Density vs. Distance: Housing and Transportation Energy Tradeoffs

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ABSTRACT

We compare the energy use and emissions of an efficient, infill accessory dwelling unit (ADU) with a studio unit in a greenfield multifamily building. We also account for energy and emissions differences in transportation emissions that might result. This study considers the emissions and energy to operate different housing types as well as the energy use and emissions related to transportation of occupants. With the assumption that greenfield development would lead to longer commutes, we quantify the tradeoffs that exist between housing location (infill development vs greenfield) and housing type (ADU vs multifamily). Using BEopt, we model operating energy use and emissions for a small ADU and multifamily apartment unit of equal size (400 square feet) across a range of design choices and across different climates (Seattle, Chicago, Phoenix, Atlanta). We estimate the annual breakeven distance that would lead to equivalent emissions between the housing types using the GREET vehicle emissions model and estimate future emissions from different housing types using forecasts of long run marginal emissions. The results show that the annualized energy use and emissions for an efficient ADU are a lower emissions choice if they reduce internal combustion engine vehicle miles traveled by only 130-1400 miles per year (0.5-5.4 mile longer roundtrip commute per workday) compared to the greenfield multifamily option in the locations that we investigated. When typical electric vehicles are considered, this distance increases to 280-2800 miles per year (1.1-11 mile longer roundtrip commute per workday).

Introduction

The challenges of housing affordability and climate change may encourage growth of housing types other than the traditional single-family home. Policymakers are encouraging infill housing of all scales, from elimination of single-family zoning, encouraging more infill multifamily development, and loosening restrictions on accessory dwelling units (ADUs) that can be added on existing single-family lots. All of these options have the potential to reduce costs and potentially reduce energy use compared to single family homes (Berrill et al. 2021). ADUs have the potential to increase density in existing neighborhoods and may provide rental income streams to their owners. Multifamily housing has potential advantages of lower cost per unit compared to single family homes and lower heating energy use per unit of floor area (Obrinsky and Walter 2016). Since heating energy use is driven primarily by the temperature difference between inside and outside, the total envelope area, and the R-value of envelope components, it stands to reason that a house with less envelope area will have lower heating (and cooling) demand compared to a unit with more envelope area. However, lower construction costs and cheaper land can shift multifamily housing to suburban areas, with the land use and transportation impacts potentially undermining the efficiency and emissions advantages of the multifamily housing type.

Estimating the magnitude of this effect and putting it in context with transportation emissions is a core result of this paper. Prior studies have shown that multifamily housing uses less energy than single family homes, and transit-oriented development can further reduce energy use (Jonathan Rose Companies 2011). The purpose of this study is a targeted comparison of greenfield multifamily with infill ADUs.

While the core purpose of this study was to better understand the envelope area to floor area effect, there are other factors that can impact energy use and emissions. For example, there may be economies of scale in heating and cooling systems. Larger systems can potentially be more efficient by including advanced technology that may not be included in smaller units. Larger heat exchanger surface area will lead to efficiency gains at part load and aggregated demand will lead to smoother load profiles. There may, however, be larger losses in the distribution system of larger systems. Both ADUs and multifamily buildings may benefit from construction advantages of prefabrication which can reduce construction waste (Zohourian et al. 2025). ADUs have the potential to avoid new infrastructure investments by using existing utility services. While we compare two housing units of equal size, a reduction in floor area per person also has the potential to reduce embodied energy and emissions. When compared per capita or per unit, tiny homes perform better than single-family homes and multifamily units, though with less floor area per occupant (Kuittinen et al. 2023).

Given current patterns of urban growth, land availability, and development costs, there are four relevant new construction housing types to compare: (1) single family neighborhoods or (2) low-rise multifamily suburban homes on undeveloped land, (3) ADUs that add density to urban single-family neighborhoods, or (4) multifamily urban infill redevelopment. If we compare the total emissions from both housing and transportation, it is clear that multifamily buildings near urban cores or near public transit would have the lowest emissions, and single-family homes or ADUs in the suburbs would have higher total emissions. Multifamily buildings have an advantage due to their geometry and housing closer to urban centers would typically reduce vehicle miles traveled (VMT) and the associated emissions from transportation. In this study we focus on the middle two cases (infill ADUs vs greenfield multifamily) where the answer is not obvious. ADUs have the potential to reduce emissions related to transportation when compared to new housing options that might encourage urban sprawl. An EPA study found that if development shifts from the urban fringe to infill locations, vehicle miles traveled (VMT) can be reduced by 30-60% (US EPA 2007). Additionally, Brownstone and Golob find that a lower density of 1000 housing units per square mile imply an increase in driving of 1200 miles per year per household (2009).

Energy use and emissions come both from the materials and construction phase (embodied energy and emissions) and from the operation phase. At first glance, it is not readily apparent which option would be “higher performing” on a lifecycle basis. The answer also likely relies on the set of assumptions that are made in building design, location, and transportation mode/distance. It is important to consider the “whole system” emissions that include embodied energy/emissions from construction, operational energy/emissions, and transportation emissions. While operational energy has historically received significant attention, embodied emissions from material extraction, manufacturing, and transportation represent a quarter of total building lifecycle impacts (Bawden and Williams 2015). As communities seek housing solutions that address both affordability and sustainability, there is a need to better understand how different housing types compare in terms of embodied energy and emissions.

Given that site availability, construction cost, and permitting timelines may be challenging in urban centers relative to suburban areas, the largest share of new multifamily housing is built in semi-urban areas that may have both urban and suburban characteristics (Dale 2025). Where housing is located needs to be considered when determining the true performance of a building. While an efficient multifamily building may perform well, it might be a worse performer than other options when transportation emissions are included if long, vehicle-dependent, commutes are necessary.

In this paper, we begin to evaluate these tradeoffs between housing type and location by comparing two specific options: an infill ADU with a studio unit in a greenfield multifamily development. We recognize that many more options are worthy of consideration in future work, but we begin our analysis with these two options. We seek to determine the breakeven annual marginal travel distance where locational advantages of ADUs might start to outweigh thermal performance advantages of multifamily buildings. Figure 1 shows a hypothetical decision between two options. Bellingham, WA has a small urban core surrounded by single family homes with the potential for ADU development. There also is rapid development of multifamily buildings further away from downtown.

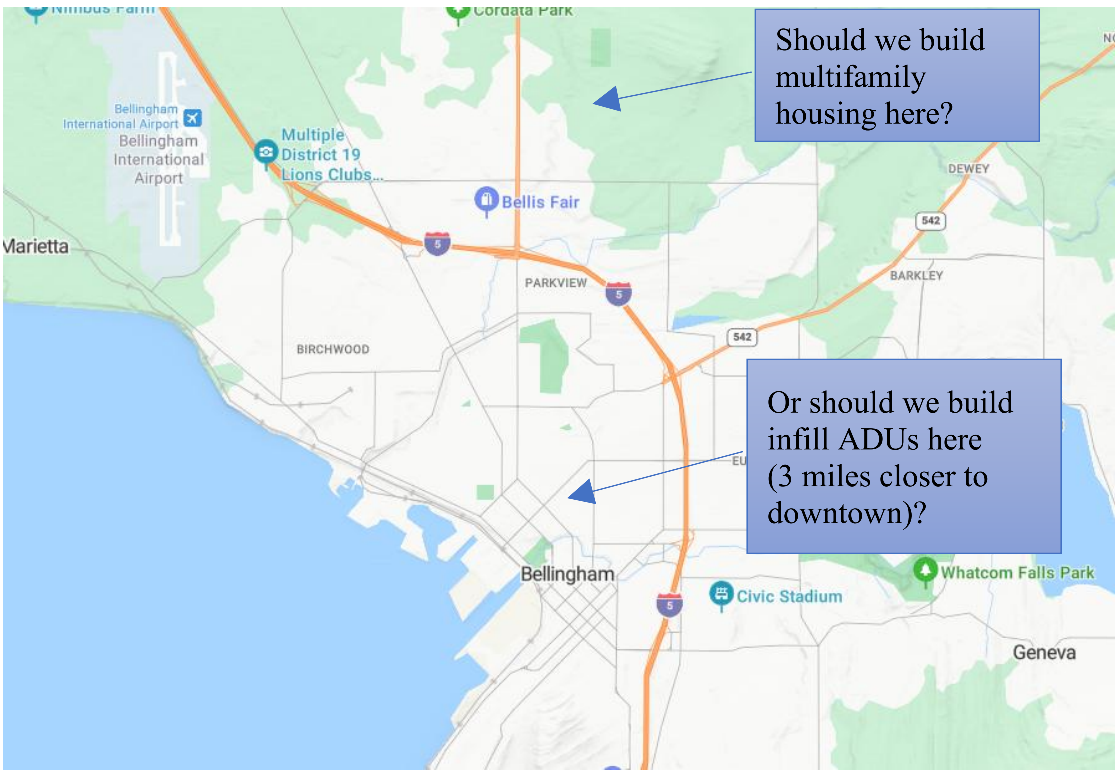

Figure 1. Illustrative example of two options to provide additional housing in Bellingham, WA. New housing could either be added as infill in existing neighborhoods near the city center or further away on greenfield sites.

Our literature review finds conflicting estimates on embodied energy of tiny homes and apartment buildings. Rauf et al. find that larger buildings have lower embodied energy per square foot (2025) with initial embodied energy ranging from 0.6-0.9 GJ/ft^2 of initial embodied energy for buildings ranging between 5700 and 1200 square feet. Bawden and Williams find that the energy from the construction stage for an 11-story apartment building is 0.96 GJ/ft^2 and that shorter apartment buildings have lower cumulative energy demand per floor area than taller apartment buildings (2015). Kuittinen et al. compare the embodied and operating emissions of a set of tiny homes with other housing types and find that the initial embodied emissions from tiny homes are smaller than for detached houses and apartment blocks, even on a per floor area basis—but the tiny homes perform worse when operating energy is also considered (2023). The embodied energy and emissions values will vary depending on the specific construction type, but there are elements that can give an advantage to either housing type. ADUs will have greater total envelope area (exterior wall, roof, and slab/crawlspace area) per ft^2 of floor area, and that comes at a higher energy/emissions cost than interior walls/floors. Multifamily embodied emissions are largely driven by building height, with higher embodied emissions in taller buildings due to greater use of high energy/emissions steel and concrete (compared to wood in ADUs). Taller buildings may also have more common space (halls, stairwells, elevators, etc.) that use resources but do not count toward the floor area of the units. Greenfield development also will require new utility hookups which come with energy, emissions, and capital cost. In this study we focus on the operating energy and emissions.

Methods

We estimate the annualized operating energy and emissions for two housing types (multifamily studio and ADU) of the same unit size in four locations. We then put this difference in emissions into context with emissions that might come from transportation using internal combustion engine and electric vehicles.

We also assume that behavior-driven energy use in each building type is the same. While occupant behavior can lead to large differences in energy use, even in identical buildings, the impact of occupant behavior is outside the scope of this study. We assume the same set of occupants, with the same schedules and preferences, is housed in either an ADU or multifamily studio. Therefore, we only estimate the difference in energy use based on thermal performance of the two building types. We use a single set of occupancy, schedules, and temperature setpoints for all modeling. We assume that both building types present the same options with respect to ventilation, operable windows, and HVAC controls.

Given these assumptions about behavior, we estimate the difference in thermal performance of each building type that is isolated to the difference in geometry of each building type. This difference is due to shared walls, and lower envelope area for each unit of floor area. We developed energy models in BEopt software for both the ADU and multifamily unit to determine the operating energy performance of each type. The floor area of the ADU and multifamily studio had the same floor area (400 ft^2). The ADU was a detached, single-story structure on a slab with perimeter insulation, while the studio unit was modeled as a middle floor, end unit apartment, with adiabatic thermal boundaries on one wall, below, and above. One wall is also modeled as buffer space, like an unconditioned hallway.

We assume that both the multifamily and ADU are all-electric buildings with efficient air source heat pumps for space conditioning and efficient unitary water heaters. Some of the specific performance assumptions are given in Table 1. The occupancy of both units is assumed to be two people. We model two scenarios with appliance and envelope efficiencies at or greater than ENERGY STAR standards as well as a less efficient case.

To determine the breakeven annual travel distance at which infill ADUs have the same emissions as greenfield multifamily housing transportation emissions, we used the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) model to estimate emissions from both light-duty internal combustion engine (ICE) vehicles and electric vehicles (EV). The ICE vehicle is assumed to have 427 g CO_2 per mile emissions today and decreasing to 349 g per mile in 2035. The EV has emissions of 229 g CO_2 per mile, though decreasing as the grid electricity mix decarbonizes and EVs become more efficient (Department of Energy 2025). These values account for the full lifecycle of the vehicle and fuel production and use phase. We adjust the EV emissions based on location. We use average electricity emissions intensity from eGRID specific to each location (US EPA 2023) to estimate emissions from the different building types (excluding transportation of occupants). The emissions rates given by eGRID will decrease over time as renewables make up a larger share of the electricity generation mix. We also calculate results of building emissions using levelized long run marginal emissions rates from the Cambium model (Gagnon 2025). These assumptions can be seen in Table 2.

Table 1. Building performance assumptions

City	IECC 2024/EnergyStar (or better)	Less efficient case
Heating efficiency (HSPF2)	8.5	100% efficient baseboard
Cooling efficiency (SEER2)	15.2	13.4
Wall R-value	21+5 continuous	21+5 continuous
Ceiling R-value	60, cellulose, vented	N/A
Water heater efficiency (UEF)	3.5	0.93

Table 2. Current and future electricity and EV emissions rates used for each location

City	eGRID subregion	Electricity emissions intensity (kg/MWh)	**Levelized long run** marginal **emissions** (LRMER) **(kg/MWh)**	**LRMER region**	**Adjusted EV emissions rate (g CO_2/mile)**
Seattle	NWPP	286.5	78.9	Northern Grid West	165
Phoenix	AZNM	319.2	201.7	WestConnect South	175
Atlanta	SRSO	382.1	240.0	SERTP	196
Chicago	RFCW	413.4	183.9	PJM West	206

Results

Since many of the attributes of the model inputs were the same for the ADU and multifamily units, the differences in energy use between the two cases were mostly attributable to thermal performance (heating and cooling energy use) because of differences in the geometry and envelope area of the buildings. Additionally, since both unit types had efficient heating and cooling equipment, we did not see large differences in total annual energy use between the unit types. Tables 3 and 4 show how the CO_2 emissions and site energy use vary between the building types. We calculate the difference in site energy use and emissions between the building types and then calculate how many more miles would need to be driven on an annual basis by the multifamily occupants in order to have the same emissions as the ADU occupants. Table 3 shows the equivalent additional miles that would need to be traveled per year by the multifamily occupants to surpass the emissions from the ADU occupants and Table 4 shows the difference in site energy. We calculate the breakeven distance for the two different vehicle types. For instance, in Seattle, if the multifamily occupant drove more than 399 *more* miles per year than the ADU occupant, then their total housing *plus* transportation emissions would be greater than the ADU occupant's emissions. In other words, if the multifamily occupants were commuting daily (five days per week, 50 weeks per year) and only had to drive about *two* additional miles per workday (roundtrip), the emissions savings from living in a more efficient building would be outweighed by the larger transportation emissions. Even in Chicago, with the largest breakeven distance of the sites studied, if the multifamily building was located three miles further away from average commuting destinations compared to the ADU, then it would lead to greater emissions.

Table 3. Key results of emissions and breakeven distance per year

City	ADU (kg CO2/year)	MF (kg CO2/year)	Difference in emissions (ADU-MF, kg/year)	Breakeven distance (EV, miles/year)	Breakeven distance (ICE, miles/year)
Seattle	1331	1160	170	1036	399
Phoenix	1765	1408	357	2037	836
Atlanta	1835	1782	54	275	126
Chicago	2318	1741	577	2794	1351

Table 4. Key results of site energy use

City	ADU (kWh/year)	MF (kWh/year)	Difference in site energy use (ADU-MF, kWh/year)
Seattle	4645	4050	595
Phoenix	5530	4411	1119
Atlanta	4804	4663	141
Chicago	5607	4212	1395

We also performed this analysis using long run marginal emissions rates rather than current average emissions rates from electricity generation to see how the results would change in the future with cleaner electricity. Cleaner electricity means that there is a smaller difference in emissions between the two housing types (the more efficient MF unit saves fewer GHG emissions) but transportation emissions per mile also get cleaner. These results are shown graphically in Figure 2. Vehicle emissions in the future (dotted line) cases are assumed to be coming from a 2035 ICE vehicle emitting 349 g CO_2 per mile (Department of Energy 2025).

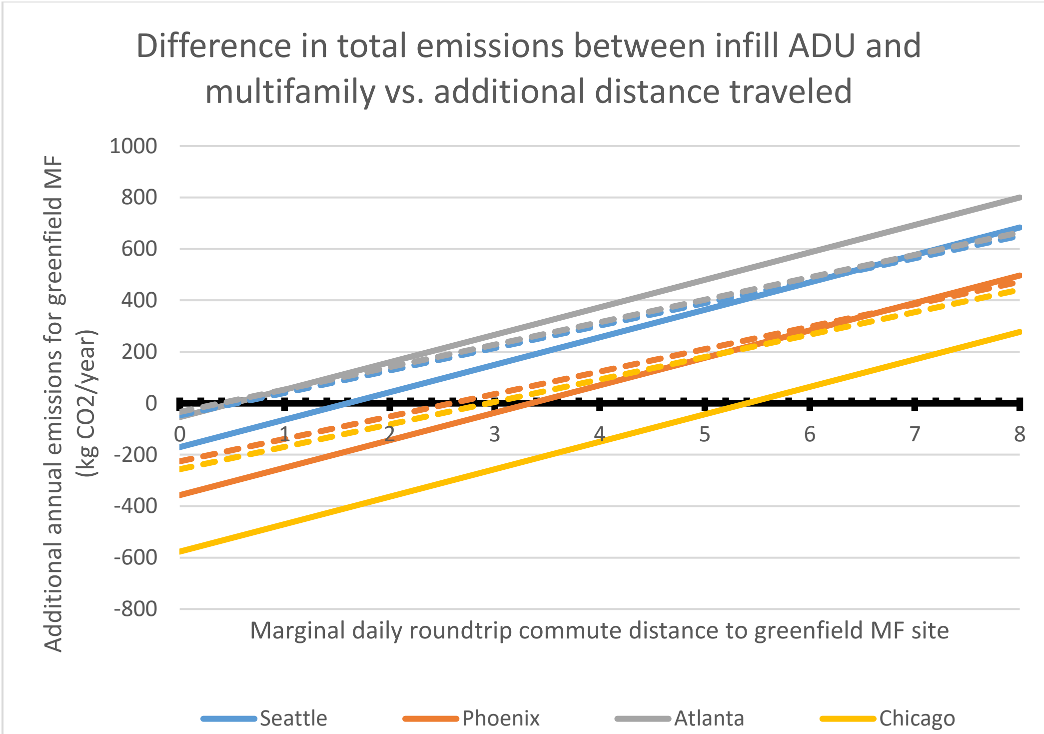

Figure 2. Additional annual housing + transportation emissions vs additional roundtrip commute distance traveled by ICE vehicle for the multifamily type. Dotted lines show results using LRMER (future marginal emission rates) and more efficient future ICE vehicles.

In order to see how sensitive these results were to wall construction and equipment efficiency, the models were also run with a different set of parameters as shown in the "less efficient case" in Table 1. The results from that analysis are shown in Tables 5 and 6.

Table 5. Key results of emissions and breakeven distance per year, less efficient case

City	ADU (kg CO2/year)	MF (kg CO2/year)	Difference in emissions (ADU-MF, kg/year)	Breakeven distance (EV, miles/year)	Breakeven distance (ICE, miles/year)
Seattle	2355	1730	625	3796	1463
Phoenix	2371	1836	534	3047	1251
Atlanta	2904	2298	606	3090	1419
Chicago	4406	3110	1296	6277	3034

Table 6. Key results of site energy use, less efficient case

City	ADU (kWh/year)	MF (kWh/year)	Difference in site energy use (ADU-MF, kWh/year)
Seattle	8218	6038	2180
Phoenix	7427	5753	1674
Atlanta	7600	6014	1586
Chicago	10657	7523	3134

These results can also be seen graphically in Figure 3. In this case EVs are used in order to estimate an upper bound commute distance for breakeven emissions. EV emissions rates from Table 2 were used to make this estimate. Note the change in scale of the x-axis.

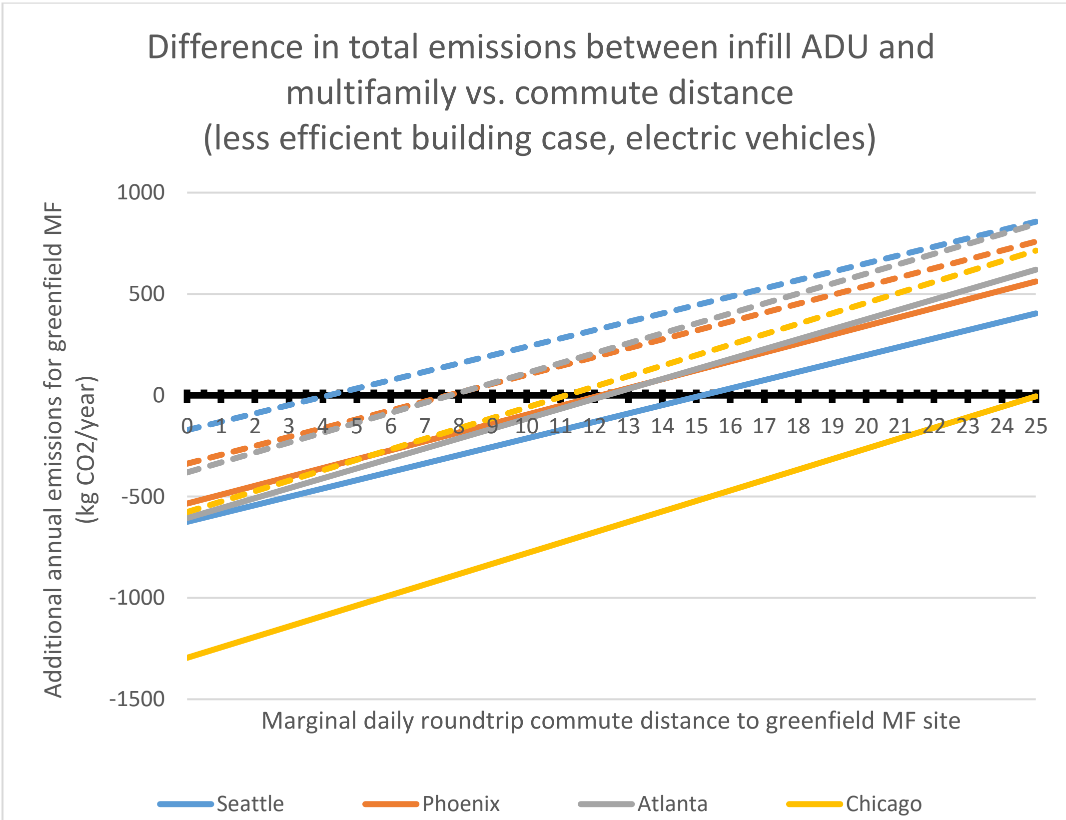

Figure 3. Additional annual housing + transportation emissions vs additional roundtrip commute distance traveled by electric vehicle for the multifamily type in the less efficient building case. Dotted lines show results using LRMER (future marginal emission rates) for building emissions but the same EV emissions rate is used for both line types.

Discussion and Conclusions

The results show that the difference in performance between an efficient ADU and studio unit in a multifamily building is equivalent to the emissions of driving 0.5-5.4 miles per day with an ICE vehicle or 1-11 miles per day with an EV in the locations studied. Reduced emissions intensity of electricity in the future will both decrease the difference in emissions between ADUs and multifamily (driving down the breakeven distance) but switching to EVs that use clean electricity will drive up that breakeven distance. Additionally, when buildings are more efficient, the breakeven distance gets shorter. If we assume that we are trending toward more efficient buildings, cleaner electricity, and more EVs, then the breakeven distances are in the 1-11 mile per day range, and even less if ICE vehicles are the main transportation mode. This highlights the fact that the commute distance may outweigh the differences in thermal performance between multifamily units and ADUs.

For policymakers, this clearly points to the benefits that come from prioritizing infill development if emissions are a metric of concern. Multifamily infill opportunities would be the best option to gain both the thermal benefits and the locational benefits. But, if there is a tradeoff between location and small differences in performance due to the geometry of the buildings (larger surface to volume ratios), these results seem to point to location being more important. While multifamily buildings may be more efficient, and potentially cheaper to build per unit, where they are located is hugely important. Policymakers should try to prevent construction of buildings that will drive up commute distances, particularly if ADUs are an option to increase density.

While the thermal performance of ADUs is slightly worse as this modeling has shown, they do have an advantage of greater roof area per unit floor area. This greater roof area gives more space to put solar PV systems and therefore makes ADUs easier to achieve net zero performance compared to larger multifamily buildings.

One shortcoming of this study was not including the embodied emissions of different housing types. While the literature review showed that embodied emissions of the different building types vary on the order of hundreds of megajoules (MJ) per square foot, this difference is on a scale similar to the difference in operating energy between housing types. Over a 50 year lifetime, a 100 MJ/ft^2 difference in embodied energy would correspond to about 200 kWh/year difference between the ADU and MF units, so the embodied energy differences are likely smaller than the operating energy differences that the modeling suggests (ranging from 141-3134 kWh/year) and either housing type could potentially have lower embodied energy and emissions. Reducing embodied energy and emissions is gaining attention from policymakers and the literature lacks a thorough and methodological investigation comparing embodied emissions from different housing types. It is also worth deeper study to approximate how prefabricated construction of ADUs and multifamily housing might impact their embodied energy/emissions.

Commuting distances are not only important for climate but also for overall quality of life. Development of housing on greenfield sites that result in longer commutes also lead to land use changes and decline of ecosystems. Development of multifamily housing predominantly in semi-urban areas is likely due to desire for more people to live near amenities, but also have more space than might be available in the urban core. This study could further be developed by expanding the analysis to beyond understanding what the breakeven VMT is between different housing types but also to better understand how housing type drives VMT.

While we distill housing down to energy use, emissions, and miles traveled in this study, housing is much more than that. Density, when done right, can yield more vibrant communities, durable investments, and housing access to diverse household types. If there is one takeaway from this study, it is that geography trumps geometry.

References

Bawden, Kimberly, and Eric Williams. 2015. “Hybrid Life Cycle Assessment of Low, Mid and High-Rise Multi-Family Dwellings.” *Challenges* 6 (1): 98–116. https://doi.org/10.3390/challe6010098.

Berrill, Peter, Kenneth T. Gillingham, and Edgar G. Hertwich. 2021. “Linking Housing Policy, Housing Typology, and Residential Energy Demand in the United States.” *Environmental Science & Technology* 55 (4): 2224–33. https://doi.org/10.1021/acs.est.0c05696.

Brownstone, David, and Thomas F. Golob. 2009. “The Impact of Residential Density on Vehicle Usage and Energy Consumption.” *Journal of Urban Economics* 65 (1): 91–98. https://doi.org/10.1016/j.jue.2008.09.002.

Dale, Nina. 2025. “Semi-Urban Growth Leads Multifamily Housing Expansion - CRE Daily.” https://www.credaily.com/briefs/semi-urban-growth-leads-multifamily-housing-expansion/.

Department of Energy. 2025. “Light Duty Vehicle Greenhouse Gas Life Cycle Assessment.” January. https://www.energy.gov/sites/default/files/2025-01/eere-greet-ldv-fact-sheet_january-2025.pdf.

Gagnon, Pieter. 2025. “Workbooks for Cambium 2024 Data.” National Renewable Energy Laboratory. 2 files. https://doi.org/10.7799/2560791.

Jonathan Rose Companies. 2011. *Location Efficiency and Housing Type - Boiling It Down to BTUs*.

Kuittinen, Matti, Ksenia Ruuska, Bergpob Viriyaroj, and Laura Zubillaga. 2023. “Are ‘Tiny Homes’ Good for the Environment? Focus on Materials, Land-Use, Energy and Carbon Footprint.” *The Journal of Architecture* 28 (5): 698–722. https://doi.org/10.1080/13602365.2023.2280849.

Obrinsky, Mark, and Caitlin Walter. 2016. “Energy Efficiency in Multifamily Rental Homes: An Analysis of Residential Energy Consumption Data.” *Journal of Sustainable Real Estate* 8 (1): 2–19. https://doi.org/10.1080/10835547.2016.12091885.

Rauf, Abdul, Daniel Euroizing Attoye, Malik Mansoor Ali Khalfan, and Muhammad Tariq Shafiq. 2025. “Examining the Impact of House Size on Building Embodied Energy.” *Buildings* 15 (3): 467. https://doi.org/10.3390/buildings15030467.

US EPA. 2007. *Smart Growth: Measuring the Air Quality and Transportation Impacts of Infill Development*. https://www.epa.gov/sites/default/files/2014-01/documents/transp_impacts_infill.pdf.

US EPA, OAR. 2023. “Power Profiler.” Data and Tools. https://www.epa.gov/egrid/power-profiler.

Zohourian, Mohammadamin, Apurva Pamidimukkala, Sharareh Kermanshachi, and Deema Almaskati. 2025. “Modular Construction: A Comprehensive Review.” *Buildings* 15 (12): 2020. https://doi.org/10.3390/buildings15122020.