part of the economic advantage derives from the mandate itself, which would reduce the costs of rooftop solar compared to custom retrofits.*
- **The conclusion that new net-zero-energy detached homes have lower energy costs is robust**: Sensitivity analyses varying mortgage rates, rooftop solar system costs, loss of net metering, rate of inflation of purchased electricity and natural gas, electricity rates, and the Energy Use Intensity show that the conclusion that new net-zero-energy solar homes have lower energy costs than gas-heated homes is robust. The sensitivity analysis is summarized in Figure ES-1 below. It is noteworthy that the analysis assumes no federal income tax credit for the solar installation. That credit is due to expire in 2021 for residential construction and may or may not be renewed. It also does not take into account that the cost of rooftop solar is declining.[2] Therefore, over time the energy cost savings in a net zero home are very likely to be greater than those shown in Figure ES-1.
- **Builders would save money on interest costs during construction by using Maryland's program for promoting efficient homes.** The Department of Housing and Community Development offers construction loans at low interest, with the interest rate declining with increased performance. For a net-zero home, the interest rate offered is 2%, which is significantly lower than commercial construction loan rates. Assuming a six-month construction period, builders would save about $2,000 in interest costs for a 2,400 square foot home and about $3,200 for a 3,500 square foot net-zero home.
- **Greenhouse gas emission reductions over time of a net-zero-energy policy for new detached homes will be substantial.** If a total of 20,000 new net-zero-energy detached homes are built in over the next decade, the cumulative avoided carbon dioxide equivalent (CO_2e) emissions over

[1] References to the material in the Executive Summary are in the main body of the report; they are not repeated here. Dollar values in this summary are rounded.

[2] The National Renewable Energy Laboratory Annual Technology Baseline estimates that the cost of residential rooftop solar will decline between 1.2% per year and 7.6% per year from 2019 to 2025 depending on the rate of innovation, with the decline continuing during 2025-2030. NREL ATB 2020, Solar PV Residential Worksheet.

the typical 30-year mortgage period of these homes would be between 3.3 million and 4.9 million metric tons. For comparison Montgomery County's residential sector CO_2e emissions in 2018 were 2.53 million metric tons. The cumulative energy cost savings would be more than $700 million over the same period (ignoring likely cost decreases in rooftop solar, which would increase the savings).

- **A net-zero mandate would avoid large amounts of climate damage while saving consumers money.** The damage from an added unit of CO_2e emissions is known as the social cost of carbon; the Intergovernmental Panel on Climate Change noted in a 2018 report that a value of over $100 per metric ton could be supported. At $100 per metric ton,[3] the cumulative social benefit of avoided emissions from these 20,000 homes would be between 330 million and 480 million dollars over the 30-year period of their mortgages.
- **New natural gas-heated homes would cause significant harm to climate, health, and consumers.** Homes are meant to last much longer than the 15-year time horizon of Montgomery County's timetable for eliminating greenhouse gas emissions. Allowing new homes with natural gas connections and equipment therefore risks incurring significant unnecessary costs to meet the County's 2035 climate target. If new gas distribution infrastructure is needed, consumers would also be faced with the stranded costs of that infrastructure. In addition, natural gas use, notably for cooking, causes more indoor air pollution than all-electric homes, all other things, like ventilation, being equal.
- **The equity issues created by the higher initial cost of net-zero energy homes can be easily overcome.** The increased first cost of a net-zero-energy home would create an additional obstacle for low- and moderate-income households to own a home if not offset by suitable policies. At 20%, the down payment increase would be about $5,200 for a 3,500 square foot home, and about $3,000 for a 2,400 square foot home. A direct cash incentive can address the potential inequity. For comparison, the current state incentive for residential geothermal heat pumps is $3,500 ($3,000 from the state and an additional $500 provided by utilities). This incentive is provided regardless of income level of the homeowner.
- **Homeowners typically recover the cost of rooftop solar at the time of sale:** Many homeowners do not stay in their homes for the full 30-year duration of a typical mortgage. As a first approximation, the added cost of solar is typically recovered at the time of sale, according to data collected by the real-estate firm Zillow.
- **Net-zero-energy mandates can be economical for other types of new construction but significant issues need to be resolved to make them practical.** Townhomes could accommodate net-zero-energy with rooftop solar, but probably only with tighter construction. This means a smaller solar system but likely higher construction costs. A rooftop solar deficit could be met using dedicated community solar systems. But coordinating dedicated community solar construction with new multi-unit construction to fulfill a net zero-energy mandate would be challenging at present, especially given that Maryland's community solar program is still in a pilot stage. Resolving these issues would make residential energy more economical in townhomes and multi-unit structures, while eliminating greenhouse gas emissions.

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[3] The 1.5°C IPCC report (IPCC 2018) estimated the social cost of carbon as more than $100 if climate tipping points were taken into account. Given the shape of things, it seems reasonably clear that tipping points such as Arctic summer melting and coral reef destruction have been crossed or soon will be crossed. For instance, the 2018 IPCC estimated that even if global temperature rise were limited to 1.5°C, 70% of global coral reefs would be destroyed. At 2°C, that would rise to 99%. The world has already exceeded a 1°C average temperature rise.

- **A mandate for rooftop solar in the context of deep retrofits to existing housing appears warranted on economic and climate grounds, but needs study.** At present (and declining) costs of rooftop solar, a mandate for installation rooftop solar to the extent that can be accommodated in the context of deep retrofits appears to be warranted. But existing housing has site-specific issues such as shading and roof orientation. This issue needs further evaluation.

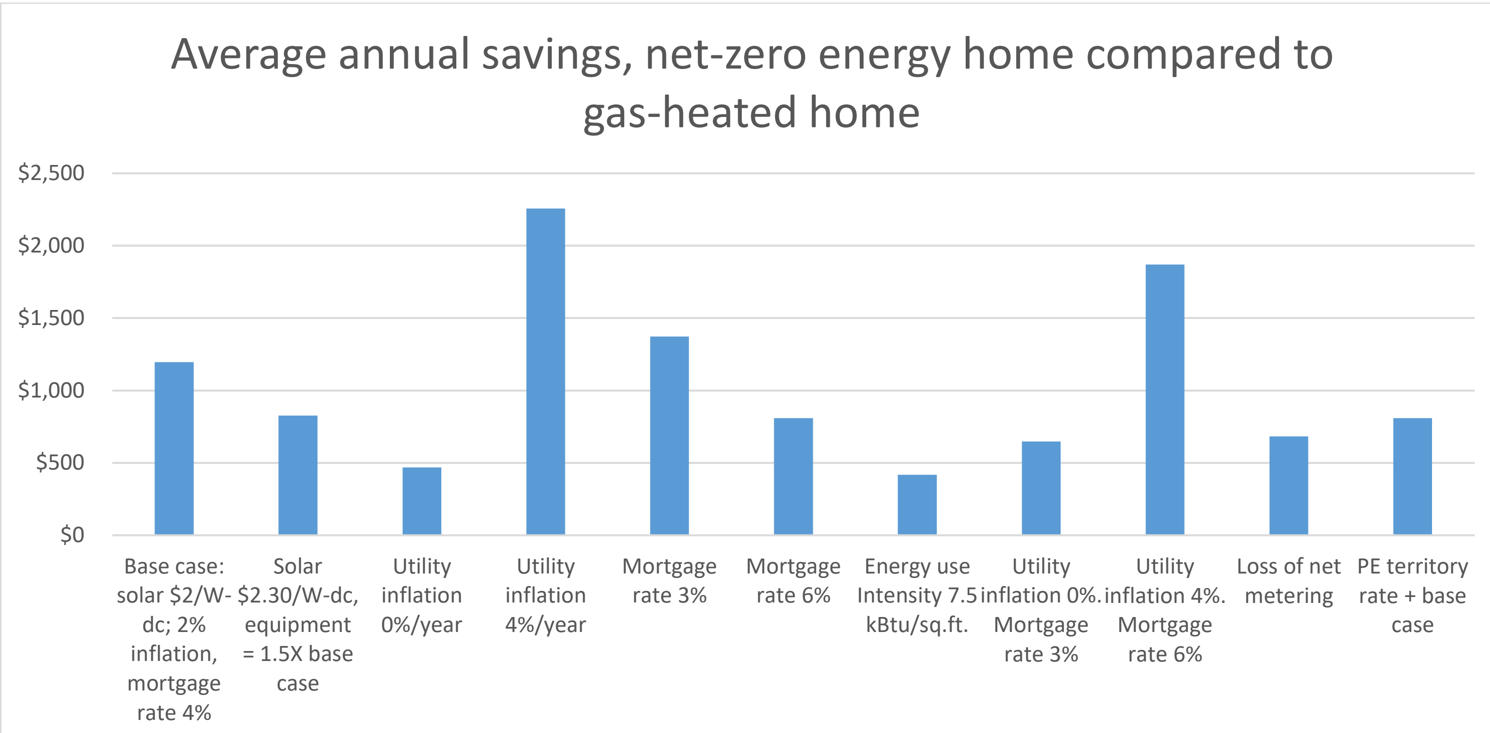

Figure ES-1: Sensitivity analysis showing the energy cost savings for various scenarios of new net-zero-energy home cost; **all savings are relative to a new gas-heated home**; home area = 3,500 square feet. "PE territory rate" refers to the residential rate in the service area of Potomac Edison in Montgomery County; the PE rates are the lower than in the Pepco service area, the rate used for the base case and most of the analysis because Pepco serves the vast majority of Montgomery County households.

b. Recommendations

- **Montgomery County should enact a rooftop solar mandate with net-zero-energy performance for new detached residential construction**. A mandate for new net-zero-energy detached homes with rooftop solar would allow Montgomery County to make progress towards its climate goals while saving its residents money. It would reduce the risk of stranded costs of new natural gas infrastructure. Failure to mandate net-zero-energy for new detached construction would make it more costly to achieve the county's greenhouse gas goals. Homeowners wanting to voluntarily retrofit solar later would also face higher costs. A net-zero-energy mandate with rooftop solar for new construction is one of the most straightforward steps that the County can take to demonstrate its commitment to its 2017 climate emergency declaration. The County should adopt a suitable inspection protocol for net-zero-energy homes.
- **The net-zero-energy mandate should be made equitable by a grant to low- and moderate-income households for the added down payment.** Maryland provides comparable amounts in

grants for geothermal heat pumps, regardless of income. Since premature equipment failure would affect low- and moderate-income households disproportionately, the County might consider providing low- to no-cost insurance to them for the expected life of the equipment.

- **A "solar-ready" mandate without rooftop solar is poor policy and should be avoided.** A "solar-ready" approach involves installing the structural and equipment aspects of a home for future solar installation; it would increase costs and provide none of the benefits. "Solar-ready" policies made economic sense when rooftop solar costs were high. But rooftop solar costs have declined so much that the approach is economically obsolete; it makes neither economic nor ecological sense. Later installation of solar would be on a retrofit basis, which by its nature is higher cost than solar installed at the time of construction under a mandate. In the meantime, greenhouse gas emissions would continue.
- **Maryland's net metering limit should be doubled to 3,000 MW.** Increasing the net metering limit would enable Marylanders to take advantage of the present economic opportunity while giving time to address the broader issue of the business-model of the electricity system. Many studies have shown that net metering provides ample benefits to consumers and society and is warranted.
- **Given the demand for land for ground-mounted solar installations, community solar should be preferentially be used for situations where rooftop solar is infeasible or cannot accommodate all the electricity demand**:
  - All renters;
  - All owners of existing homes who have roofs inappropriate for solar installations for reasons such as shading or structural issues;
  - Existing or new multifamily residences that have limited capacity for solar; in such cases community solar can supplement residential rooftop solar to reach a net-zero-energy target;
  - New townhomes and multi-unit residential structures that have insufficient area for solar on their rooftops to meet the net-zero-energy criterion.
- **Montgomery County should study hybrid models to analyze the potential for solar-plus-storage microgrids in new housing developments to increase energy system resilience.** Given the federal mortgage rules, it is important for homeowners to own the rooftop solar. But the rooftop solar can be "in front of the meter," compensated at the net metering rate. A number of such rooftop solar installations can be coupled with third-party-owned energy storage. This could be an innovative approach to developing microgrids in residential areas to increase electricity system resilience; it deserves to be examined.
- **Montgomery County should evaluate the ways in which a net-zero-energy mandate can be economically and efficiently extended to new townhomes and new multi-unit residential construction.** A promising, economical option for net-zero-energy for townhomes and multi-unit residential is to require as much rooftop solar as is economically reasonable with the rest being met by dedicated community solar in the territory of the same utility. The county should evaluate the coordination and state-level policy changes that will be needed to make this practical and efficient for new residential construction.
- **Montgomery County should examine the county-specific circumstances in which mandating rooftop solar for deep residential retrofits would be economical and practical.** As a general matter, rooftop solar appears to be economical in the context of deep residential retrofits. But the circumstances of existing homes are very varied. The county should assess the conditions under which such a mandate would be practical and economical.

I. Introduction and context

Montgomery County, Maryland has set a goal of eliminating greenhouse gas emissions by the year 2035, with an intermediate goal of 80 percent reductions by 2027.[4] The County has undertaken an extensive effort, with public involvement, to develop recommendations to achieve these goals. Six Workgroups issued 850 recommendations in early 2020 as part of that public involvement effort.[5] Follow-up technical analyses are underway in order to develop a Climate Action and Resilience Plan for release in 2021.

Montgomery County is the most populous in Maryland, with just over one million people and about 391,000 housing units. Almost two-thirds of the housing units are owner-occupied.[6] The county's overall greenhouse gas emissions for 2018, the most recent year for which detailed inventory data are available, were 10.5 million metric tons of carbon dioxide-equivalent (CO_2e). Of those, 2.53 million metric tons, about 24%, were attributable to the residential sector.

The distribution of CO_2e emissions due to energy use within the Montgomery County residential sector is shown in Figure 1.

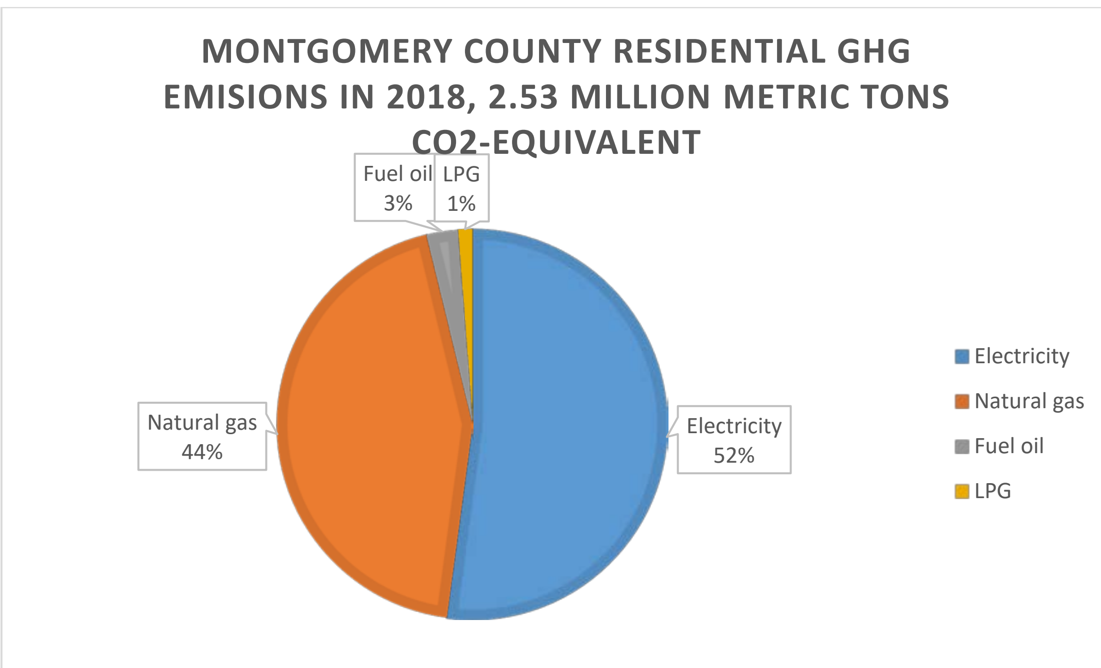

Figure 1: CO_2e emissions in the residential sector in Montgomery County
Source: Montgomery County GHG Inventory 2018

There are two broad categories of energy use in the residential sector:

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[4] Montgomery County Climate Change FY 21
[5] Montgomery County Climate Workgroup 2020.
[6] Quick Facts, Montgomery County 2019.

1. Direct fuel use – which consists almost completely of fossil fuels.[7] The vast majority of direct fossil fuel use is for space and water heating. Natural gas is also a common cooking fuel; it is used in clothes drying as well.
2. Electricity use. Electricity is also a common energy source for space and water heating; in addition, it powers almost everything else, including air-conditioning (also called "space cooling").

As part of the effort to drastically reduce greenhouse gas emissions, the County's Executive, Marc Elrich, announced a new initiative for new single-family residential construction in the county to include rooftop solar starting in 2022.[8] There are a number of ways to assess the implications of this policy. The cost and CO_2 emission aspects are obviously central: What will be the net cost, if any, to reduce or eliminate greenhouse gas emissions from new single-family housing compared to conventional housing in the absence of a solar mandate? What will be the impact on emissions of such a policy?

This report addresses the following questions:

- Is it economical for homebuyers to have a solar mandate when mortgage payments and energy bills are taken together, all other things being equal? Specifically, is it economical to install sufficient solar on the rooftop of an all-electric detached residential home so that it generates as much electricity as it uses every year? We pose the question in this manner because a net-zero-energy policy would have the most impact on reducing emissions.
- If there is a net cost increase, what is the implicit cost per metric ton of CO_2 reduced? If the homeowner saves money, despite the added first cost of the home, what are the savings?
- Are there options other than ownership of the rooftop solar by the home-buyer that could fulfill the same public purposes of climate protection? What are the potential advantages and disadvantages of such options?
- What about equity considerations? Low income households, already at a disadvantage in the new housing market for a variety of reasons, may face even higher hurdles if the initial price of the home is higher, even if it is more economical overall. How can these obstacles be overcome in practical ways?
- Does the analysis apply to other types of residential structures, including townhomes, and multi-unit residential buildings?

We have posed these questions in the context of an efficient all-electric home with a rooftop solar installation.

II. Comparison of a new, single family net zero energy home in Montgomery County with and without rooftop solar

The basic approach is to compare a new gas-heated single-family detached structure *that is built to the same building code* as efficient all-electric home except that the latter has an efficient heat pump for space heating in place of an efficient gas furnace, a heat pump water heater in place of an efficient gas water heater, and induction cooking in place of natural gas cooking. The all-electric home also supplies

[7] A very small proportion of households also use wood for heating.
[8] Masters 2019

all its annual electricity requirements from a rooftop solar installation.[9] In other words the heat losses from the home and all energy using devices other than the three mentioned would be the same in the two homes.

We also perform a sensitivity analysis that examines the effects of different costs of rooftop solar, inflation rates in natural gas and electricity costs, mortgage rates, and construction standards for new homes. The vast majority of homes in Montgomery County are in the service territory of the electric utility Pepco, where the analysis is centered. A relatively rural part of the county in the northwest is served by Potomac Edison and a small eastern-northeastern part of the county is served by Baltimore Gas & Electric. Of these two, residential rates are lower in the service territory of Potomac Edison, whose rates are examined as part of the sensitivity analysis.

We take a performance-based approach to building specifications, rather than a prescriptive approach that specifies insulation levels, appliance efficiency, etc. We use a single number, the home's Energy Use Intensity, to capture the energy aspect of the efficient all-electric home. This parameter is the energy used per square foot of the home's area. The energy used to deliver energy to the home is not included in this parameter, which therefore reflects envelope performance and appliance efficiency.

We use a detached home size of 3,500 square feet for most of the comparisons; this size is typical of new, detached housing in Maryland (see Table 1 below). We also examine a 2,400 square foot home to provide another point of reference (Table 4 in Section IV.c.). All of the characteristics of the compared homes are assumed to be the same except for the replacement of natural gas for space heating, water heating, and cooking that is used in the conventional home. Specifically, the insulation, construction standards, appliances such as refrigerators, dishwashers, and clothes washers, as well as any options that the homebuyer might want, are assumed to be identical. Once the performance parameters of space heating and water heating heat pumps and induction stove along with those of the corresponding natural gas devices are specified, the energy consumption of the natural gas-heated home with the same thermal envelope and all other electrical appliances can be computed.

The net-zero-energy rooftop solar has a solar system is sized to meet the entire annual average energy requirements of the home, the definition of a "net-zero-energy" structure. The Department of Energy has defined a zero-energy building as follows:

> A zero energy building (ZEB) produces enough renewable energy to meet its own annual energy consumption requirements, thereby reducing the use of non-renewable energy in the building sector. ZEBs use all cost-effective measures to reduce energy usage through energy efficiency and include renewable energy systems that produce enough energy to meet remaining energy needs.[10]

Such a building is also often called a "net-zero-energy building" or a "zero-net-energy building." We will use the term "net-zero-energy" home, sometimes abbreviated as "net-zero" home, in this report. The use of the term "net" conveys important technical realities. The home does not provide all of its energy from the rooftop at all times. Rather, the home imports and exports energy but the net imports on an annual basis are zero. In this report, "energy" for the net-zero-energy home means electricity, since the

[9] "Rooftop" solar could include solar on carports or other parts of the land where the detached house is built.
[10] DOE 2015, p. 1

home is all-electric.[11] An important caveat to the Department of Energy definition of a zero-energy building is that some definitions "renewable energy" sources include carbon dioxide emissions like trash incineration. In this report, energy generation in a net-zero-energy home refers to solar electricity only.

For a strict net-zero-energy system using photovoltaics, it is important to take account of the degradation in system performance over time; a decline in generation of 0.5% per year is a common assumption. In this report, we construe the term "net-zero-energy" in this strict sense: it means overall net-zero-energy generation over 30 years – the typical length of a mortgage. This approach means that electricity generation in the years immediately after construction will be greater than annual requirements, while generation in the latter part of the 30-year period will be less than the annual requirements. It is a net-zero-energy home over a 30-year period.

As noted, the net-zero and gas-heated homes have the *same envelope performance characteristics* and the same appliances, except that in a net-zero-energy home the natural gas space and water heating and natural gas cooking are replaced by efficient electrically-powered devices – a cold-climate heat pump,[12] a heat pump water heater, and an induction cooking range (with compatible cookware). This approach allows a straightforward comparison of the costs and carbon dioxide CO_2 impacts of the proposal made by Montgomery County's Executive. Since we assume air-source heat pumps, we have de-rated the nameplate performance to account for additional electricity use during cold spells.

We first analyze a "base case" with estimates for solar costs, mortgage rates, and other parameters important to the comparison. We then perform a sensitivity analysis varying these parameters to test the robustness of the conclusion about relative economics. For instance, we test how the comparison changes if mortgage rates were higher or lower than in the base case, since the energy costs in a net-zero-energy home are basically paid through a higher mortgage payment,[13] while utility bills are paid regularly, usually once a month. The inflation rate in utility bills is also important. That is because utility rates change over time; solar costs, if they are part of a fixed rate mortgage, will be about the same each year (apart from degradation of solar generation). If the utility inflation rate is positive, the relative costs of solar payments compared to purchased energy decline over time.

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[11] Some homes may have rooftop solar hot water heating. We have not considered this option in the present report.

[12] There are many different designs of heat pumps, which extract heat energy from the environment (air, ground, water) and "pump" it up to the temperatures required for space heating. Heat pumps that extract heat from the air (known as "air-source" heat pumps) usually operate efficiently only at temperatures above freezing. Cold-climate heat pumps are designed to operate with good efficiency to much lower temperatures – typically in the 10^{o}F, and often lower. In places where temperatures below freezing are common, cold-climate heat pumps use considerably less energy than typical heat pumps. In the summer, heat pumps operate in a manner similar to an air-conditioner, extracting heat from inside the home and rejecting it to the outdoors. Cold climate heat pumps are typically much more efficient in the summer than ordinary central air-conditioners. In this report we assume that the gas-heated home will have central air-conditioning with performance similar to the summer performance of a cold climate heat pump. For further discussion about efficient residential heating and cooling in Maryland see Makhijani and Mills 2015.

[13] In reality, there would be a down payment and a mortgage on the balance of the price of the home. We have considered the entire first cost increase for the home due to its net-zero-energy features to be part of the mortgage loan. This implicitly assumes that the interest that the homeowner would have derived by keeping the down payment is the same as the mortgage rate.

a. The base case

The most important parameter in determining the overall energy consumption of the house is the on-site energy consumption per square foot, called the Energy Use Intensity. However, as demonstrated in Section II.b below, the overall conclusion about which home is more economical is not affected by the choice of this parameter. The practical feasibility of a net-zero energy single family home may depend on this parameter in some instances. If the energy consumption is too large, say on the order of 20 kBtu per square foot or more,[14] there may not be enough room on the roof for sufficient solar capacity to meet the electricity requirements.

Within the limitation of accommodating sufficient solar panels, a large range of values for the energy use per square foot is still possible. This limitation is likely to be moot in the near future. The use of 380-watt panels is present-day common practice. 500-watt panels were introduced in early 2020;[15] 600-watt panels are now available. The area per watt has already declined by about 7 percent so far in 2020 alone,[16] reducing the roof area needed for a given capacity. Further, the recommendation for a net-zero-energy standard allows the builder flexibility between building envelope performance, heating system performance, and solar system size.

We have assumed that the new all-electric net-zero-energy home will have an overall Energy Use Intensity that is 60% of the 2015 standard.[17] On the other hand, the Energy Use Intensity we have used in the base case is not as stringent as the 5 to 10 kBtu/sq. ft. recommended by Montgomery County Climate Technical Work Group on Buildings;[18] this is a very stringent standard that corresponds approximately to "passive house" standards.

Comparisons of zero-net-energy homes or zero-net-energy-ready homes are sometimes made between a net-zero-energy home built to high construction standards and rooftop solar with a conventional home built to more lax standards. This raises the first cost of the zero-net-energy home relative to the reference home on issues that have nothing to do with rooftop solar. For instance, the Rocky Mountain Institute 2019 study comparing net-zero-energy homes to a "reference" home used the prevailing Energy Use Intensity and then added insulation, better windows, etc. in addition to rooftop solar to achieve net-zero-energy performance. A significant portion of the cost was to improve the performance of the building to decrease the Energy Use Intensity.[19]

The present report seeks to evaluate the efficacy of a solar mandate for new homes. Thus it is critical to compare performance and cost with and without solar for a building that is otherwise essentially the same, except for the space heating, water heating, and cooking arrangements. Otherwise the

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[14] kBtu stands for kilo-Btu – thousands of British thermal units.

[15] Sylvia 2020. As solar panel efficiencies improve, the generating capacity per panel will likely increase beyond the 500-watt number. Higher efficiency panels reduce the roof area needed for a given capacity.

[16] Based on Trina panel specifications for Tallmax for 380-4-05 watt panels and Vertex for 500 and 605 watt panels; Trinasolar 2020

[17] Most homes built to that standard had natural gas heating. PNNL 2016, p. C.6. Using efficient heat pumps for space and water heating instead of natural gas, by itself allows a reduction of the 2015 Energy Use Intensity because heat pumps draw energy from the environment for meeting part of space and water heating energy requirements. In May 2020, Montgomery County updated its building code requirements and adopted, among other codes, the 2018 International Energy Conservation Code, which is more stringent than the 2015 code.

[18] Montgomery County Climate Work Group 2020. See the recommendations of the Work Group on Buildings.

[19] Petersen et al. 2019, p. 17

comparison would not be "apples-to-apples"; it would not allow a conclusion about the economics of a solar mandate. We have examined a net-zero-energy home since it is most compatible with Montgomery County's ambitious climate goals.

Table 1: Characteristics of the single-family detached home used for the comparison: a natural gas-heated home vs. a zero-net-energy home

Physical attribute	Net-zero solar home	Natural gas-heated home	Comments
Area, square feet	3,500	3,500	Note 1
Space heating (COP for heat pump, AFUE for gas, annual)	2.5	97%	COP derated; Note 2
Water heater COP for heat pump, efficiency for gas	2.7	90%	COP derated; Note 3
Reduction in site elec. Use due to natural gas for cooking, natural gas-heated home	N/A	0.02	Note 4
Natural gas use for space and water heating and cooking, million Btu	0	79	
Electricity requirement other than for space and water heating and cooking	8,400	8,400	For appliances and plug loads in both homes
Total annual electricity use, kWh	16,967	8,400	Represents total energy use for the net-zero home
Solar electricity generation rate kWh/kW-dc	1,363	N/A	First year generation, Note 5
Solar generation degradation per year	0.50%	N/A	
Number of panels	36	N/A	380-watt panels. 500-W panels: 27. 600-W panels: 23
Solar capacity kW-dc	13.68	N/A	Corresponding to the integral number of panels

Sources and notes: 1. PNNL 2016. New homes in 2015 average 3,232 sq. ft. For the net-zero-energy home, we use 60% of the Energy Use Intensity 2015 standard of 27.56 kBtu/sq. ft. for Climate Zone 4, which covers almost all of Maryland. We assume 35% of EUI for space heating and 15% for water heating.

2. For the heat pump, see Energy Star 2020. We used the heat pump with HSPF = 10.5 to 12 (Coefficient of Performance (COP) = 3.08 to 3.52) in the 4 to 5 ton range. We de-rated this COP to 2.5 for calculating the electricity use throughout the winter to take account of auxiliary heater use during very cold spells.

3. For the heat pump water heater, see GE GeoSpring 2020. The COP of 3.25 was de-rated to 2.7 to take account of additional heating required in the winter; the additional winter electricity requirement is partly offset by lower cooling energy requirements in the summer. The water heater is assumed to be in conditioned space; it draws energy from that space for part of its water heating, increasing winter space heating needs and decreasing air-conditioning requirements.

4. Cooking gas energy 0.72 million Btu/year. Sweeney et al. 2014. Converted to electric equivalent using a 30% efficiency for gas and 76% for an induction cooktop.

5. Annual generation calculated from PVWatts (National Renewable Energy Laboratory solar calculation tool), for Rockville, Maryland for a fixed rooftop installation with a tilt of 20 degrees.

As noted, the net-zero-energy approach allows the builder to make the trade-offs between tighter construction and the efficiency of appliances and the amount of solar on the rooftop. For instance, geothermal heat pumps could be used instead of cold-climate heat pumps, significantly reducing electricity requirements for heating and cooling. A builder could also choose to use passive house standards, instead of the Energy Use Intensity of 16.54 kBtu/sq. ft used in the base case. For instance, a 7.5 kBtu per square foot EUI would reduce needed solar capacity from about 13.7 kW-dc to just 6.1 kW-dc. This would decrease solar costs but likely increase construction costs. Table 2 shows the additional costs for building a net-zero-energy home compared to a gas-heated home.

Table 2: Added initial cost of a net-zero-energy home (relative to a gas-heated home)

Net zero home and solar cost calculations	Net-zero solar home	Comments
Rooftop solar system cost, net	$22,940	Net of Maryland rebate and advance SREC sale. Note 1.
Net added cost of cold climate heat pump	$1,800	Note 2
Added cost of heat pump water heater	$330	Note 3
Added cost of induction range	$830	Note 4
Added costs for cookware	$500	Note 4
Cold climate heat pump rebate	($40)	Net utility rebate, electric minus gas
Heat pump water heater rebate	($325)	Net utility rebate, electric minus gas
Net added equipment cost other than solar	$3,095	
Total net added first cost of net-zero-energy home	$26,035	Solar, space and water heating heat pumps, induction range, cookware
Inverter replacement cost, $/watt-dc, present value	$0.13	Note 5; 15 year inverter life
Annual amount to deposit in inverter depreciation fund, $/W-dc	$0.007	Note 5
Annual amount to deposit in equipment depreciation fund	$166	Note 5; 15-year equipment life

Notes: 1. SEIA 2020 adjusted for elimination of customer acquisition costs and lower installation costs; see report text. Gross cost, $27,360. Solar Renewable Energy Credits are granted corresponding to solar generation at the rate of 1 credit per MWh. They can be held by the owner and sold each year or sold at a discount to brokers. We assume here that they would be sold at a steep discount at the time of commissioning in order to reduce the first cost of solar, at $250/kW-dc for a total of $3,420. On June 3, 2020, the fixed price for three years of SRECs was $45 per SREC and the spot price was $74. Sol Systems 2020, viewed on June 3, 2020. Maryland rebate = $1,000.
2. ACEEE gives an added cost of $1,030 for a 3-ton high-end heat pump. ACEEE 2019. We have scaled this to $1,800 assuming that a 5-ton heat pump would be used for a 3,500 square foot home.
3. GE GeoSpring, Table 1; cost $960. We got a premium gas water heater cost of $639 from a major home improvement company and rounded up the cost difference.
4. Cost of premium ranges from a major consumer rating website. Added cost of cookware for induction cooking assumed to be about double the cost of one full set of cookware.
5. Heating equipment, water heater, range, and solar system inverter assumed to be replaced after 15 years. The differential cost of replacement between a net-zero home and a gas-heated home is represented as an annual escrow payment to a fund earning 3%; this increases the cost of the net-zero home for the first fifteen years by the amount shown. For inverter cost, NREL 2019

The cost and energy use differences involve the space heating, water heating, and cooking elements needed for an all-electric home compared to a natural gas heated home. Of course, the major added investment needed is for the rooftop solar installation. The costs of the heat pump and induction range are added equipment purchase costs relative to efficient gas appliances, net of utility rebates. They do not include installation costs, which are incurred both for gas and electric equipment. If the comparison were for a retrofit of an existing home with a heat pump replacing a natural gas furnace and central air conditioner, installation cost differences would need to be taken into account. For new homes, installation cost differences would be relatively minor since similar overall space heating arrangements are assumed. The added costs of natural gas plumbing are not taken into account.

The costs shown in Table 2 include the added costs of replacing the equipment in the net-zero home after 15 years – inverter, water heater, heat pump, and cookware – half way through the 30-year mortgage period. We assume the relative costs of gas and electric equipment will remain the same. The equipment replacement costs are included as annual payments into an escrow fund for 15 years.

Figure 2 shows the evolution of energy costs over the 30-year period of the mortgage of the net-zero and gas-heated homes. Solar energy generation in the early years is greater than the requirement for the home, offsetting lower generation in later years. The surplus in the early years is not compensated at the retail rate but at the wholesale rate.[20] In the deficit years, the deficit in electricity, provided by the grid, is paid for at the full residential electricity rate.

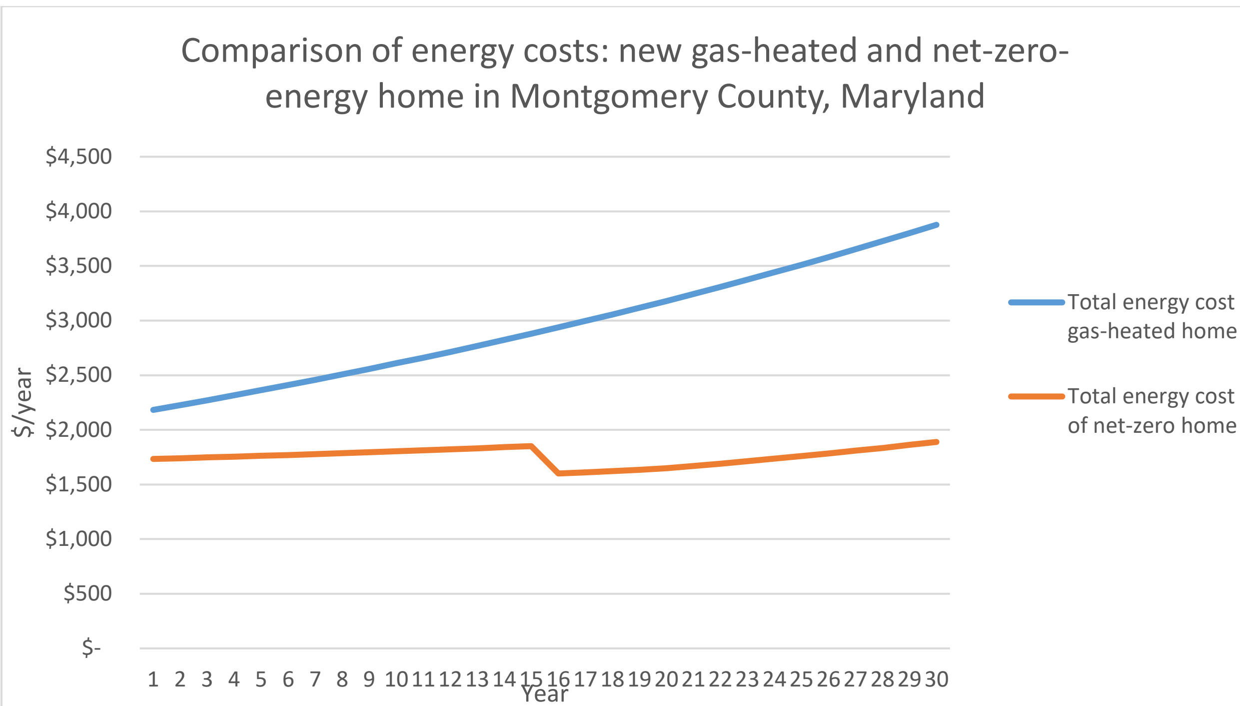

Figure 2: Annual energy costs of a gas-heated home compared to a net-zero-energy home, including the cost of rooftop solar; home area = 3,500 square feet.

Figure 2 shows that a net-zero-energy solar home, with the same thermal envelope performance characteristics as a gas-heated home, and the same appliances, except for the three using natural gas, would save a significant amount of money every year. Moreover, this is a simple dollars and cents comparison; it does not take into account the health and environmental benefits experienced by the

[20] This wholesale rate is called the “commodity rate” in Maryland’s regulations. Maryland Codes at COMAR 20.50.10.01 and 20.50.10.05

occupants of the home and by society at large by elimination of pollutants (including but not only CO_2) attendant upon burning natural gas.

The cost of purchased electricity and gas tend to rise over time. This increases the relative energy cost of a gas-heated home. Since utility rates change over time, it is necessary to make an assumption about a rate of increase in utility rates in order to make a comparison. This is especially important in the present comparison because the added cost of solar is part of a mortgage loan, with a fixed payment over time. Thus the solar cost remains the same over time regardless of inflation (we assume a fixed-rate, 30-year mortgage). Utility rates tend to rise in the long-term. We have used a reference inflation rate of 2% per year to do the calculations shown in Figure 2. (See Section b. in this chapter for a discussion and the sensitivity analysis relative to inflation assumptions.)

Figure 3 shows the annual savings in total energy costs of the net-zero-energy home relative to the gas-heated home.

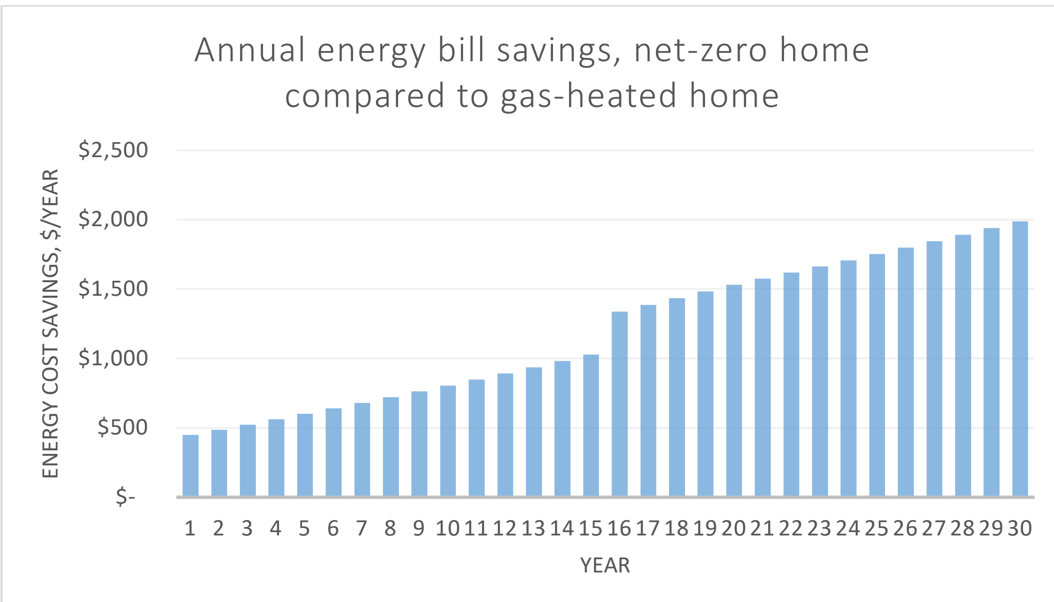

Figure 3: Annual savings in energy costs of a new net-zero-energy home of 3,500 square feet relative to a new gas-heated home. The savings jump in Year 16 because the escrow fund needed for replacing equipment in Year 15 is no longer needed.

The bump in savings after year 15 shown in Figure 3 is due to the fact that payments for the depreciation of the inverter and all-electric equipment are required only for the first 15 years. As discussed below (Section II.c) the costs of solar are expected to decline. The $2 per watt-dc is on the higher side and therefore implicitly includes some margin for the builder. Further, the builder of a net-zero-energy home can use the cheap credit available for construction of net-zero-energy homes from the Maryland Department of Housing and Community Development (DHCD) and thousands of dollars in interest costs over a six-month construction period.[21] For these two reasons, an explicit margin for the builder is not included in the cost estimates. Specifically, we assume that the builder will keep the interest cost savings accruing from the DHCD loan for net-energy-energy construction.

[21] Builder interest cost savings would be about $3,200 for a 3,500 square foot home and about $2,000 for a 2,400 square foot home. See Section IV.d.

We also calculated the energy costs of a "solar-ready" home, which would be the like a net-zero-energy home in all respects, except that it would not have a rooftop solar installation. In this case the result is reversed. A solar-ready home would have higher energy costs than a gas-heated home; the energy cost penalty in the first year would be $330 and grow after that with utility rate inflation; in addition, the first cost of the home would be higher than a gas-heated home, entailing about $180 per year in added mortgage payments.

Over the life of the mortgage, the annual costs of a solar-ready home would be greater than a gas-heated home by about $600 per year; it would be higher than a net-zero-energy home by about $1,800 per year. *The energy costs of a net-zero-energy home with rooftop solar are lower than the energy bills in a gas-heated home built to the same performance standards or a "solar- ready" home, which has the highest energy costs. This result derives from the simple fact of rapid declines in the costs of residential rooftop solar installations.*

b. Sensitivity analysis

The conclusion that a new net-zero home would be significantly more economical than a gas-heated one depends on a number of assumptions that have been carefully made. However, they are still assumptions about future conditions. A sensitivity analysis is therefore needed to examine how robust this conclusion is to changes in key assumptions. We have done a sensitivity check for the following parameters:

1. Cost of rooftop solar and equipment for a net-zero-energy home and added all-electric equipment.
2. Inflation in the cost of purchased electricity and natural gas.
3. Mortgage rates.
4. Energy Use Intensity.
5. Combined parameter variations: utility inflation rate and mortgage rate.
6. Abandonment of the "net metering policy" under which electricity exported to the grid from a rooftop solar installation is compensated at the same rate as purchases of electricity by running the meter in reverse when electricity is exported.
7. Variation in electricity rates from Pepco rates, applicable to the vast majority of county residents, to the lowest rates in Montgomery County – those of Potomac Edison, which serves a small fraction of homes in the county.

We should also note the sensitivity analyses that we have *not* done. We have not evaluated (i) a cost of solar below $2 per watt-dc, despite the high likelihood that the cost of rooftop solar (like other solar market segments) will continue to decline;[22] (ii) a resumption of the federal income tax credit for solar; it is currently set to expire in 2021; (iii) any imputed cost to CO_2 emissions even though the climate impact of continued CO_2 emissions is substantial; (iv) higher cost of natural gas. We will discuss the

[22] Ardani et al. 2018 examined the evolution of the cost of residential rooftop solar under the assumptions of a mandate for new construction and for deep retrofits. They examined two scenarios for the year 2030 for each. The range of residential rooftop solar for new homes under a mandate in the year 2030 was $1.62 to $1.10 per watt-dc, depending on the whether the development was "less aggressive" or "visionary." Figure ES-2, p. vii. We have used $2/watt-dc in this report. NREL ATB 2020 estimates that the costs of rooftop residential solar will decline between 1.2% and 7.6% per year between 2019 and 2025 and similar declines will continue after that.

amount that could reasonably be imputed to damage attributable to CO_2 emissions from the gas-heated home in Section III.a below. All these considerations would make the net-zero-energy home even more economical than shown in Figure 3. A sensitivity test for falling natural gas costs is not necessary because natural gas is already very cheap; in any case the result is insensitive to falling wholesale prices of natural gas. The parameters used in the sensitivity tests are shown in Table 3, along with the base case parameters.

Table 3: Base case parameters and values used for sensitivity analysis for a net-zero home

Parameter	Base case values	Values used for sensitivity analysis	Comments
First cost	\$2/watt-dc, \$3,095 added equipment cost	\$2.30/watt-dc, 1.5X added equipment cost	
Energy cost inflation rate	2%/year	0%/year; 4%/year	
30-year mortgage rate	4%/year	3%/year; 6%/year	Early September 2020 rates were about 3%; the maximum rate since January 1, 2011, rounded-up, is 5%. We use 6% to account for possible higher inflation in the future.
Site Energy Use Intensity, kBtu/square foot	16.54	7.5	Middle of the Montgomery County Work Group recommendation of 5 to 10.
Combined parameter changes	Energy cost inflation 2%; mortgage rate 4%	Energy cost inflation rate 0% + mortgage rate 3%; inflation rate 4%,+ mortgage rate 6%	Higher utility rate inflation assumed associated with higher mortgage rate and vice versa
Net metering	Net metering	Electricity exported to the grid compensated at commodity rate	Loss of about 45% of the value of exported electricity relative to net metering
Residential electricity rate	Pepco	Potomac Edison	Lower by about 3.5 cents per kWh

In all but one case, we vary a single parameter, while keep all other values at the base case level. We also do a combined case by testing variations in both the inflation rate in utility costs and mortgage rates.

Another issue relates to home infrastructure. All new homes must be provided with electricity wiring and connections. While the wiring itself may be somewhat higher capacity in the case of a net-zero home, the installation and labor costs would not change materially. In any case, heavier wiring should be installed to accommodate in-home charging of electric vehicles, which will be critical to greenhouse gas emission reductions in Maryland, as elsewhere. But a net-zero home does not need internal natural gas plumbing or a natural gas connection. We have omitted this added cost of the natural gas-heated home even though it is important because the net-zero-energy home is already more economical. In some cases, distribution pipelines may also be needed. We have also not taken these costs into account. We will discuss the risks of stranded costs of natural gas infrastructure in the climate Section III.c. A summary of the results of the sensitivity analysis is shown in Figure 4.

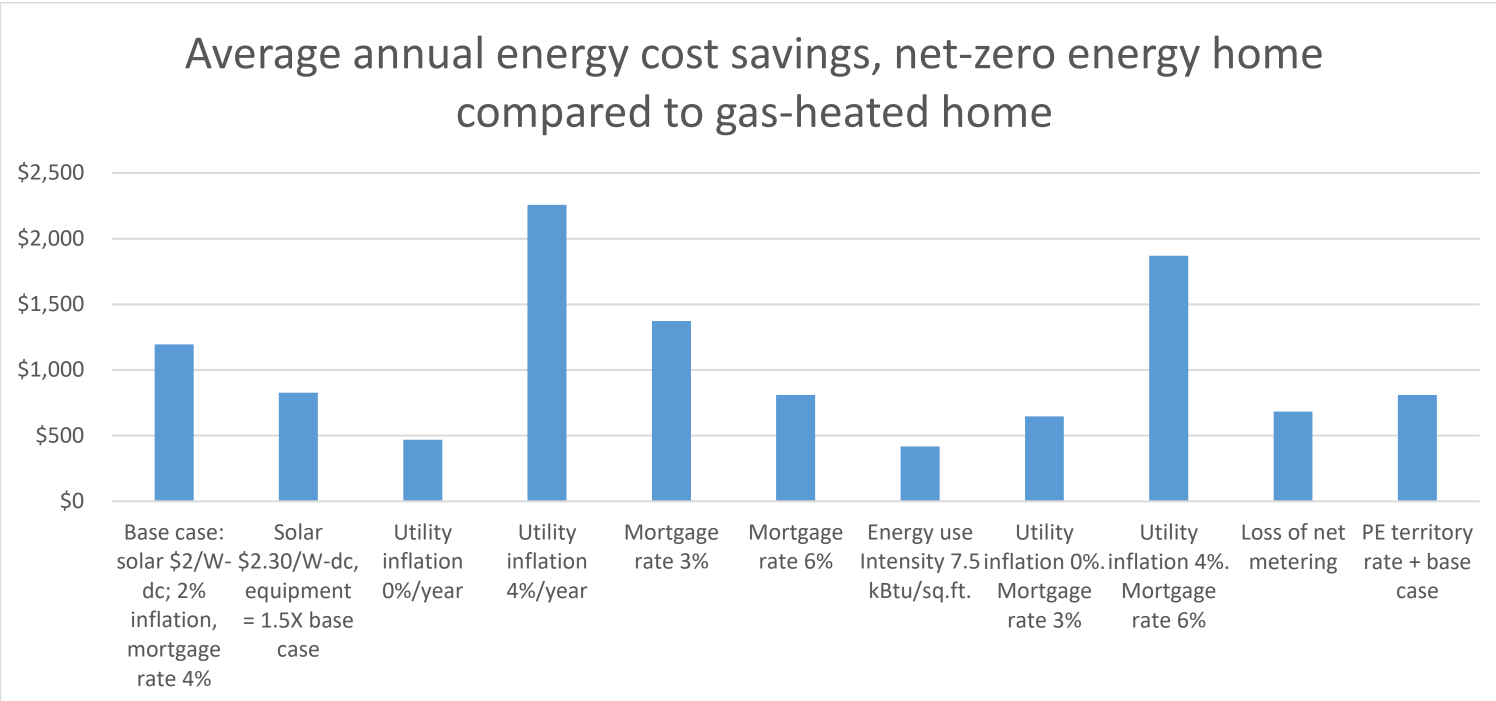

Figure 4: Sensitivity analysis showing the energy cost savings for various scenarios of new net-zero-energy home cost. *All savings are compared to a new gas-heated home*. "PE" refers to Potomac Edison.

Figure 4 shows annual energy cost savings averaged over the life of the mortgage; see Figure 2 above for annual details in the base case. Other choice of parameters shown in Figure 4 would follow the same annual pattern with different specific annual savings, which are positive in all years for all the scenarios shown in the sensitivity analysis. The sensitivity tests show that conclusion of the base case that a net-zero-energy home is substantially more economical than a gas-heated home is robust.

The inflation rate of purchased electricity and natural gas is among the most sensitive parameters. If there is zero inflation in purchased energy costs, that is, if the real costs of energy fall steadily over a 30-year period, an unlikely eventuality,[23] the net-zero home will still be lower cost than a gas-heated one, but the savings would go down from an average of about $1,200 a year to about $470 a year. Passive-house construction standards lower the total energy costs of both the gas-heated and net-zero homes: utility bills for the gas-heated home; the needed solar size for the net-zero home. But the overall energy cost of a net-zero home still averages about $420 per year less than the gas-heated home. The first cost of both homes would likely increase be higher with a passive construction standard.

Overall, the sensitivity analysis shows that the range of energy costs (including the costs of the rooftop solar) savings of the net-zero home relative to a gas-heated home ranges from $420 per year to over $2,200 per year. The base case savings are in the middle of this range – about $1,200 per year.

We now discuss the choice of parameters for the sensitivity analysis.

23

c. Cost of rooftop solar and other initial costs

The current typical residential solar installation is a residential retrofit on an existing home. Such retrofits are significantly most costly than rooftop solar resulting from a mandate for new construction. The most significant cost difference is "customer acquisition cost." In residential retrofit work, a company must respond to many potential customers before a single project that is actually implemented; several sites must be assessed and estimates provided. The most serious customers require site visits and preparation of cost-benefit analyses. Several bids per installation are common, but only one of the final bidders gets the job. The cost incurred for all the potential customers who did not actually commission a project is spread out over the much smaller number of customers who did.

Estimated customer acquisition costs increased from $0.41 per watt-dc in 2013 to $0.52 per watt-dc in 2016. Customer acquisition costs are not related to the nature of the system, but rather to the amount of prospecting that needs to be done to get one installation contract; they are expected to rise as a fraction of the total cost as the total installed cost declines. [24] *They are eliminated if there is a mandate*.

The Solar Energy Industries Association estimates that in the fourth quarter of 2019, residential solar rooftop costs averaged $2.84 cents per watt. More than half of this cost – about $1.50 per watt-dc – is estimated to be "supply chain, overhead, and margin," not including installation labor or "design, engineering and permitting," which are separately listed. Just eliminating the customer acquisition cost would reduce the cost to about $2.40 per watt-dc. When the other cost reductions are factored in, such as buying components in bulk because of the mandate, the cost of a rooftop solar mandate would be somewhere between the cost of retrofitted solar installation and the cost of commercial rooftop installation, estimated by the Solar Energy Industries Association to be $1.39 per watt-dc at the end of 2019. It is also noteworthy that the average cost of rooftop solar declined by 14 cents a watt-dc, or 4.7% in just one year -- between the last quarter of 2018 and the last quarter of 2019.[25]

A National Renewable Energy Laboratory analysis of a rooftop solar mandate for new homes examined two approaches to implementing it over time – "less aggressive" and "visionary." The study noted the following cost reduction factors:[26]

- "…high-volume installers typically have the purchasing power to negotiate lower module and component prices…"
- "Increased business model integration" as homebuilders, roofing companies, and solar installers collaborate more closely and even integrate their operations over time;
- "Economies of scale are likely to be most accessible to the new housing market, because the cost of individual systems could be reduced by spreading fixed costs across multiple installations."
- "Product innovation could take a variety of forms, such as reduced PV racking and mounting, preassembled PV, and low-cost PV roofing tiles. An integrated PV and roofing product, in

[24] Wesoff 2020.
[25] SEIA 2020, p. 19
[26] Ardani et al. 2018, pp. 7-8

particular, could yield significant cost savings, especially if the roof and PV system could be shipped and installed in unison. Although integrated products have low market share today, it is plausible that they could reach the mass market by 2030."

This last item, product innovation, will take time to penetrate the market and become established – as part of a "visionary" approach to rooftop solar. In that case, the study estimates that residential rooftop solar cost could decline to as little as $1.10 per watt-dc, which is about the cost of utility-scale tracking solar systems today. Even with a more gradual approach, costs are estimated to decline to $1.62/W-dc by 2030.[27] Finally, the annual technology review of electricity generation costs of the National Renewable Energy Laboratory estimates continued decline in capital cost of residential rooftop solar at rates between 1.2% and 7.6% per year to 2025, continuing at similar, and somewhat faster rates after that time to 2030.[28] The different rates of decrease in cost correspond mainly to different assumptions about innovation.

In light of the above, $2 per watt-dc used here is on the higher side for a mandate. Still, we used $2.30 per watt-dc as a possible high end of solar costs, possibly relevant at the initial stages of the implementation of a net-zero-energy mandate. It is far more likely that costs in the coming years will be significantly lower than $2 per watt-dc. Every ten-cent per decrease in cost per watt-dc would increase the energy savings relative to a gas-heated home by about $80 per year for a 3,500 square foot home and about $55 per year for a 2,400 square foot home.

A net-zero-energy home involves higher costs for the cold climate heat pump, the heat pump electric water heater (both relative to high efficiency gas devices) and an induction range for cooking, which also requires induction-compatible cookware. These added costs, less the available utility discounts, are taken into account in the net-zero-energy home. Since discounts are available for both high efficiency electric and gas appliances, the net added discount for the electric heat pump and water heater were calculated (see Table 2 above). It is important to note here that high-end gas furnaces, central air-conditioners, and gas ranges also cost more than the usual varieties. The overall difference in first cost was estimated at $3,095 for the base case. To account for uncertainty in these cost elements, added 50% to their cost, for a total of about $4,640. We used this higher equipment cost together with the higher solar cost of $2.30/W-dc in the sensitivity analysis. The net-zero energy home energy costs were lower that the gas-heated home by almost $700 per year.

d. Inflation rate for utility rates

A net-zero-energy home is designed to fulfill all its energy requirements from the rooftop and so is insulated from inflation in utility rates. In contrast, a gas-heated home purchases all its natural gas and electricity and is therefore subject to changes in those rates. As a result, the inflation rate in utility supply energy affects the economic comparison between the two types of homes.

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[27] See Figure ES-2, p. vii. Ardani et al. also estimated rooftop solar costs for deep residential retrofits for the years 2030 under a similar range of assumptions. The retrofit cost estimates were $1.82/W-dc ("Less Aggressive") to $1.21/W-dc ("Visionary").

[28] NREL ATB 2020. The technology review estimates costs declines starting with historical cost estimates, which for rooftop solar are almost entirely retrofits on existing roofs. The 2019 cost in this report is consistent with that in SEIA 2020.

In Maryland, electricity rates rose during the last half of the first decade of this century, after relatively stable rates in the first part of that decade, a situation that was partly a result of deregulation. Rates have been relatively stable in current dollars over the past decade, and have even declined slightly since 2016, in part due to low natural gas costs.

Maryland's electricity deregulation law was passed in 1999. Rates were required to be kept low until the middle of the 2000s. When that restriction expired, rates skyrocketed, though at different rates in the various utility regions, until the Great Recession. Thereafter, moderating demand and low natural gas prices plus the large rate increases up to 2009 have kept rates approximately stable. A surplus of generating capacity in the PJM grid region (of which Maryland is a part) has also played a role.

Overall, the rate increase between the year 2000 (the first full year after the passage of deregulation) and 2018 was about 2.9% per year. Between 2005, when rates were close to their bottom, and 2018, the average rate increase was over 3.5% per year. Rates have slightly declined since their peak in 2009; they have been approximately stable since about 2013.

Figure 5 shows a bar chart of average residential electricity rates in Maryland. We used a utility rate inflation rate of 2% per year in the base case to reflect this complex experience. We used utility rates specific to Pepco, which serves the vast majority of Montgomery County homes; we also tested the analysis for Potomac Edison residential rates, which are the lowest of any utility serving county residents (Figure 4 above).

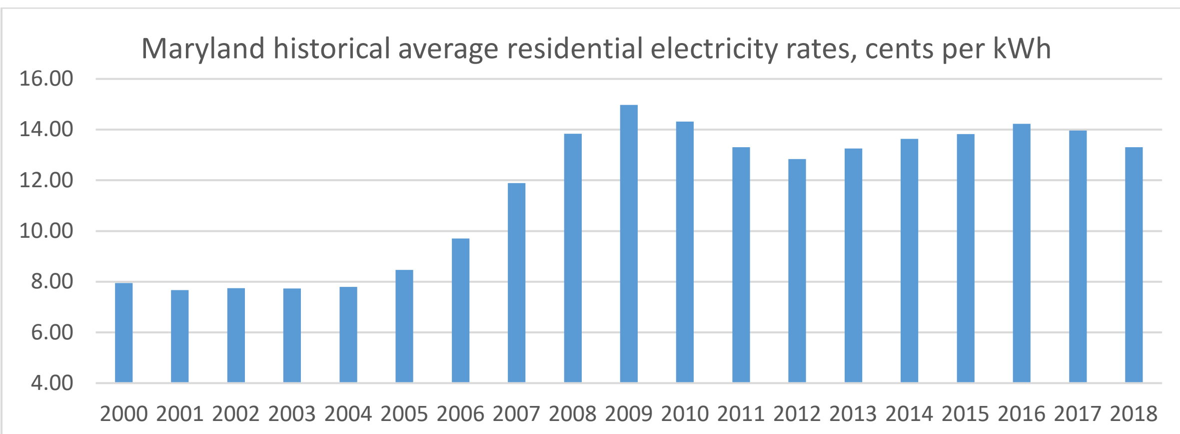

Figure 5: Average residential electricity rates in Maryland
Source: Maryland State Electricity Profile 2018, Table 8

The sensitivity analysis using 0% per year and 4% per year is designed to reflect the range and bracket the possible range in the future.

We have used the same inflation rate for natural gas and electricity rate increases and the same range for the sensitivity analysis. It is important to remember that the calculations for a long period – 30 years. Residential natural gas rates have fluctuated a great deal in the last 30 years. They have generally been in the $11 to $12 per million Btu (rounded) range since 2010. But they have been much higher and much lower before that time, ranging from a low of $6.28 in 1990 – that is 30 years ago – to a high of $15.78 in 2006.[29] A 0% to 4% range reflects this experience reasonably well over a long period.

[29] Residential natural gas rate data from SEDS Maryland 2018, Table ET3.

The stability of natural gas rates in recent years has largely been due to the low wholesale prices of natural gas accompanying the large production increases due to hydraulic fracturing. Wholesale prices do not have far to fall since they are already low.[30] ,[31]

The analysis shows that even if utility rates stay constant and do not increase with general inflation over a period of time as long as 30 years, the duration of the mortgage, a net-zero-energy solar home is still significantly more economical than a gas-heated home. The annual average net savings estimates range from a low of about $470 per year (0% annual inflation in purchased energy costs) to a high of more than $2,200 per year (4% annual inflation in purchased energy costs).

e. Mortgage rates

We assumed a 30-year fixed-interest rate mortgage rate of 4% per year in the base case. The maximum mortgage rate from January 1, 2011 to May 2020, the time of the preparation of this report was 4.95% per year. The minimum up to early January 2020 was 3.23% per year.[32] We have used a range of 3% to 6% for the sensitivity analysis shown in Figure 4 above. The higher end of this range, 6%, is to make room for higher inflation in the future than has been characteristic of the last decade.

At 3% per year, the economics of the net-zero-home are improved; the energy cost savings average $1,370 per year. At a 6% per year mortgage rate, the savings decline but remain substantial at about $810 per year for a 3,500 square foot home.

f. Energy Use Intensity

We used a site Energy Use Intensity index of 16.54 kBtu/square foot for the base case calculations for a net-zero-energy home. As noted, the Montgomery County climate workgroup on buildings recommended a range of 5 to 10 kBtu/square foot. We examined the impact of using a value in the middle of this range – 7.5 kBtu/square foot. With this stringent standard for energy use, purchased energy bills decline greatly for the gas heated home and the solar capacity declines greatly for a net-zero home. Whether the lower solar cost would offset likely higher construction cost is beyond the scope of this report. What is relevant, however, is that the relative economic benefit of the net-zero-energy solar home is not affected. The money savings decline because energy bills are low in both cases, but the net-zero-energy home energy costs are still lower than the gas-heated home by about $420 per year for a 3,500 square foot home.[33]

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[30] See also Section III.c for discussion of natural gas distribution costs and rates in the context of a phase out of fossil fuel use.

[31] Wholesale prices of natural gas, at the Henry Hub, averaged $3.17 per million Btu in 2018; EIA 2020. A $1 per million Btu decline in wholesale price, passed on to consumers, persisting for 30 years, would reduce the savings in energy costs of the net zero home by about 8%.

[32] Historical mortgage rates can be downloaded from www.macrotrends.net

[33] Account was taken is this case of a smaller cold climate heat pump. The cost differential used was $1,000 rather than $1,800 in the case of the reference performance parameter.

g. Combined factors

The parameters used in this analysis may, of course, vary simultaneously. We examined the two parameters that affect the relative costs the most – the utility cost inflation rate and the mortgage rate. We assume that a low inflation rate would be accompanied by a low mortgage rate and vice versa and examine two variants: (i) a 0% inflation rate in purchased energy costs with a 3% mortgage rate (reflective of recent conditions in Maryland) and (ii) a 4% inflation rate in utility costs with a 6% mortgage rate to represent a higher inflation economic environment. As shown in Figure 4, the net-zero home had lower energy costs in both cases – by about $650 per year on average in the first case and about $1,870 per year in the latter case. A separate evaluation of these two parameters, discussed above, shows that energy cost savings are more sensitive to assumptions about utility rate inflation than to the mortgage rate.

h. Net metering

Residential rooftop solar is net-metered. That is, the energy exported in times of surplus rooftop generation is credited at the retail rate that the consumer pays when purchasing electricity. This is accomplished by running electricity meters backwards.[34] This process nets the imports, or purchases of electricity, and exports or the sale of electricity by the resident with rooftop solar. Under Maryland law, total net metering capacity in the state is limited to a total of 1,500 MW, including residential, commercial, and community solar installations. Maryland has not yet reached this limit but is likely to do so in the next few years. Somewhat less than 1,000 MW of Maryland's solar was net metered as of the first quarter of 2020.[35]

Many studies have shown that the value of solar electricity is greater than electricity rates.[36] Given that (i) community solar is in its initial stages, (ii) low- and moderate-income people have benefited very little from solar, and (iii) solar has large climate and other environmental benefits, the net metering cap should be significantly expanded. A doubling to 3,000 MW would give sufficient time to consider options and alternatives in the context of the value of solar energy to Marylanders and to the state's climate and economic goals.

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[34] Net-zero-energy homes with rooftop solar must pay the monthly charge to be connected to the utility; this has been taken into account.

[35] Estimated from the SEIA Maryland Fact Sheet 2020.

[36] For example, eight of the eleven studies compiled in Environment America estimated the value of solar electricity to be greater than electricity rates. The three that did not were all commissioned by utilities. Hallock and Sargent 2015, pp. 5-6. The present report has shown that the value of solar to consumers is greater than the electricity rate. In addition, the value of avoided CO_2e emissions to society adds another two-thirds to the economic savings in energy costs. There are additional health benefits of net-zero-energy homes from avoided indoor air pollution; we have not quantified them here. A study done for the Maryland Public Service Commission (Daymark et al. 2018) suffered from a number of defects of incomplete valuation, despite some merits (Rábago 2018). For the purposes of the present report, it should be noted that the Daymark study did not value the distribution services provided by rooftop solar systematically. Even so, its example calculations showed that distribution benefits of behind-the-meter solar alone have are over 10 cents per kWh (Figures 50, 52, 54, 56, Daymark et al. 2018, pp. 128-131) – a value comparable to the average price of delivered electricity in Maryland. The total value of solar in these examples was greater than Maryland residential rates. (Maryland State Electricity Profile 2018, Table 8).

Since an increase in net metering capacity is not guaranteed, we did a sensitivity test in the event that the policy lapses. It is likely solar installations that exist at the time of any change would be "grandfathered in"; still, even in that case, a lapse net metering would affect new homes built after that time.

One possible economic outcome for solar owners in case of a lapse of net metering would be that all exported solar electricity would be compensated at the "commodity" or wholesale rate. This varies and depends partly on the utility service area. The solar generation that is consumed within the home is "behind-the-meter" and does not show up in the utilities accounts at all. So far as the utility is concerned the net effect on overall electricity use is the same as if the resident were conserving electricity by frugal habits or purchasing more efficient appliances and lights, thereby reducing electricity purchases from the utility as a result. Thus a lapse of net metering affects only the portion of electricity that is exported to the grid form the rooftop.

An analysis of the impact of compensating electricity exports at the commodity rate requires an estimate of the fraction of solar generation that is exported to the grid. In a net-zero home of the type analyzed here, electric heating in the winter together with all the other uses, would likely result in essentially all winter generation being consumed behind-the-meter; there would normally be additional imports of electricity from the grid in the winter. In the summer, there would be some imports and exports, depending on the weather. Exports would dominate in the spring and fall. A month-by-month generation estimate using the PVWatts tool of the National Renewable Energy Laboratory indicates that under these assumptions roughly one-third of the rooftop solar generation would be exported for a loss of about 6.5 cents per kilowatt-hour exported – or about $380 in the first year. The net-zero-energy home's average energy costs would still be lower than the gas-heated home by about $680 per year, but lower than the savings of about $1,200 per year in the net-metering framework.

i. Electricity rates

The vast majority of homes in Montgomery County lie in the service territory of the electricity utility Pepco. A small fraction of homes in the northwestern part of the county are in the service area of Potomac Edison and some to the east-northeast are in the territory of Baltimore Gas & Electric (BGE).[37] Potomac Edison's residential rates are lower than those of BGE. That means that the purchased electricity costs for a gas-heated home in the Potomac Edison area would be lower than in either the Pepco or BGE area. Therefore we examined whether a net-zero-energy home would still be economical in the Potomac Edison area. Such an evaluation also suffices for the BGE area, where electricity rates are higher than the Potomac Edison area.

Potomac Edison's residential rates are lower than Pepco's by about 3.5 cents per kilowatt-hour; monthly connection charges are lower by about $2 per month. Taking these lower costs for a gas-heated home into account does not change the overall conclusion that a net-zero-energy home would have lower energy costs. However, it does lower the savings from about $1,200 per year on average in the Pepco area to about $800 per year in the Potomac Edison area. Savings in both areas would increase as the cost of rooftop solar declines.

[37] All of Montgomery County is served by Washington Gas; therefore a similar sensitivity test for natural gas rate variation in different parts of the county is not necessary.

j. Estimated Recovery Value

Many people do not stay in their homes over a typical 30-year mortgage period used for this evaluation. Thus, there is the material issue of whether the added cost of solar can be recovered at the time of resale of the home. A detailed assessment by the real estate firm Zillow found that the average increase in sales price of a home with rooftop solar compared to one without was about 4.1%. The range was 2.7% (Riverside, California) to 5.4% (New York City).[38] The average is approximately equal to the added net undepreciated cost of a net-zero-energy home compared to a gas-heated home – 4.4% in the base case in the analysis in this report. Thus, homeowners with rooftop solar can expect to recover their additional investment in solar at the time of sale, in addition to benefiting from lower energy costs while they live in it.

III. Climate and health considerations

There are significant benefits for both climate and health of a net-zero-energy mandate. We briefly evaluate both in this chapter.

a. Greenhouse gas emissions of the gas-heated home

Annual CO_2e emissions from a 3,500 square foot gas-heated home over a 30-year period are shown in Figure 6. We assume that Maryland grid electricity will have zero emissions in 2040. This assumption is favorable to the gas-heated home. A net-zero-energy home would eliminate these greenhouse gas emissions.[39]

The reduction in emissions for a single home should be seen in a broader climate context. Montgomery County has recognized that there is a climate emergency. The county's climate resolution calls for an 80% reduction in greenhouse gas emissions by 2027 and a 100% elimination by 2035;[40] both are ambitious and difficult targets. The resolution reflects the increasingly grim assessments of the impacts of climate disruption due to human activities made by the Intergovernmental Panel on Climate Change (IPCC). For instance, in its comprehensive 2018 report comparing the impacts of 1.5^{o}C average global temperature rise with 2^{o}C, the IPCC noted that at the former level, coral reef losses would be in the 70 to 90% range; at 2^{o}C, the losses would be more than 99%.[41]

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[38] Zillow 2019

[39] Net-zero-energy homes have approximately zero CO_2e emissions. In practice, a net-zero-energy home could result in emissions that are slightly less than or slightly greater than zero on an annual basis. Less than zero means that rooftop solar exports to the grid would displace more CO_2e emissions than rooftop solar imports create. The exact balance of emissions depends on when electricity is exported to the grid, when it is imported from the grid to the house, and the emissions from the specific mix of supply sources at those times. Generally, rooftop solar electricity in the net-zero home modeled here would be exported during most spring and fall days and on the cooler summer days. It would be imported during the vast majority of days in the winter, during hotter summer days, and at night on all days. As a result, imports are drawn from a somewhat different mix of generation than the mix displaced by exports. Overall, in Maryland exports of rooftop solar generation would tend to displace natural gas and coal generation, while imports would be a mix of nuclear, natural gas, and coal generation.

[40] Climate Emergency Resolution 2017

[41] IPCC 2018, p. 8

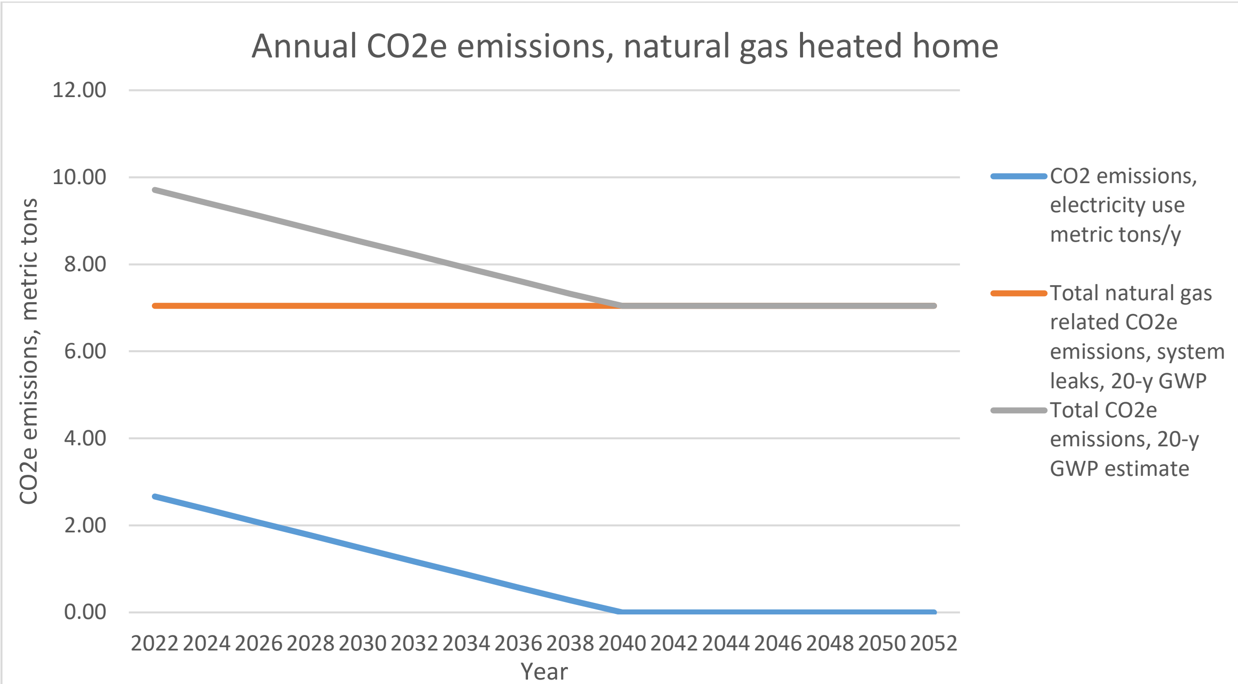

Figure 6: Annual CO_2e emissions from a conventional, new detached single-family home with natural gas space and water heating built in 2022

The cumulative emissions over 30 years are shown in Figure 7.

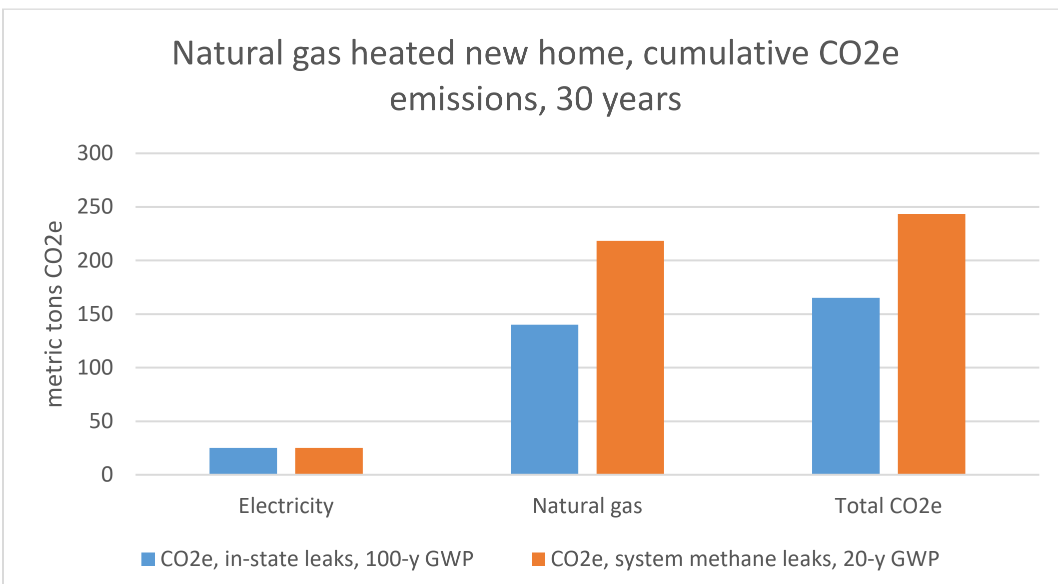

Figure 7: Cumulative CO_2-equivalent emissions, natural gas heated new home in Maryland

The benefit to society from the elimination of emissions by a net-zero-energy home can be estimated in various ways. One approach is to estimate a "social cost of carbon." According to the IPCC, this parameter "measures the total net damages of an extra metric ton of CO_2 emissions due to the associated climate change"; the IPCC has stated that damage estimate "support" values in excess of

$100 per metric ton of CO2e,[42] when climate tipping points are included. At $100 per metric ton, the undiscounted value of the emissions avoided by a net-zero-energy home (3,500 square feet) over 30 years would be between $16,500 and $24,300.[43] This range of avoided damage can be compared to approximately $5,000 in costs for solar renewable energy credits and the rooftop solar rebate. The range is due to the varying assumptions about methane leaks in the natural gas system and the value used for the global warming potential of methane. Methane is the principal hydrocarbon in natural gas. A 5% discount rate for the future social cost of carbon reduces these values by about a factor of two.

If 2,000 new homes net-zero-energy detached homes were built to these specifications each year for 10 years,[44] the cumulative avoided CO_2e emissions would be between 3.3 and 4.9 million metric tons of CO2e, mostly from avoided natural gas use. This is a low estimate in one sense since it assumes that Maryland will have a net-zero electricity grid by 2040 (not renewable energy certificates but actual electricity). For reference, Montgomery County's 2018 residential sector emissions were estimated to be 2.53 million metric tons, as noted above.

b. Indoor air pollution

Two major studies released in 2020 concluded that natural gas use inside the home frequently causes significant indoor air pollution, particularly in older homes with unvented natural gas stoves and ovens.[45,46] Even when vented, new homes with gas cooking have higher nitrogen dioxide and carbon monoxide pollution than all-electric homes. One of the findings of the Rocky Mountain Institute study was as follows:

> Cooking food, regardless of the type of stove used, produces certain pollutants, such as particulate matter. To separate emissions generated by the fuel or the food, a key differential is combustion (burning) of gas. Nitrogen dioxide (NO2) and carbon monoxide

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[42] IPCC Chapter 2, 2018, p. 2-77 and 2-78.

[43] The higher value corresponds to a leak rate of 2.3% and a 20-year methane global warming potential of 84. The lower value uses an in-state only leak rate of 0.8% and a 100-year global warming potential of 28. IPCC 2014, Box 3.2, p. 87. Dollar values are rounded.

[44] The number of new homes built each year in Montgomery County has varied a great deal. In the 1980s, new 1-unit homes were built at the rate of almost 6,000 per year. That rate dropped to about 2,700 in the 1990s, about 1,900 in the 2000s, and 1,100 in the 2010s. Residential construction with more than 1 unit has tended to rise – from an average of about 1,000 per year in the 1980-1999 period (rounded) to about 1,500 to 1,700 per year in the 2000-2019 period (rounded). Over 70% of the 1-unit homes in the County are detached homes (Montgomery Housing 2020, Figure 33). Housing construction has been depressed since the Great Recession. It has averaged only about 2,600 units of all types in the 2010-2019 period. Montgomery County estimates the need at 4,200 units per year of all types. Construction since 2015 has been about 2,000 units per year below that, making for a cumulative deficit of about 10,000 housing units in the 2015-2019 period (inclusive). In view of these data, past housing deficit, projected population growth, and estimate of housing needs, 2,000 new detached units per year is a reasonable estimate for putting the greenhouse gas and cost issues in perspective assuming housing construction in the coming decade occurs at a rate about equal to the need. The actual number of new units and the fraction of detached units will depend on many factors, including zoning, population growth, the economic condition of the County and its residents, preferences for different housing types, and the evolution of those preferences over time. New housing data cited are approximate because they were read off from a bar chart: Figure 10 in MNCPPC 2020, p. 21. The estimate of housing need is also on p. 21 of MNCPPC 2020.

[45] Zhu et al. 2020.

[46] Seals and Krasner 2020.

> (CO) are primary pollutants produced from combustion. Nitrogen dioxide levels are consistently higher in homes that cook with gas rather than electric stoves, and cook for longer periods of time. Poorly maintained stoves are more likely to emit elevated levels of carbon monoxide.[47]

While poorly maintained gas stoves result in higher pollution, all gas stove cause more indoor air pollution than comparable cooking with electric stoves. What is worse, there are no air quality standards for indoor air pollution. A UCLA study (Zhu et al. 2020) found that peak indoor nitrogen dioxide (NO_2) exceeded outdoor air quality standards a majority of the time when only the stoves were used and almost all the time when both the stove and oven were used. Carbon monoxide (CO) exceedances, while much less common (usually under 10%), also occurred.[48] In addition to NO_2 and CO, natural gas stoves and ovens are also associated with formaldehyde and fine particulate pollution.

These are dangerous pollutants – which is why there are limits on them for outdoor air quality. But most people spend most of their time indoors. Further, indoor time has increased for tens of millions of people during the CoVid-19 pandemic, along with increased at-home cooking. All other things being equal, people cooking at home with electric stoves and ovens are less at risk of breathing seriously polluted air.

There is also some Maryland-specific evidence of indoor air pollution. Measurements of NO_2 in 30 homes in Baltimore found elevated levels associated with use of gas cooking stoves, often at levels that are unhealthy for children and older people; 29 out of 30 households were African American, and 25 of the 30 rented their homes.[49] The study did not measure carbon monoxide. This Johns Hopkins study provides clear, if limited, evidence of indoor air pollution due to natural gas stoves in Maryland's largest city.

The health impacts of NO_2, the most common natural gas-related indoor air pollutant, are briefly noted here. Acute health effects of nitrogen oxides include decreased lung function, aggravation of asthma and stroke, while chronic exposure effects include "premature mortality, lung and breast cancer" as well as respiratory ailments. NO_2 is also associated with adverse pregnancy outcomes, specifically lower birth weight.[50] The impact of the combination of pollutants associated with natural gas stoves and ovens on "childhood respiratory illnesses is not well understood."[51]

c. Natural gas stranded assets

Getting to zero emissions from the energy sector will require, among other things, the elimination of fossil fuels from the buildings sector. The main investments required in the building sector will be to eliminate the use of natural gas, propane, and fuel oil for space and water heating in existing buildings. Adding natural gas infrastructure in new buildings compounds this problem. New natural gas

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[47] Seals and Krasner 2020, p. 7.
[48] Zhu et al. 2020, p.
[49] Paulin et al. 2017.
[50] J. Lepeule et al. 2010.
[51] Seals and Krasner 2020, p. 13.

infrastructure for any purpose, including for use in buildings, is at odds with Montgomery County's policy of zero greenhouse gas emissions by 2035. The life of natural gas infrastructure is much longer than 15 years. This will create the problem of stranded assets for homeowners as well as utilities.

Were natural gas heated new homes more economical than net-zero-energy homes with rooftop solar, there would be some tension between economics of homeownership and the County's climate policy. But there is not. The conclusion that net-zero-energy solar homes are more economical is robust across a wide range of relevant parameters. There is therefore no reason to add to the burden of transitioning to a zero-emissions buildings sector by adding to the stock of homes that burn natural gas.

We should note that the largest fraction of CO_2e emissions in a natural gas heated home is due to direct use of natural gas, even if we use a low estimate for methane leaks that excludes out of state leaks. The emissions estimate increases substantially when methane leaks from the entire production and supply system of natural gas are taken into account and a 20-year warming potential for methane is used.

The 2015 Paris Agreement goals will necessitate the phaseout of the use of all or almost all fossil fuels, including natural gas, in the next few decades. Montgomery County's goals are even more ambitious. As natural gas use declines significantly, the large, relatively fixed cost of the distribution system will have to be spread over smaller and smaller amounts of natural gas. The cost per million Btu of natural gas delivered to the home will rise as a result. Existing buildings using natural gas are already vulnerable to this risk; new homes would unnecessarily add to that number. We have not quantified this risk.

IV. Economic equity considerations

Low- and moderate-income households face higher obstacles than other households to purchasing homes and getting mortgages. Increasing the first cost of a new home and hence the amount of the mortgage would raise the bar and make the system more inequitable than it already is. Therefore it is essential that a net-zero-energy solar mandate, which this analysis clearly indicates is appropriate and desirable, be accompanied by policies that, at the minimum, do not increase obstacles to homeownership for low- and moderate-income households. At best, policies should lower the obstacles that currently exist.

a. First cost hurdle

A net-zero-energy home with rooftop solar would cost about $7.40 per square foot more than a natural gas-heated home built to the same standard (other than the space and water heating heat pumps and induction range). This represents a construction cost increase of about 4.4%, assuming a construction cost of $170 per square foot.[52] Assuming a down payment of 20%, then first cost of the house increases by almost $1.50 per square foot, amounting to about $5,250 for a 3,500 square foot home and about $3,600 for a 2,400 square foot home.

The increased down payment can be covered by a grant. Such a grant (or rebate) should be compared to other grants currently provided to homeowners. For instance, for just one piece of the home's

[52] https://www.homeadvisor.com/cost/architects-and-engineers/build-a-house/#calc – including a basement. The national average is $115 per square foot. https://www.24hplans.com/how-much-does-it-cost-build-new-house/

energy system, a geothermal heat pump, the State of Maryland provides a grant (or rebate) of $3,000. In addition, utilities provide a rebate of $500, for a total of $3,500. There is no income test to get the incentive. The climate and environmental value of a geothermal heat pump is substantial, but that of a net-zero-energy home is much larger.

The facts indicate that the most straightforward way to approach equity would be to give low- and moderate-income purchasers of a new home an outright grant corresponding to the increased down payment. Such a grant is amply justified. First, the amount would be broadly comparable to the incentives already being paid out for geothermal heat pumps, regardless of household income. Further, low- and moderate-income households, about 40% of the state's households, have very low ownership of solar, because they have not been able to take advantage of the available incentives for a variety of reasons, including relatively high first cost. Rolling the cost of solar into a mortgage makes it affordable because the added monthly cost would be less than the normal energy bills.

Moreover, there is the simple issue of fairness. The cost of the most important incentive for solar, notably Solar Renewable Energy Credits, is ultimately picked up by the state's electric utilities and added to electricity bills. Thus, low- and moderate-income households have contributed to the development of solar in Maryland but have not benefited correspondingly. A net-zero-energy mandate for new detached homes would not fully redress this imbalance, but it is one easy place to reduce the disparities.

The total amounts involved in such a grant are likely to be small. For instance, if 10% of new detached single-family homebuyers in Montgomery County were low- or moderate-income, and 2,000 detached homes are built each year, the total cost would be on the order of $1 million per year, possibly less.

A policy of an outright grant would have significant social benefits for the county. It would provide greater stability of homeownership since the cost of owning a net-zero-energy solar home would be lower than the cost of a gas-heated, when utility bills are included. Conflicts between paying utility bills and mortgages are all too frequent; they sometimes result in the loss of homes.[53] A net-zero-energy home would mitigate such conflicts, reducing the risk of default, making it less likely that the mortgage holders would lose their homes. Besides the benefit of this reduced risk to households themselves, the social benefits accruing to society of preventing loss of a home are large. Each homelessness event cause by rent/mortgage and utility bill conflicts costs society (taxpayers, health insurance companies, hospitals, charitable agencies) tens of thousands of dollars in the form of higher shelter costs and more frequent emergency room visits.[54] There are, of course, costs to the families themselves such as loss of jobs or lower productivity at work and school.

Ensuring sound construction and installation of the solar and heat pump systems will be especially important for low- and moderate-income purchasers. Premature failure or poor performance would disproportionately affect low- and moderate-income households adversely. It is all the more essential in such cases to ensure that construction is sound and warranties are honored and inspections be rigorous.

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[53] Makhijani, Mills, and Makhijani 2015, pp. 87-91

[54] Arjun Makhijani, Christina Mills, and Annie Makhijani, *Energy Justice in Maryland's Residential and Renewable Energy Sectors*, Institute for Energy and Environmental Research, Takoma Park, Maryland, 2015. On the Web at https://ieer.org/wp/wp-content/uploads/2015/10/RenMD-EnergyJustice-Report-Oct2015.pdf

b. Fannie Mae and Freddie Mac

Most mortgages do not remain with their originators but rather are sold to the federally-supported agencies known as Fannie Mae and Freddie Mac. These agencies purchase mortgages and bundle them to be sold as investment instruments. Fannie Mae and Freddie Mac's approach to solar differs on whether the property owner owns the solar system or leases it. The ownership provision is straightforward: Fannie Mae will purchase or securitize such mortgages:

> Fannie Mae will purchase or securitize a mortgage loan on a property with solar panels. If the property owner is the owner of the solar panels, standard eligibility requirements apply (for example, appraisal, insurance, and title).[55]

There are a number of restrictions if the system is "leased from or owned by a third party under a power purchase agreement or other similar arrangement…."[56] The restrictions are extensive and include a provision that disallows the inclusion of the value of solar in the value of the home. They could be burdensome for any homeowner but especially for low- and moderate-income homeowners. *The most straightforward way to address this problem is to have ownership of the solar by the property owner as part of the sale of the home.*

Freddie Mac purchases "GreenCHOICE" mortgages that encourage lower utility bills through higher efficiency homes to put "families in a better financial situation and helps preserve home affordability over time."[57]

c. A 2,400 square-foot detached home

The reference home analyzed above is a 3,500 square foot, detached structure; the size was chosen to be slightly higher than the average for new detached homes in 2015. Smaller homes are also built and, as such, they are more affordable, all else being equal. We therefore did an analysis of a 2,400 square foot net-zero-energy home with rooftop solar and compared it to a gas-heated home, with all other parameters remaining the same as in the base case of the 3,500 square foot home. The result is also the same – the net-zero-energy home with rooftop solar is more economical. Of course the overall energy use is lower, resulting in smaller rooftop solar to meet the net-zero-energy standard. Table 4 shows a summary of the analysis.

Table 4: Comparison of a 2,400 square foot new net-zero-energy energy home with a gas-heated home.

	Net-zero-energy	Gas-heated	Comments
Size of home, square feet	2,400	2,400	
Electricity use, kWh/year	11,634	5,734	
Natural gas use, million Btu/year	0	54	
Solar system size, kW-dc	9.5	N/A	
Added first cost of net-zero-energy home	$18,120	N/A	After SREC sale and state and utility rebates

[55] Fannie Mae 2020
[56] Fannie Mae 2020
[57] Freddie Mac 2020

Down payment increase	$3,624	N/A	Assuming 20% down payment
Average annual energy cost, $/year	$1,251	$2,064	
Average annual savings of net zero home	$813	N/A	
Cumulative greenhouse gas emissions, mt CO2e	0	168	20-y warming potential for methane, over 30 years
Social cost of cumulative greenhouse gas emissions	0	$16,754	@$100 per metric ton CO2e

d. Maryland's loan program for efficient homes

Maryland's Department of Housing and Community Development has a loan program that aims to promote efficient homes, as measured by the Home Energy Rating System ("HERS") Index; a score of 100 on this index is a reference home. A HERS score of zero is a net-zero-energy home. The loan program provides builders 12-month construction loans at a 2% annual interest rate for a net-zero home, which DHCD defines as having a HERS Index of 0 to 15.[58] Table 5 shows that a builder of a 2,400 square foot house would save about $2,000 on interest cost, assuming a six month construction period. The savings on a 3,500 square foot home would be over $3,200. We assume these savings in interest would accrue to the builder and be a substitute for any mark-up of the added construction cost of a net-zero-energy mandate.

Table 5: Builder's interest savings using the Maryland program to promote efficient home construction

	Gas-heated	Net-zero	Comments
Construction cost $ per sq. ft.	$170	$170	including basement
Construction cost, 2,400 sq. ft.	$408,000	$408,000	2,400 sq. ft.
Added construction cost for net-zero home	$0	$22,530	Gross added cost
Total construction cost	$408,000	$430,530	
Commercial construction loan amount	$408,000	$43,053	DHCD max. loan to value is 90%. Also see Note 1.
DHCD loan amount	$0	$387,477	
Commercial construction loan rate, %	5.5%	5.5%	Prime rate +1.5%; Note 1.
DHCD loan rate for net-zero home	N/A	2%	
Total interest during construction	$11,220	$9,223	Six-month loan; includes DHCD 1% admin. fee + $290 application fee for net-zero home
Interest cost savings for builder with net-zero DHCD loan	N/A	$1,997	

[58] DHCD 2020

Builder savings as % of added construction cost for net-zero construction	0	9%	

Note 1: We assume that any capital put up by the builder has the same cost as a commercial loan
Source for Maryland program rules: DHCD 2020. Source for building cost: Promatcher Cost Report.[59] For construction loan interest rate, Korte 2020 cites rates of the prime rate "plus one or two percent." Prime rates since 2015 have varied from a low of 3.25% to a high of 5.5%. Based on this, the range for construction loans would be 4.25% to 7.5%. per year; 5.5% is a bit below the average. For prime rate history see HSH 2020.

e. Homes other than detached structures

In principle, a net-zero-energy mandate can also be considered for residential structures other than single family detached homes. Townhomes, with high building envelope performance and very efficient appliances may be able to achieve full net-zero-energy performance, with rooftop solar but possibly not with the Energy Use Intensity we have chosen (16.54 kBtu/sq. ft.). A tighter standard, along the lines recommended by the County's Building's Workgroup, between 5 and 10 Btu/sq. ft. would likely make net-zero-energy feasible in many or most new townhomes. For instance, a 2,400 square foot net-zero townhome with an Energy Use Intensity of 7.5 kBtu/sq. ft. would require only about eleven solar panels of 380 watts each and only seven panels of 600 watts each for the needed 4.18 kW-dc of solar capacity. An evaluation of the construction cost implications of such a stringent standard is not within the scope of the present report. Considering that townhomes are often built as affordable housing, a detailed evaluation of the tradeoff is warranted.

New multi-unit structures would likely not be able to meet electricity requirements solely from the rooftop. But dedicated community solar systems could provide the balance of the electricity not met from the rooftop. The combination would be at least as economical as a rooftop system. This would make net-zero-energy performance in multi-unit buildings possible with a combination of the two systems. The same applies to townhomes. In principle therefore, there is a strong case for mandating net-zero-energy performance for new townhomes and multi-unit structures with the proviso that the amount of estimated electricity use that cannot be provided by a rooftop solar installation be provided by a *dedicated* community solar installation. However, some practical issues need to be addressed.

First, the community solar program in Maryland is a pilot program of limited duration and capacity. A durable net-zero mandate combining rooftop and community solar would require certainty for the long-term that community solar capacity is available. This can only be achieved if the community solar program is made permanent.

Second, community solar installations are developed by the solar industry. Acquiring the land (since they are usually ground-mounted), planning, permitting, construction and commissioning happen on rhythms that are different from the residential construction industry. With rooftop solar, the builder can contract for the solar or even integrate solar operations into the company's roofing operations, an option explored by the National Renewable Energy Laboratory.[60] But at this time, it is not clear how dedicated community solar capacity could be joined in a timely and efficient way with new townhome

[59] The Promatcher Cost Report cites costs from various parts of Maryland. We used, $170, which is the average value for Bethesda rounded up to the nearest $10 per square foot. The value for Gaithersburg is the same.
[60] Ardani et al. 2019

and multi-unit residential construction so as to achieve net-zero-energy performance at the time of sale of the new home.

Yet, the economic and environmental attractiveness of a net-zero-energy mandate remains, as does the climate emergency. The challenges of coordination between the two industries to ensure that both proceed smoothly in new townhome and multi-unit developments are well worth addressing and resolving.

V. Options for net-zero-energy homes other than occupant-owned solar

Ownership of rooftop solar and a net-zero energy performance standard would together be the most straightforward mandate for new detached residential homes. We briefly review other options in this chapter.

a. Third-party ownership

The developer or other third party could own the rooftop solar and provide the electricity at a discount to the homeowners. Another option would be for the homeowner to lease the rooftop solar. However, neither of these options is conducive to Fannie Mae rules for mortgages, which are oriented to ownership of the solar by the homeowner. Therefore, they should not be implemented. Ownership of the rooftop solar and the home should go together.

But other options are compatible with homeowner ownership of rooftop solar. For instance, a number of such systems in new developments could be combined with third-party ownership of storage to make up a microgrid. Residential rooftop solar in Maryland is normally "behind-the-meter": that is, electricity generated on the rooftop is consumed inside the house. If there is any surplus it is exported to the grid; the deficits are imported from the grid. A solar microgrid with rooftop systems tied together would enable "in-front-of-the-meter" solar as an option, with the electricity being managed by the microgrid operator.

Local storage would increase system resilience by providing electricity to the connected homes for essential uses during times of grid outage. Rules for appropriate compensation of microgrid electricity would need to be worked out. Compensation for solar electricity at the net metered rate would be a good starting point since it would result in the same costs and benefits for the homeowner as a behind-the-meter system. Given the need for increasing resilience in a manner compatible with reducing greenhouse gas emissions, the county should explore this concept for situations were a number of new homes are being built in an area.

b. Community solar

Community solar systems have been proposed as an alternative to rooftop solar for fulfilling net-zero-energy mandates. Such an approach to meeting California's solar mandate was proposed by the Sacramento Municipal Utility District and accepted by the California Energy Commission.[61] Given the analysis in this report showing that net-zero-energy homes with rooftop solar are economical and save

[61] SMUD 2020

money relative to natural gas heated homes, such an exception for new detached housing is unwarranted, at least in Maryland.

Space for expanding solar in Montgomery County is at a premium. Giving preference to rooftop solar and other locations not on farmland was one of the recommendations of the County's Climate Workgroup.[62] The space for ground-mounted community solar is also at a premium, given the high value of land in the county and the significant portion that has been set aside as an Agricultural Reserve.[63] Community solar installations, especially of the ground-mounted variety, should be reserved for renters, for low- and moderate-income households who cannot afford solar and for all owner-occupied households who have unsuitable rooftops. Community solar could also be used for meeting the part of net-zero-energy requirement for new townhomes and new multifamily housing that cannot be reasonably met by rooftop solar. Such provisions would be in the spirit of the arguments made for community solar in the context of net-zero-energy buildings by the American Council for an Energy Efficient Economy.[64]

> Community renewable energy can help buildings with little access to onsite renewable energy (e.g., due to lack of available roof area or excessive shading) achieve zero energy. Particularly energy- intensive buildings may not achieve ZEB performance without community solar.

c. "Solar-ready" homes

Some have argued for "solar-ready" homes – that is, houses that have all the electrical and physical infrastructure to accommodate rooftop solar, including for a net-zero-energy home, but without the solar installation, which is the largest investment needed to achieve the net-zero target. Such arguments had some merit for new construction when solar costs were high.[65] But those conditions no longer apply. It is important to reiterate in this context that, in considering the cost issue, it is essential take into account the significant cost reductions that go with a mandate, relative to solar retrofitted on existing homes on a custom basis. The analysis in Section II.c. shows that, in a fair market, a solar mandate would necessarily result in reducing the cost of a rooftop solar installation because it eliminates or reduces major cost elements that characterize custom retrofits. In Maryland, builders also benefit by having access to very low interest construction loans (at 2%) from the Department of Housing and Community Development.

Our analysis also shows that a new net-zero-energy "solar-ready" home *would incur an increased first cost of a few thousand dollars for being ready but not reap the economic benefits.* Energy bills due to the added electricity use plus few thousand dollars needed to make the house solar ready would make the home more expensive than a natural gas home, especially at current low natural gas prices. The energy cost of a solar ready home of 3,500 square feet would average about $600 per year more than a

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[62] Montgomery County Climate Workgroup 2020. Carbon Sequestration, Appendix B, pdf p. 7

[63] The issue of solar on farmland is a complex topic that is beyond the scope of this report. It is an area of research at IEER.

[64] Perry 2018, p. 6

[65] Rooftop solar costs would have to be $3.50 per watt-dc in the Pepco service area and $3 in the Potomac Edison area for average annual energy costs of new net-zero-energy homes and natural gas heated homes to be comparable, using other base case parameters. Both are higher than retrofitted rooftop costs and 75% and 50% higher (respectively) than the $2 per watt-dc cost we have estimated for the base case comparison.

gas-heated home. In contrast, the energy cost of the same home with rooftop solar sufficient to make it a net-zero-energy home would average $1,200 per year less than a gas-heated home over the life of the mortgage.

In addition, if the mandate is for solar-ready structures, many (most?) home builders would likely not install solar with the aim of reducing the home's sticker price. In such cases, when an individual owner of a solar-ready home decides to acquire solar, the cost would be higher than if it were installed at the time of development – since it would be an installation on a retrofit basis. In sum, a "solar-ready" approach to new detached homes is obsolete due to the decrease in solar costs in recent years. It leads higher costs without corresponding environmental benefits. It is an economically and ecologically obsolete idea.

Is a solar-ready mandate appropriate for deep retrofits of existing homes? Or should there be a rooftop solar mandate instead? These are important questions that have not been addressed explicitly in the present analysis. A net-zero mandate for new homes would be economical for solar for cost of solar less than $3 to $3.50 per watt-dc, depending on electricity rates. The cost of custom retrofits of residential solar is already less than $3 per watt. Moreover, a National Renewable Energy Laboratory report indicates that costs would decline in the context of a mandate for rooftop solar as part of deep retrofits.[66]

The above considerations indicate that a rooftop solar mandate at the time of deep retrofits is warranted on general economic and climate change mitigation grounds. However, some additional study is needed to determine the specific circumstances in which this generic analysis would translate into an economic advantage at specific sites. For instance, issues such as roof orientation and shading that often limit solar output be per unit of installed capacity would need to be considered. Given Montgomery County's ambitious climate goals and the economics of rooftop solar, a deeper look at how solar may fit into the permitting process for deep retrofits is warranted.

VI. Conclusions

- A net-zero-energy with rooftop solar mandate for new single-family detached homes is clearly supported by this analysis. It is more economical and has significant environmental and health advantages.
- The higher first cost of a net-zero home would create an additional barrier for low- and moderate-income people to purchase a home and get a mortgage unless suitably offset. The additional down payment needed is small enough to be provided as a grant to qualified prospective purchasers. Such a policy should be put into place; the estimated cost to the county would be a few thousand dollars per eligible household and overall cost on the order of one million dollars per year or less. For comparison, the state's rebate just for a geothermal heat pump is $3,000, plus an added $500 from the utility. Thus, the recommended grant is comparable to a geothermal heat pump rebate, which has no income qualification.
- It is essential that Montgomery County conduct stringent inspections to ensure the quality of equipment and construction and the proper transfer of warranties to the property owners.

[66] Ardani et al. 2018

- Since premature equipment failure would disproportionately affect low- and moderate-income households, the County might consider providing low- to no-cost insurance to them for the expected life of the equipment.
- Net-zero-energy mandates can be economical for other types of new construction and for deep retrofits. In contrast to new detached residential construction, there are significant issues associated with making such mandates practical and efficient. Resolving them would make residential energy more economical and allow more progress towards the county's climate goals.
- A "solar-ready" approach to new detached home construction would result in higher cost without concomitant benefits; it is obsolete and should not be pursued.
- Net metering is an important policy instrument for valuing solar. Unless renewed it will expire once net-metered installations reach a capacity of 1,500 megawatts. Maryland net metering capacity should be doubled to 3,000 MW. This is especially critical for low- and moderate-income households who have so far benefited only minimally from Maryland's promotion of solar energy.

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