Ground Source Heat Pumps: Peak Impacts in Maryland

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Summary

- Significant deployment of ground source heat pumps would meaningfully reduce summer peak electricity demand in Maryland, due to their greater efficiency relative to conventional air conditioning systems.
- For a representative Maryland house, a ground source heat pump would reduce peak consumption by about 1.5 kW. This would save about $179 per year in overall peak-related system costs associated with generation, transmission and distribution.
- Relating this total value to the number of thermal RECs that would be created by such a replacement yields a range of about $6 to $8 per thermal REC.

I. Introduction

Maryland, like a number of other states, has adopted plans to begin decarbonizing its energy sector and the broader economy. An October 2019 draft plan from the Maryland Department of the Environment increased the state's ambitions, with a goal of a 44% reduction in greenhouse gas (GHG) emissions by 2030, relative to a 2006 baseline. Electrification of heating and transportation is one of the most promising pathways for decarbonizing large portions of the economy. Heating, for example, traditionally involves the direct onsite combustion of fossil fuels (fuel oil, natural gas, propane, for space and water heating), and accounts for a significant share of the state's overall emissions.[1] Rather than burning fossil fuels in the building, heat pumps driven by electricity can provide heating. This can enable essentially total decarbonization of heating if the heat pump is powered by clean or renewable electricity.[2]

There are two broad classes of electric heat pumps – air-source heat pumps (ASHP) and ground-source heat pumps (GSHP) – with many different designs, configurations, models and sizes of each. The basic difference is that air-source heat pumps use the outside air as the source or sink for heat, using a heat exchanger to transfer heat between the working fluid of the heat pump and the outside air. Ground-source heat pumps use the constant temperature of the ground beginning a few feet below the surface, usually accessed via water circulating in a series of underground pipes to transfer heat between the heat pump and the ground. Both types of heat pump can operate in either direction, to heat or to cool a building.[3] In winter, electrified heating replaces fossil fuel burned in a furnace or boiler for space heating. In summer, the same heat pump provides cooling, replacing a central or room air conditioner as well.

Heat pumps can offer additional benefits beyond decarbonization, and one of those benefits is the subject of this brief paper. Here, we consider how ground-source heat pumps may help to reduce the electricity system peak – the highest demand for electricity at any one time. Electricity is not easily stored, so it must be produced and delivered at the same time it is consumed. Consumption varies considerably across the hours of the day, being higher in the morning and evening, and lowest overnight. It also varies seasonally, with overall peaks in summer and winter corresponding to electricity used for space cooling and heating. Each part of the electricity system – the generators that produce the power, the bulk transmission network that moves power over long distances, and the local distribution system that moves power from a substation to homes and businesses where it is consumed – must be sized to accommodate peak electricity consumption conditions. This means that reducing the system peak (or limiting growth in peak) saves costs throughout the power system.

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[1] Residential, commercial and industrial fuel use, of which a substantial component is for heating, accounts for 17% of the state's total GHG emissions. See Figure ES-1, State of Maryland 2017 Greenhouse Gas Emission Inventory Documentation, Maryland Department of the Environment, July 26, 2019.

[2] A heat pump will typically achieve some GHG reductions even when powered by conventional fossil-fired electricity, simply because it uses less electricity overall. Once installed, a heat pump becomes cleaner as the electric grid is decarbonized, with no further onsite intervention.

[3] A GSHP system in particular may be configured so that it can also provide water heating year-round.

II. How GSHP Affects Electricity System Peak

To understand the potential impact of a GSHP on system peak, it is necessary to understand what technology it displaces at the time of system peak. Maryland, like the much larger PJM electricity system of which it is part, is currently a summer-peaking system.[4] High electricity consumption by air conditioning in hot summer weather drives the electricity demand peak. At the summer electricity peak, typically late afternoon on one of the hottest summer days, an efficient GSHP would displace the conventional air conditioner that would otherwise be used to keep the building cool. An air conditioner requires a considerable amount of electricity to keep a building cool, particularly in extreme heat when the building requires more cooling in total, and the air conditioner itself becomes less efficient because it must work harder to reject heat to the hotter outside air. A GSHP uses less electricity to provide the same amount of cooling under these peak conditions, for several reasons. In part, the heat pump equipment itself is typically more efficient than most conventional air conditioners (and its efficiency degrades less over time since the equipment is housed indoors, protected from harsh weather, dust, etc.). Its efficiency is also enhanced by the fact that water absorbs heat more readily than air, and that the ground is a somewhat cooler heat sink.[5] The reduction in system peak attributable to the GSHP is thus the difference between the electricity demand of the air conditioner and that of the GSHP under those peak conditions.[6]

In the considerably longer term, Maryland and PJM could become winter peaking if electrification of heating becomes widespread as a means of decarbonizing the economy. Although the winter electric peak is not currently as high as the summer peak in the region, loads are higher in winter than in spring or fall, due largely to the use of electric resistance space heating (both as the primary heat source in some homes, and for auxiliary heat from portable electric space heaters in others). Widespread adoption of electric heat pumps as a substitute for fossil fuel heat (natural gas, heating oil, propane) would increase winter peak

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[4] Maryland is part of the PJM Interconnection, the world's largest wholesale electricity market, stretching from Virginia to Chicago.

[5] The heat sink for a GSHP is not as cool as the normal ambient ground temperature of about 55˚F (the ground does warm up somewhat as the GSHP transfers heat to it over time), but it is cooler than the outside air at peak times.

[6] Air conditioner penetration is very high in Maryland, mostly relying on central air conditioning systems (see U.S. Census Bureau, American Housing Survey data). For this calculation, we assume a GSHP displaces a typical central air conditioning system, rather than replacing room air conditioning (which is less efficient) or simply adding cooling to a building that would not have it otherwise.

electric loads. This is particularly true if electrification involves ASHPs. Not only does a building need more heat as it gets colder outside (an issue for any heat source), but the efficiency of an ASHP declines as the outside temperature falls. This is because the heat pump must work harder, using more electricity, to extract heat from the colder ambient air. So just when the demand for heat is greatest, an ASHP must use more electricity to extract each unit of heat. In heating mode, a GSHP uses less electricity than an ASHP to provide the same amount of heat. While the GSHP and ASHP both use efficient heat pump equipment, the GSHP has an advantage in operation compared to an ASHP. Water transmits heat more readily, and on the coldest days, the temperature of water underground is higher than the outside air temperature; both of these factors make it easier for the GSHP to extract heat, improving efficiency. Further, since ASHP efficiency does decrease as the outside temperature falls, ASHP systems often use electric resistance heat to supplement their output capacity for extreme cold conditions. Thus during winter heat peak conditions, even when comparing to an ASHP system, a GSHP may actually displace electric resistance heat, which is even less efficient than the ASHP equipment itself.

III. Estimating the Peak Impact of GSHP

We have estimated the potential impact that GSHP installation may have on summer peak loads in Maryland, based on energy consumption and performance measures for a typical residential GSHP installation, compared with the alternative conventional central air conditioning system that it would displace.[7] A representative Maryland single-family house may have a peak cooling need of 36,800 Btu/hour (approximately three tons). To cool this house, a GSHP (peak design day EER of 16.0; average annual EER 20.8) would use 2.3 kW at peak conditions. To provide the same amount of cooling for this house using a conventional air conditioner with average efficiency (peak design day EER of 9.8; average annual EER 12.2) would use about 3.8 kW at the peak. That is, the GSHP uses about 39% less electricity than a conventional air conditioner under peak conditions, reducing system load by about 1.5 kW.

In evaluating their energy efficiency and peak load management programs, the Maryland utilities estimate the value of avoided capacity as approximately $121/kW-year in the near

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[7] Performance data was provided by the Maryland Geothermal Association and Dandelion Energy.

term.[8] This value reflects avoided costs across the electric system, including costs associated with generation, transmission and distribution, as well as line losses and RPS compliance costs. Applying this value of avoided capacity to the amount of capacity avoided for the representative Maryland house, estimated above, yields an annual value of about $179 (= 1.5 kW * $121/kW-year). See calculations in Table 1 below, comparing the peak impact and value of a GSHP vs an average conventional air conditioning system.

TABLE 1: PEAK IMPACT AND VALUE, GSHP VS AVERAGE-EFFICIENCY A/C

	Units	**GSHP**	**Average A/C**	**Difference**
House Cooling Requirement	Btu/hour	36,800	36,800	
Design Day EER	Btu/Watt-hour	16.0	9.8	
Peak Electricity Demand	kW	2.3	3.8	1.5
Value of Avoided Capacity	$/kW-year	$121	$121	
Value of Avoided Capacity	**$/year**	**$279**	**$458**	**$179**

To put this in context, under Maryland REC accounting rules, a GSHP such as this would earn thermal RECs, with the REC quantity based on the type and efficiency of the heating and cooling systems being replaced. Replacing an oil heat system with central A/C would earn approximately 29 thermal RECs, while replacing electric resistance (also with central A/C) would earn about 23 thermal RECs; replacing a natural gas heating system would have a value between these. Thus, calculating the potential value of avoided system capacity cost per thermal REC yields a range of about $6 to $8 per thermal REC. Regardless of the heating system that is replaced by the GSHP, the peak impact and its total dollar value would be the same (given the assumption about the efficiency of the central A/C system being replaced). But the number of RECs earned by the replacement depends on the heating system that is replaced, with an oil replacement yielding more RECs and thus a lower value per REC, while replacing electric resistance yields fewer RECs and a higher value per REC. Replacing natural gas would yield an intermediate value. Table 2 below presents representative calculations. These values do not necessarily characterize any particular house or GSHP installation. The actual values in any particular instance will depend importantly on the thermal requirements of the house and the type and efficiency of the heating and cooling equipment that is replaced.

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[8] EmPOWER Energy Efficiency Programs Strategic Evaluation Guidance, Evaluation Advisory Group, February 22, 2019. See Appendix C, Cost Effectiveness Assumptions, Avoided Capacity ($/kW-year). The value used here, $121/kW-year, is the weighted average across the values for the Maryland utilities for 2021.

TABLE 2: REPRESENTATIVE RANGE OF PEAK CAPACITY VALUE OF GSHP, PER THERMAL REC

	Units	Replace Oil	Replace Natural Gas	Replace Electric Resistance
Avoided Capacity Value	$/year	$179	$179	$179
Approx. Number of Thermal RECs		29	25	23
Estimated Value per Thermal REC	**$/Thermal REC**	**$6**	**$7**	**$8**

The total avoided capacity value of course depends on the cooling requirements of the house involved. A house with larger or smaller cooling requirements would provide proportionally larger or smaller total peak reduction, and thus larger or smaller avoided cost value. Still, the range of values per thermal REC would be similar across houses with different cooling requirements (given the particular type and efficiency of the heating system being replaced). This is because both the magnitude of the peak impact and the number of thermal RECs earned will scale up or down proportionally with the house's thermal requirements. For larger buildings, such as multi-family housing, commercial buildings, schools or hospitals, generally similar relationships would hold. The magnitudes might differ since the technologies and efficiencies of the relevant cooling systems (for both GHSP and conventional air conditioning systems) may differ from those that are typical in residential home installations. Still, a GSHP system is likely to be materially more efficient than a conventional air conditioning system under peak conditions, for most any size or type of building.

A similar conceptual relationship would apply in the long run future if widespread electrification of heat shifts the system peak to winter. In this case, the winter peak impact of GSHP is not measured relative to an air-conditioning unit, of course, but rather to ASHP and/or electric resistance heating. It is difficult to estimate the value of the impact because by the time the system might become winter peaking, the avoided capacity value could be quite different. All the components of avoided capacity value – generation, transmission, and distribution – would change, perhaps substantially, in a much more heavily renewable future with highly electrified heating. For generation, the value of capacity is likely to change substantially with the introduction of large quantities of intermittent renewable generation, and probably storage technologies. Both the transmission and distribution systems will need to change significantly to accommodate much higher electric loads, a changing geographic distribution of generation, and potentially much more distributed generation.

This paper considers only the system peak benefits of a GSHP system, though of course there are other benefits, primarily the reduction in GHGs (and other pollutants) that GSHP enables. To estimate these benefits requires comparing the electricity consumption of the GSHP and the GHG intensity of grid electricity, relative to the GHGs emitted by the systems that would be replaced (direct fossil burning for winter heating, electricity for summer cooling with a conventional air conditioner). GSHPs also ease the transition to a decarbonized grid by reducing the total amount of electric energy and capacity that the grid must supply in the long run.