

Climate-Smart Housing Production Strategies

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Acknowledgments



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The project team helped to develop this report based on their professional knowledge of land use, transportation, and greenhouse gas emissions implications of the housing and the built environment. The project team also relied on information derived from scholars, government agencies, the reports of others, and other sources believed to be reliable. ECONorthwest has not independently verified the accuracy of all such information.

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Climate-Friendly Housing Production Strategies Executive Summary

Oregon communities are working to increase housing options that address shortages and reduce greenhouse gas pollution. Many policies on housing, land use, and urban form support both outcomes.

This study from the Department of Land Conservation and Development summarizes research about the relationship between housing attributes (land use patterns, design, and building components) and greenhouse gas pollution to help cities use the updated Housing Production Strategy (HPS) menu of tools, actions, and policies. It focuses on the factors that affect pollution from housing production, primarily the type of housing (detached or attached), the size of housing, the distance to destinations, and the presence of diverse modes of transportation (walking, biking, and transit). It also focuses on adaptive reuse of buildings to produce additional housing.

This study found three key concepts that will help cities select Housing Production Strategy actions to increase housing and reduce greenhouse gas pollution:



Infill development offers the greatest benefits.

The greatest reduction in climate pollution comes from increasing housing in areas that already have dense housing, diverse uses, good active transportation networks, and good access to daily needs. Supporting infill development will reduce pollution.



Neighborhoods with diverse transportation options are key.

Neighborhoods with higher density, diverse uses, good active transportation—improve the potential for reducing climate pollution. Density and small housing in auto-oriented neighborhoods far from most destinations does little to reduce transportation-related greenhouse gas pollution.



Smaller, attached housing reduces climate pollution.

Compared to large, detached homes, smaller attached homes consume much less energy and are built with less material per unit. These benefits increase when housing is attached and are highest for apartment buildings with five or more units. Policies that encourage or incentivize smaller, attached housing—particularly when located in areas that reduce car dependence—reliably and measurably reduce pollution from the residential sector.

Introduction

Background

The built environment contributes greenhouse gas emissions because of the significant share of emissions that are generated by the construction and operation of the buildings we live and work in, daily transportation needs, and the embodied carbon in the materials we use for buildings and infrastructure. Policies and actions to reduce greenhouse gas emissions occur at all levels of government. Under Oregon’s state land use planning requirements, many local governments are asked to consider climate impacts from transportation, and many jurisdictions are developing climate action plans that address other ways they can reduce local and non-local emissions. Alongside these climate considerations, many local governments are also required to encourage the production of new housing to address a statewide housing shortage, affordability crisis, and inequitable housing outcomes as they plan at the local level.

Purpose of the Study

As Oregon cities work to make planning choices that support goals for increased housing options and more sustainable communities, understanding the potential climate effects of different policy options can support progress toward both outcomes.

This review summarizes research about the relationship between land use, design, and building component choices and greenhouse gas emissions. Greenhouse gas emissions are categorized in two ways: sector-based and consumption-based. Sector-based emissions are created within Oregon from the generation and use of energy, transportation, buildings, agriculture, manufacturing, etc. Consumption-based emissions include all the greenhouse gas emissions generated by the goods that Oregonians consume, including energy, food, building materials, consumer goods, services, etc. Research by Oregon’s Department of Environmental Quality (DEQ) shows that Oregon has made important progress reducing sector-based emissions, by 15 percent between 1999 and 2021 (Oregon DEQ, 2024). At the same time, consumption-based emissions have increased 53 percent since 1990, contributing to an overall increase in greenhouse gas emissions statewide (Oregon DEQ, 2024).

Both sector-based and consumption-based emissions are priorities for the State of Oregon to meet its climate goals. While the source of building and infrastructure materials play a key role in the total greenhouse gas emissions related to land use and the built environment, this literature review focuses on the sector-based elements that are most within the control of local governments as part of their standard planning processes related to housing. These include regulating land use through zoning (such as encouraging neighborhoods that allow residents to meet more of their daily needs without driving) and setting building design standards (such as those that encourage compact and energy-efficient housing). These decisions also have important effects on consumption-based emissions. To the extent possible, we examine estimates of energy consumption, greenhouse gas emissions, building characteristics, and

climate factors that are specific to data from Oregon. The information in this review informed recent updates to the Department of Land Conservation and Development's (DLCD) Housing Production Strategy menu of tools, actions, and policies to indicate the options that reduce greenhouse gas emissions or offer related co-benefits.

Because of the focus on informing the Housing Production Strategy (HPS) menu of tools, actions, and policies, this literature review explores the factors that impact emissions from the standpoint of housing production, primarily type of housing (detached or attached), the size of housing (square feet), the proximity of the housing to destinations, and the presence of low-carbon modes of transportation (walking, biking, and transit). It focuses primarily on new construction and adaptive reuse of buildings to produce additional housing. Given the focus on new production of housing, the literature review does not emphasize literature related to decarbonization of existing housing.

Methodology

This study relies on a literature review including research published in peer-reviewed scholarly journals, by the National Renewal Energy Labs, government agencies, academic institutes, and professional organizations.

The body of literature that studies the relationship between urban form and greenhouse gas emissions typically measures this relationship indirectly, through vehicle miles traveled (VMT) per capita or household. One of the more common ways to estimate emissions reductions is by evaluating the elasticity of a change in an urban form factor relative to the amount of VMT that might be reduced by the measure. In this review, we discuss elasticity to understand the strength of some policy and built environment changes compared to others.

What is elasticity?

Elasticity refers to how much one variable changes, relative to a change in another variable. For example, the elasticity of a change in an area's population density would measure how much driving is reduced in proportion to the increase in population density.

This study focuses on the estimated greenhouse gas emission reductions for select features of urban form separate from one another. Many aspects of the built environment that affect transportation behaviors or greenhouse gas emissions are complementary and reinforce each other. This review evaluates different policy choices to help inform planners working across different contexts and addressing specific local needs.

Framework for Understanding Housing Production and Greenhouse Gas Emissions

Policy Framework

Oregon has set ambitious targets to address the simultaneous—and intersecting—challenges of meeting the state’s need for additional housing and mitigating and adapting to climate change to create a more livable future for all Oregonians. Many state agencies are involved in implementing policy, creating guidelines for local action, and helping local governments to make progress toward these goals. This section describes the landscape of state policies and programs related to housing production and reducing greenhouse gas emissions, including the role of state agencies and local planners and policymakers.

Increase Housing Supply

In Oregon, cities have a long-standing requirement to study and plan for their community's housing needs. While the originators of the Goal 10 Housing policy intended for careful planning that would result in balanced, diverse, and affordable housing supply, implementation has fallen far short of that intent. The historic implementation of Goal 10 resulted in a narrow focus on “accommodation” of housing need by completing an accounting exercise of the theoretical capacity of land, while doing little to ensure that housing is built or address where it should be located and whether households are realistically able to access it. ECONorthwest’s analysis for Up for Growth (2024) found that Oregon has underproduced housing by about 78,000 units to keep up with population trends. This has had negative consequences for all Oregonians, including a shortage of housing, rising rates of cost burdening and homelessness, and continued patterns of segregation and involuntary displacement.

Since 2019, the state has passed legislation and conducted rulemaking to improve how housing needs are measured and to create guidelines for local governments to implement strategies that encourage the production of needed housing in their communities.

Housing Capacity Analysis

Cities in Oregon must conduct a Housing Capacity Analysis (HCA) to determine if they have enough land to meet projected housing needs for the next two decades. If there is a shortfall in housing capacity, the city must either amend its urban growth boundary (UGB), allow more housing development within the existing UGB, or combine both approaches.

Cities with a population larger than 2,500 have a broader responsibility to plan for a variety of housing types beyond single-unit detached housing. They must include multi-unit housing, manufactured homes, renter occupied units, government assisted units, and other forms of housing in their planning. Collectively, this range of housing types, characteristics, and locations is known as "needed housing," and to highlight one characteristic, it must be affordable to community members' income levels.

Housing Production Strategy

House Bill 2003 requires cities with over 10,000 people to create a Housing Production Strategy (HPS) within a year of adopting their HCA. The HPS must contain specific and meaningful policies, programs, investments, and other tools collectively referred to as "actions" to address housing needs identified in the HCA. Each action must include a timeline for adoption and execution each. DLCD reviews and approves each city's HPS to ensure it effectively meets housing needs, encourages necessary housing production, and promotes fair and equitable housing outcomes.

To support cities, DLCD collected a list of example actions through crowdsourcing, literature review, and dedicated research. These examples provide ideas for cities to promote housing development within their jurisdictions to meet their identified needs. ECONorthwest worked with DLCD to update the list of actions and this literature review was designed to help inform that process.

Local Planning and Policies

The Housing Production Strategy process required by House Bill 2003 builds on many years of local government efforts to establish policies and programs that support residential development in their communities. Many cities that are not required to create a Housing Production Strategy are working to encourage new housing in their communities to provide affordable housing for renters, homeownership opportunities, provide options for older residents to age in place, and reduce homelessness.

Reduce Greenhouse Gas Emissions

Oregon has a goal to lower greenhouse gas emissions by 75 percent by 2050. Transportation accounts for roughly 35 percent of Oregon's sector-based emissions, and 22 percent of consumption-based emissions, while the built environment account for an additional 33 percent of sector-based and 29 percent of consumption-based emissions (Oregon DEQ, 2023, 2024). Meeting this state goal requires vehicle efficiency, using cleaner fuels, reducing how much vehicles travel, improved energy efficiency in buildings, and reducing embodied carbon of building materials. Vehicle efficiency is largely a matter of state and federal policy, while the state has set clean fuel policies and is working to improve energy-efficiency standards for buildings. Reducing how much Oregonians must drive is primarily addressed at the local level through transportation and land use planning.

Climate-Friendly and Equitable Communities

The Climate-Friendly and Equitable Communities (CFEC) program, launched in 2020, aims to help meet Oregon’s climate policy and goals, provide more transportation and housing options, and promote more equitable outcomes in regions with populations over 50,000. CFEC provides updated rules and guidance for land use and transportation planning and is jointly administered by DLCD and the Oregon Department of Transportation (ODOT). CFEC actions related to land use planning are a key element for achieving the state’s greenhouse gas reduction goals because they strengthen local planning efforts to reduce barriers to housing development in walkable, transit-accessible, mixed-use areas where essential services and amenities are located.

The program directs fifteen communities in Oregon’s metropolitan areas to identify and allow walkable areas with significant housing capacity, and update zoning where needed. In these “climate-friendly areas,” Oregonians should have a range of transportation choices and be able meet most of their daily needs without having to drive long distances.

Nearly all jurisdictions in Oregon must adopt a transportation system plan (TSP), a long-range planning document that describes a transportation system and outlines projects, programs, and policies to meet transportation needs now and 20 years in the future based on community goals. CFEC communities must follow TSP guidelines for metropolitan areas that encourage low-carbon mobility such as walking, biking, and transit. Low-carbon and active mobility options are also important for many non-metropolitan jurisdictions to meet the needs of residents of all ages, incomes, and abilities.

Building Efficiency and Embodied Carbon

In 2017, Governor Brown signed Executive Order 17-20, Accelerating Efficiency in Oregon’s Built Environment to Reduce Greenhouse Gas Emissions and Address Climate Change. This policy seeks to increase the energy and water efficiency of new and existing buildings across Oregon and reduce the embodied carbon of building materials used in the state. Key agencies for implementing this Executive Order include the Department of Environmental Quality (DEQ), the Department of Energy, and the Building Codes Division of the Department of Consumer and Business Services. Per the requirements of House Bill 3049 (2023) the Building Codes Division produced a report discussing paths to reduce embodied carbon through the statewide building code (Oregon BCD, 2025).

Clean Energy

The Oregon Legislature passed the Clean Energy Targets bill (House Bill 2021) in 2021, establishing a requirement for investor-owned electric utility companies including Portland General Electric (PGE), Pacific Power, and electric service providers to meet carbon emissions reduction targets. Implementation of the Clean Energy Targets bill would result in an emissions reduction at 80 percent below baseline emissions level—established by Oregon DEQ—by 2030 and 100 percent below the baseline emissions level by 2040. This shift will in turn decrease the emissions related to electric

vehicles and building electricity use.

Local Climate Planning

In addition to state requirements, cities and counties across Oregon are developing policy and action plans to address issues related to climate change and sustainability. These plans include a range of strategies related to the impacts of transportation, land use, buildings, waste management, and energy sources. While these plans are not required by a state planning framework, they respond to community desires to reduce environmental impacts, transition to more sustainable energy systems, and improve resiliency to climate change and natural hazards.

Housing Production, Greenhouse Gas Emissions, and Co-Benefits

This section presents the evidence related to greenhouse gas emissions and other co-benefits (e.g., equity, health and safety, economy, and environment) of different housing production options and transportation investments. The findings are organized by the planning scales of housing production.

Planning Scale

The key characteristics of the built environment that contribute to greenhouse gas emissions work at three scales of planning and policymaking.

- The **neighborhood** scale involves the mix of land uses, allowed densities, historic development patterns, street network, and infrastructure for public transit and low-carbon modes of travel such as walking and biking.
- The **site** scale focuses on the type and overall design of buildings governed by the zoning code. Site factors include what type of residential building can be built (e.g., townhomes, apartments), the average size of different housing types, as well as other requirements, such as off-street parking.
- The **building** scale describes the components of building construction, including materials, appliances, and requirements for energy efficiency.

In this study, we discuss the research and findings within the framework of these three scales to highlight the connections to policies and interventions that are undertaken by local planners.

Neighborhood

A substantial body of academic and gray literature has explored the relationship between the built environment and greenhouse gas emissions. Much of this research examines the influence of land use patterns and urban form on travel demand, measured in vehicle miles travelled (VMT). VMT is an important metric because of the role of transportation-related emissions in overall greenhouse gas emissions, which is estimated to contribute 35 percent of greenhouse gas emissions in Oregon (Oregon DEQ, 2023).

“D-VARIABLES”

- *Density*
- *Diversity*
- *Design*
- *Destination access*
- *Distance to transit*

Other literature estimates the effect of the built environment on a broader set of activities that contribute to greenhouse gas emissions. Household carbon footprint is one measure that combines emissions from travel behaviors, household consumption, and energy use from different housing types.

Researchers commonly measure five features of land use and development, commonly referred to as “D-variables” (Ewing & Cervero, 2010; Stevens, 2017):

- **Density** measures population, households, or employment per unit area
- **Diversity** measures the mixture of different land uses in an area
- **Design** measures street network characteristics within an area
- **Destination access** measures how easy it is to reach key locations including work, school, and shopping
- **Distance to transit** measures the distance from a household to the nearest transit stop

Research finds that the magnitude of the change in VMT for each of these characteristics on its own is relatively low—less than a one percent reduction for each D-variable. Combining changes in multiple D-variables can have a more meaningful effect on reducing VMT and greenhouse gas emissions in a community. In some cases, changes in single D-variables may not reduce VMT at all without changes in other supporting D-variables, such as increasing employment density without promoting mixed-use developments in which to co-locate jobs with residential or other commercial uses (Zhang et al., 2012).

Effects of changes in individual built environment characteristics are small, but careful combination of changes across multiple characteristics can have a meaningful impact on greenhouse gas emissions.

This section summarizes literature related to density, diversity design, and distance to transit to draw connections to neighborhood characteristics Oregon cities will consider in considering where to plan for new housing.

Density

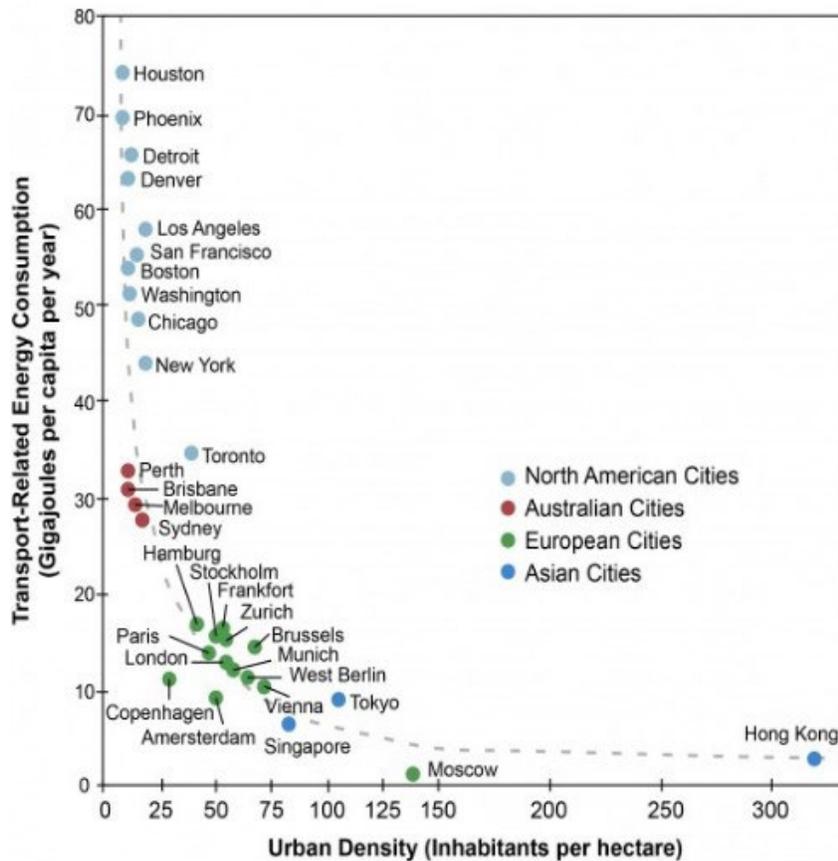
Residential

Residential density—people, households or dwellings per square mile or acre—is guided by zoning codes, which often specify maximum allowed densities for each parcel in the zone. Residential density can be increased in areas that are already built up by policies that amend zoning or development codes to enable higher densities, such as allowing multi-unit buildings, or encouraging mixed-uses in areas that have fewer residential buildings. Higher residential density creates sufficient demand for public transit, making it easier for residents to choose low-carbon or no-carbon modes of transportation such as transit, as well as walking or biking for much of their daily needs (Seto et al., 2014). The literature studying this connection primarily takes one of two approaches: an econometric approach to estimate

the elasticity between residential density and VMT (or greenhouse gas emissions through VMT), or a review of scenario planning and simulation results to quantify the effect of increased residential density. Most of the research supports this connection, finding a negative relationship between residential density and VMT. That is, as residential density increases, VMT decreases.

The estimated effect of residential density on VMT varies widely in the literature, depending on the type of analysis, the measure of VMT (e.g. per capita, per household, or annual miles), the measure of residential density (e.g. population density, dwellings per square mile), and other factors that are considered in the analysis. It is also clear that this relationship is non-linear, meaning that the greatest reduction in greenhouse gas emissions happens at the highest residential densities. This non-linear relationship between residential density and VMT is shown in Exhibit 1, which also suggests how factors such as public transit infrastructure or car ownership may also affect VMT for cities with relatively similar densities.

Exhibit 1. Relationship between residential density and transportation energy consumption



Source: (Lefèvre, B., 2009)

Jones and Kammen’s (2014) analysis of household carbon footprints (which includes emissions from transportation, housing, and consumption) in the United States shows that the relationship between density and lower greenhouse gas emissions is strongest only in the 100 largest urban cores, as shown in

Exhibit 2. This research highlights that suburban communities tend to have higher household carbon footprints compared to urban areas and even some lower-density rural areas (Jones & Kammen, 2014). Research also shows that increasing residential densities in existing neighborhoods has a different effect than building new neighborhoods, even when those greenfield developments are at higher densities than typical suburban environments. Ten studies reviewed by Ewing et al. (2007) analyzed the effect of regional location on emissions and travel for individual developments. Each of these studies concluded that “infill locations generate substantially lower VMT per capita than do greenfield locations, from 13 to 72 percent lower” (Ewing, et al., 2007). Jones et al. (2018) also found that increasing infill development in areas with lower household carbon footprints improves modeled greenhouse gas emission reductions more than scenarios that prioritize infill areas based on existing density alone.

Exhibit 2. Relationship between density and average household carbon footprints in the United States

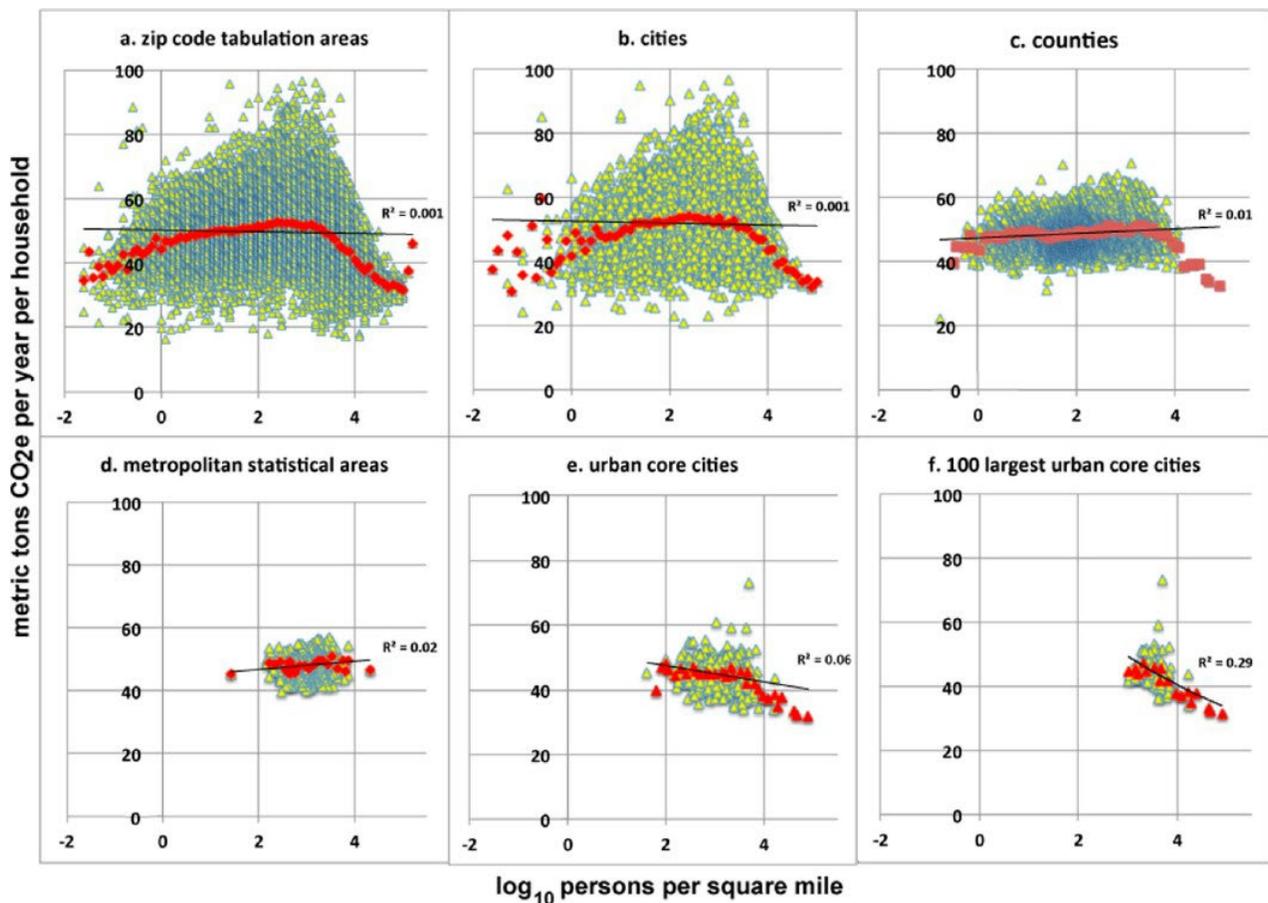


Figure 2. Average household carbon footprints (HCF) in (a) 31 531 zip code tabulation areas, (b) 10 093 U.S. Census cities and towns, (c) 3124 counties, (d) 276 metropolitan statistical areas, (e) 376 urban core cities, and (f) 100 largest urban core cities, by \log_{10} of population density (log of population density). The red line in each figure is the mean of all HCF for that population density, binned at increments of 0.1 on the x -axis. Linear goodness of fit trend lines show no correlation between population density and HCF, with the exception of the 100 largest urban core cities, $R^2 = 0.29$. Mean HCF decreases only after ~ 3000 persons per square mile (or 3.5 on the x axis).

Source: (Jones & Kammen, 2014)

Scenario planning approaches compare a baseline residential density plan against different scenarios

that increase or decrease residential density to estimate their effect on VMT. Studies that examine the results of scenario planning find that increases in density lead to a reduction in VMT and decreases in density lead to an increase in VMT. ECONorthwest's study for the Colorado Energy Office examined the results of different development pattern scenarios on VMT using the Colorado Department of Transportation's travel model. Scenarios that achieved an average of 15 dwelling units per acre led to a 20 percent reduction in VMT compared to the state average. The densest scenarios (40 dwelling units per acre) resulted in 40 percent less VMT than the state average (ECONorthwest, 2024). Across 62 scenario planning analyses reviewed by Ewing et al. (2007) the median reduction in regional VMT compared to a baseline scenario is 5.7 percent but ranged as high as 31 percent.

As part of the Transformational Integrated Greenhouse Gase Emissions Reduction (TIGHGER) Project, the Oregon Department of Energy has conducted scenario planning for 27 interventions and policies to demonstrate the relative cost and impact of each in helping the state meet its greenhouse gas emission reduction targets. While this analysis shows that higher urban residential density is on the lower end of emissions reductions, it is the most overall cost-effective policy in terms of dollars per metric ton of CO₂e (Zelenka & Baker, 2023).

Employment

Employment density can, in theory, impact greenhouse gas emissions in a similar manner to residential density. A concentration of jobs can increase demand for low-carbon travel modes to access those jobs, like public transportation and biking, which results in shorter and fewer trips by single-occupancy vehicles and a reduction in average VMT per capita (ICF Consulting et al., 2021). Employment density is, however, more correlated to other D-variables of urban form, such as diversity (mixed land uses), destination access (proximity to downtown and housing) and distance to transit. These factors play a larger role in the relationship between employment density and VMT or greenhouse gas emissions, and can make isolating the specific impact of employment density challenging (Circella et al., 2014).

There is a smaller body of academic and gray literature studying the effect of employment density on greenhouse gas emissions compared to the body of work studying the effect of population density. The findings in this literature are inconsistent, which likely reflects the challenges in disaggregating the effect of employment density from other D-variables.

Most studies find a small negative relationship or no relationship between employment density and VMT, but at least two studies found a positive relationship (Boarnet et al., 2003; Ewing & Cervero, 2010; Stevens, 2017; Zhang et al., 2012; Zhou & Kockelman, 2008). Zhang et al. (2012) and Zhou and Kockelman (2008), both found that increasing employment density was associated with an increase in VMT when studying the effect in mid-sized urban areas with populations of around one million. However, in larger urban areas such as Seattle, Baltimore, and Washington D.C. or in suburban and rural areas the authors found that increasing job density decreased VMT. The difference in results suggests that increasing employment density in mid-size urban areas may draw more workers by car to those job centers, especially if they are centrally located in downtown areas in cities surrounded by

suburban residential neighborhoods. In these cases, there may be less developed transit systems or driving is easier (abundant or low-cost parking, toll-free roads) compared to larger, denser urban areas. In contrast, in larger urban areas or in suburban and rural areas, employment centers are closer to where workers already live, leading to a decrease in VMT from low-carbon travel modes (in higher density communities) or shorter commutes (in lower density communities).

Data from multiple studies, including Zhang et al. (2012) and Zhou and Kockelman (2008), are included in the meta-analysis from Stevens (2017). The meta-analysis estimate of the elasticity between employment density and VMT is negative, but small across all studies, and when only including data from studies that control for self-selection bias (Stevens, 2017), as summarized in Exhibit 3. Self-selection bias occurs when individuals who prefer other modes of transportation to driving choose to live in denser neighborhoods with mixed land uses and transit access. Studies that do not try to control for residential self-selection may overestimate or underestimate the effect of denser development on travel behaviors and VMT.

Exhibit 3. Estimated impact of employment density on VMT

VARIABLE	CONTROL FOR SELF-SELECTION?	NUMBER OF STUDIES IN ANALYSIS	ELASTICITY ESTIMATE	IMPACT
Employment-density	Yes	2	-0.07	A one percent increase in employment-density is associated with a 0.07% decrease in VMT per capita.
Employment-density	No	11	-0.01	A one percent increase in employment-density is associated with a 0.01% decrease in VMT per capita.

Source: (Stevens, 2017)

Co-Benefits

Increased density of residences and jobs can result in highly walkable and bikeable areas that deliver co-benefits in improved public health and social equity in addition to meaningful reductions in VMT (ICF, et al., 2021; Nelson, 2017). Additionally, increasing employment density may be an important consideration for achieving other planning objectives, such as providing employment opportunities and economic development, and is prudent to evaluate as part of a neighborhood planning process (Stevens, 2017). For local governments, dense or compact development can also reduce the costs of building and maintaining infrastructure compared to serving low-density neighborhoods (Litman, 2024).

Diversity

Diversity in urban form describes the number of different land uses in an area, such as residential,

commercial, or industrial. In the literature, land uses are often analyzed using an entropy measure, where a low entropy value indicates single-use environments and higher values represent more varied land use (Ewing & Cervero, 2010; Nelson, 2017; Stevens, 2017). Less frequently, diversity in land use is measured by jobs-to-housing or jobs-to-population ratios. The literature discussed in this review focuses on the estimates of impact using measures of entropy.

Areas that have high levels of diversity in land use typically have mixed-use development with businesses and retail in the same building or adjacent to housing, putting destinations for work and shopping close to residences (Stevens, 2017). The mix of uses close to each other has positive impacts on transit ridership and on walking, which can result in fewer car trips and lower VMT (Ewing & Cervero, 2010). In contrast, neighborhoods with relatively little diversity in land use, such as residential areas, especially those with lower density detached homes, can result in more trips by single-occupancy vehicles, higher average VMT, and higher greenhouse gas emissions.

However, like the research on employment density, studies examining the impact of land use diversity on VMT do not consistently find that greater diversity leads to lower VMT. Two of the three meta-analyses reviewed found, as expected, that an increase in land-use diversity was associated with a decrease in VMT. In the meta-analysis that includes only studies that control for self-selection, however, more diverse land use was associated with an increase in VMT, as shown in Exhibit 4. While counterintuitive, it could be that increasing land use diversity without ensuring there is convenient walking, biking, or transit between the different uses, or to mixed-use destinations from other areas, could induce more driving between them (Nelson, 2017). Another important and related possibility is that historic minimum parking requirements have increased the ease of driving to mixed-use destinations.

Exhibit 4. Estimated impact of land-use diversity on VMT

META-ANALYSIS STUDY	STUDY	CONTROLLED FOR SELF-SELECTION?	STUDIES SAMPLED IN META-ANALYSIS	ELASTICITY ESTIMATE	IMPACT
Does Compact Development Make People Drive Less?	Stevens, 2017	Yes	2	0.11	A one percent increase in land-use mix is associated with a 0.11% increase in VMT per capita.
Does Compact Development Make People Drive Less?	Stevens, 2017	No	15	-0.03	A one percent increase in land-use mix is associated with a 0.03% decrease in VMT per capita.

Travel and the Built Environment	Ewing and Cervero, 2010	No	10	-0.09	A one percent increase in land-use mix is associated with a 0.09% decrease in VMT per capita.
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Source: (Ewing & Cervero, 2010; Nelson, 2017; Stevens, 2017)

Co-Benefits

Land-use diversity is a factor in amplifying the effects of other D-variables, particularly employment density. Without a sufficient mix of uses, for example, there may be inadequate commercial and office space available to achieve higher employment density. As a result, strategies to enhance employment density may need to be implemented alongside efforts to increase mixed-use areas to optimize the effect these changes have on VMT. Increased land-use diversity can also enhance climate resiliency and participation in active transportation modes by putting people closer to resources they may need to access during an extreme weather event (ICF Consulting et al., 2021). It may also shorten commutes, decreasing exposure to road hazards due to extreme heat or flooding.

Design

Design focuses on the characteristics of the street network in an area: the level of connection between streets, the number of intersections, the proportion of four-way intersections, and the length of street blocks (Ewing & Cervero, 2010; Nelson, 2017; Stevens, 2017). Together these attributes determine how direct the route is from one place to another, how long it takes to travel between destinations, and how safe and convenient it is to walk or bike, both factors that influence average VMT per capita in a neighborhood (Boarnet et al., 2003; Ewing et al., 2007; Nelson, 2017).

Dense urban areas typically have highly interconnected, straight streets that make it more convenient to walk, bike, or take transit. In contrast, suburban areas tend to have sparse networks of curvilinear streets that form loops or end in cul-de-sacs which make the distance to destinations longer, making walking and biking more challenging (Ewing et al., 2007; Ewing & Cervero, 2010; Stevens, 2017). There is typically a positive correlation with walking, and therefore lower greenhouse gas emissions, in areas with high street connectivity, where blocks are smaller and allow frequent changes in direction (Seto et al., 2014).

Multiple studies show that street networks that make low-carbon modes of travel like walking, biking, and public transit more comfortable, safe, and convenient result in lower car use and thus lower VMT. The literature finds a wide range in the effect of street networks on VMT, with elasticities ranging from -0.06 to -0.26 (Ewing & Cervero, 2010; Salon et al., 2012, 2014; Seto et al., 2014; Stevens, 2017; Zhang et al., 2012). These estimates depend on the specific street network attribute measured, as well as the existing residential density, type of housing in the area, and the overall land use mix of the area studied. For example, Salon, et al. (2014) find that higher road density is associated with a decrease in weekday

household VMT ranging from -0.06 in suburban areas with single unit homes to -0.15 in suburban areas with multi-unit homes. The results from Zhang, et al. (2012) suggest that reducing the average block size is the most effective in the areas with largest existing average block size. Ewing et al., (2007) finds in a meta-analysis of the literature that households living in developments with higher density, diversity of uses, accessible destinations, and interconnected streets drive about 33 percent less when compared to low-density sprawl.

Among the various characteristics related to the design of street networks, some factors have a stronger relationship to changes in VMT. Intersection density has the largest estimated effect on VMT in all the literature reviewed. Salon, et al. (2012) found an elasticity of -0.26, while the meta-analyses summarized in Exhibit 5 found elasticities between -0.14 and -0.12. Ewing and Cervero (2010) also find an elasticity of 0.39 between intersection density and walking. Within the literature, intersection density has the largest effect on increasing walk trips of all the D-variables (density, diversity, design, destination access, and distance to transit).

Exhibit 5. Estimated impact of increased street network connectivity on VMT

META-ANALYSIS STUDY	AUTHOR, YEAR	CONTROLLED FOR SELF-SELECTION?	DESIGN VARIABLE	ELASTICITY ESTIMATE	IMPACT
Does Compact Development Make People Drive Less?	Stevens, 2017	1 of 15 studies	Intersection/ street density	-0.14	A one percent increase in street density is associated with a 0.14% decrease in VMT per capita.
Does Compact Development Make People Drive Less?	Stevens, 2017	1 of 4 studies	Share of 4-way intersections	-0.06	A one percent increase in the percentage of 4-way intersections is associated with a 0.06% decrease in VMT per capita.
Travel and the Built Environment	Ewing and Cervero, 2010	0 of 6 studies	Intersection/ street density	-0.12	A one percent increase in street density is associated with a 0.12% decrease in VMT per capita.
Travel and the Built Environment	Ewing and Cervero, 2010	1 of 3 studies	% 4-way intersections	-0.12	A one percent increase in the percentage of 4-way intersections is associated with a 0.12% decrease in VMT per capita.

Source: (Ewing & Cervero, 2010; Stevens, 2017)

Co-Benefits

Beyond the potential to reduce VMT per capita and greenhouse gas emissions, street networks that include higher street connectivity and more gridded design are associated with improved health and safety co-benefits. These types of street network designs increase pedestrian and cyclist safety and result in fewer serious crashes with cars, primarily because they reduce and slow car traffic (ICF Consulting et al., 2021; Porter et al., 2013). The increase in walking and biking observed in neighborhoods with better street networks ultimately correlates with improvements in public health (Ali et al., 2021).

Distance to Transit and Transit-Oriented Development

Distance to public transit is a key determinant of travel behavior in cities. When people live or work closer to transit stops or stations, they are more likely to use transit and less likely to drive, which leads to lower VMT and reduced transportation greenhouse gas emissions (Ewing & Cervero, 2010; Guerra et al., 2011; Stevens, 2017). Transit-oriented development (TOD) builds on this principle by clustering housing, jobs, and amenities near transit hubs, making transit use convenient and reducing the need for car trips. Typically, TOD projects focus development within a half-mile radius around a transit stop, the distance that an adult of average ability walking at a moderate pace can reach within ten minutes (Guerra et al., 2011).

Numerous studies have found evidence that households living within walking distance of transit stations are much more likely to use transit on a day-to-day basis and drive less. A case study of the Bay Area Rapid Transit (BART) system found that workers living within half a mile of BART stations are three times more likely to walk, bike, or take transit to work (BART, 2017). Another study looked at transit and walking behaviors around the Westside MAX light rail system between Portland and Beaverton/Hillsboro and found that the number of transit trips increased from 0.05 to 0.85 per household in the 13 years after the line was constructed (Ewing & Hamidi, 2014). This study also found that VMT per capita increased over the same 13-year period. Yet along the transit corridor, VMT per capita increased 22 percent—much lower than the 62 percent increase along the control corridor (Ewing & Hamidi, 2014). ECONorthwest’s study for the Colorado Energy Office found that compared to “business-as-usual” housing growth, scenarios that enabled TOD were expected to see an average decrease in daily VMT between 2 and 6 percent by 2050 (ECONorthwest, 2024). These studies and the other literature considered in this review examining the impact of distance to transit or TOD on VMT are summarized in Exhibit 6.

Exhibit 6. Summary of reviewed literature on distance to transit and TOD

Title	Study	Study Area	Findings
Walking, biking and transit ridership findings			
Cost of a Ride: The Effects of Densities on Fixed-Guideway Transit Ridership and Capital Costs	Guerra et al., 2011	U.S.	An additional person within 0.25 miles of a transit station correlates with 0.34 more average weekly transit trips; within 0.5 miles, 0.25 more weekly trips.
Longitudinal Analysis of Transit's Land Use Multiplier in Portland	Ewing and Hamidi, 2014	Portland / Beaverton / Hillsborough	Increase from 0.05 to 0.85 transit trips per household after construction of the Westside Max light rail.
Transit-Oriented Development Guidelines	BART, 2017	San Francisco, CA Bay Area	3 times more likely to walk, bike or take transit if living within half a mile of a BART station.
Impacts on VMT			
Effects of TOD on Housing, Parking, and Travel	Cervero et al., 2008	Portland, OR; Philadelphia/ N.E New Jersey; Washington D.C.; East Bay San Francisco Bay Area	Transit-oriented apartments average around 50% of the norm of vehicle trips per dwelling unit. Vehicle trips were 70–90% lower near downtown and 15–25% lower for low-density suburbs.
Longitudinal Analysis of Transit's Land Use Multiplier in Portland	Ewing and Hamidi, 2014	Portland / Beaverton / Hillsborough	Estimated that the Westside Max light rail is associated with a 9% decrease in average household VMT.
Transit-Oriented Development (TOD): A Solution for Reducing Greenhouse Gas Emissions.	Coalition for Smarter Growth, 2020	U.S.	Transit-oriented communities averaged 17 to 26 VMT daily per household compared to 45 for non-TOD communities.
Colorado Land Use Policy & Greenhouse Gas Co-benefits Study	ECONorthwest, 2024	Colorado	Between 1% and 10% decrease in daily vehicle miles in scenarios that enable TOD.

Co-Benefits

As with all reductions in VMT, reducing the distance to transit and transit-oriented development can also provide co-benefits of reduced traffic congestion and improved air quality (ICF Consulting et al., 2021). In addition to reducing VMT, transit-oriented development can also increase the cost-effectiveness of transit through increased ridership, as well as reducing traffic congestion (ECONorthwest, 2024; Guerra & Cervero, 2010).

Site

The academic and gray literature exploring the relationship between new or infill residential

development site-level choices and greenhouse gas emissions commonly evaluate the effect of housing type, housing size, parking requirements and the availability of bike infrastructure on greenhouse gas emissions. These studies typically define four types of housing:

- Detached single-unit homes
- Attached single-unit homes
- Small multi-unit homes (typically fewer than 5 units)
- Larger multi-unit homes (more than 5 units)

Studies examining the impact from house type or house size typically estimate greenhouse gas emissions indirectly through household energy consumption, including heating and cooling demands. Energy consumption is often measured as consumption per area, or the energy use intensity (EUI), although there are government agency datasets which provide total energy consumption by housing type or total house size. Energy consumption values can be converted to equivalent carbon dioxide (CO₂e) emissions using data about CO₂ emitted from the production of energy by different fuels and sources. The effect of site-level parking requirements and the availability of bike infrastructure is more typically measured indirectly through the impacts on VMT per household or dwelling.

Multi-unit units generally have lower emissions than single unit homes due to factors related to unit size, building characteristics, and location. Multi-unit units tend to be smaller than the average single-unit home, requiring less energy to heat and cool. Because they tend to share walls, floors, and ceilings, multi-unit units effectively provide additional insulation for each other, further reducing energy consumption for maintaining temperature. Due to historic zoning practices, multi-unit units tend to be located in central neighborhoods or higher-density corridors that have better pedestrian, bicycle, and transit infrastructure, which increase the access and convenience of low-carbon transportation modes, which also leads to reduced VMT (Berrill et al., 2021; Berrill & Hertwich, 2021; ECONorthwest, 2024). Oregon cities, however, are also seeing new multi-unit housing built at the edges of their urbanized areas, whether due to zoning or because those areas have larger parcels that are more attractive for multi-unit developers. These edge areas are often auto-oriented in their design and farther from daily needs.

Housing Type

A dwelling's energy consumption and corresponding greenhouse gas emissions depends heavily on two factors: local climate-driven demand for heating and cooling and the fuel used in electricity production—i.e., what powers the grid supplying the dwelling with electricity (Goldstein et al., 2020; Jones & Kammen, 2014). The literature controls for the local climate by including an indicator for the dwelling's climate zone indicator or by including variables that capture days that

Multi-unit housing produces the lowest greenhouse gas emissions, and large, detached single-unit homes produce the most.

require cooling or heating to a 65-degree standard. Many studies break down estimates by region or even at the state level to account for the different mix of fuel and energy sources powering the grid. Although the research can help quantify the effect of these factors on an area's greenhouse gas emissions from its housing stock, housing planning and policy can do little to influence or change the conditions of electricity production.

Planners implementing an HPS have tools they can use to encourage the type of housing, size, location, and site features, but not what materials are used for housing construction. This literature review focuses largely on the studies that estimate the operational emissions from housing, and less so on the subset of the literature that estimates lifecycle embodied carbon. Operational emissions capture a dwelling's emissions after construction and before demolition phases. Lifecycle embodied carbon includes emissions from all construction, operational, and demolition phases. The consensus in both types of analysis is that single-unit detached homes contribute more greenhouse gas emissions than multi-unit homes, and that greenhouse gas emissions increase with the square footage of single-unit homes (Brolinson et al., 2024; Goldstein et al., 2020; Hu, 2023; Jones & Kammen, 2014; Min et al., 2010; UCLA California Center for Sustainable Communities (CCSC) at UCLA, 2020). Multi-unit homes have the lowest estimated greenhouse gas emissions across the literature.

Several different measures are used within the literature to estimate operational greenhouse gas emissions, including direct estimates of CO₂e emissions per area or per housing type, as well as indirect measures that estimate energy demanded in British Thermal Units (BTU) by housing type or housing attribute. While these estimates are informative and can help identify the effect of different housing types, they are too general to account for the significant influence that local climates and fuel mixes used to generate electricity have on the greenhouse gas emissions from housing. These estimates may not accurately reflect the impact of housing choices in Oregon.

A more relevant estimate of the impact of housing choice is available using data from the National Renewable Energy Lab (NREL) ResStock survey and residential building stock model and the EPA's Emissions and Generation Resource Integrated Database (eGRID) database.

- **ResStock** is a U.S. Department of Energy model of the residential building stock, developed and maintained by NREL that provides highly granular modelling of the U.S. housing stock. ResStock is the dataset in many of the studies that calculate the energy demand by housing type, and while many studies use the data in the aggregate, the data set includes disaggregation by state and climate zone. Oregon has two climate zones, 4C (west of the Cascades) and 5B (east of the Cascades).
- The **eGRID** database integrates emission data from EPA with generation data from the U.S. Energy Information Administration to produce data on the pounds of emissions per megawatt-hour of electricity generation by grid sub-region and by state. Using state-level data is particularly important for power generation, as **Oregon's power generation emits just half of the amount of CO₂ as the national average**, primarily due to the large percentage of hydroelectric power used in the state. The emissions from electricity generation from Portland General Electric (PGE), Pacific

Power, and other electric service providers will decrease by 80 percent by 2030 and 100 percent by 2040 with the implementation of the Clean Energy Targets (HB 2021).

Using data for Oregon from both these datasets and the equations defined by the EPA’s [Greenhouse Gas Equivalencies Calculator](#) estimates of greenhouse gas emissions by housing type, size and climate zone are calculated for Oregon in Exhibit 7.

Exhibit 7. Estimated CO₂ emissions (MT) per year by house type, size, and climate zone in Oregon

ESTIMATED CO ₂ EMISSIONS (MT) PER YEAR PER DWELLING UNIT					
HOUSE SIZE (SQUARE FEET)	SINGLE -UNIT DETACHED	MULTI-UNIT WITH 2-4 UNITS	MULTI-UNIT WITH 5+ UNITS	SINGLE -UNIT ATTACHED	MOBILE HOME
Climate Zone 4C – Marine					
0–1,499	4.5	2.9	2.3	3.3	3.9
1,500–2,499	5.7	3.9	3.2	3.9	4.8
2,500+	7.7	NA	NA	6.8	6.2
Average across all sizes	6.0	2.3	1.8	4.7	5.0
Climate Zone 5B – Cool, dry					
0–1,499	4.7	3.3	2.4	3.4	4.6
1,500–2,499	6.1	NA	NA	7.1	5.6
2,500+	8.4	NA	NA	NA	NA
Average across all sizes	6.4	1.7	1.2	5.2	5.1
Average across all	6.2	2.0	1.6	4.9	5.0

Note: NA indicates that NREL ResStock determined there were not enough samples to draw a conclusion

Source: ECONorthwest analysis of data from the NREL ResStock, the EPA eGrid dataset and the EPA’s Greenhouse Gas Equivalencies Calculator - Calculations and References

Co-Benefits

Multi-unit and attached housing have co-benefits for residents and for cities. Less energy use overall offers reduced utility costs for residents. Development costs per square foot are typically lower for multi-unit housing compared to single-unit homes, in part by making more efficient use of utilities and other infrastructure, creating savings on infrastructure as much as 38 percent in some case studies (*Building Better Budgets*, 2013; NMHC, 2019). From a fiscal perspective, multi-unit housing also helps reduce the cost of delivering public services by up to 10 percent. Multi-unit buildings also generate more property and sales tax revenue for a community than single-unit homes. Lastly, multi-unit housing allows for the preservation of more open spaces and natural amenities, providing more recreational areas within a community (*Building Better Budgets*, 2013).

Parking requirements

The influence of parking, particularly parking requirements and pricing, transportation choice and VMT is not studied to the same extent as other factors of urban form, despite how much parking can dominate the urban landscape (Currans et al., 2023). This is partly because the data from travel behavior surveys that many papers rely on when studying the effects of the built environment on travel behavior do not ask about parking (Chatman, 2013; Currans et al., 2021). The literature that does examine the relationship finds that parking requirements for residential and commercial developments encourage car ownership and use, and that removing the requirements can encourage shifts to alternative travel modes (Dong, 2022).

Parking requirements in the development code make off-street parking free or underpriced (particularly for commercial uses), effectively subsidizing auto use. Such requirements encourage low-density sprawl, which effectively requires people to acquire vehicles to meet their daily travel needs, necessitating additional free parking at their destination, creating a cycle of auto-dependency (Shoup, 2005).

Off-street parking requirements also present a barrier to development feasibility, making some housing impractical to build, or more expensive than it would otherwise be. This dynamic is especially challenging for creating affordable housing, especially in infill locations where land is limited and costly. Parking requirements can also prevent refurbishment of many older buildings for new uses, as many older buildings lack the parking spaces required for the new uses (Shoup, 2005). For higher density housing, minimum parking requirements of one or more parking spaces per residential unit typically require underground or structured parking in urban areas, increasing construction costs and the ultimate cost of the housing. Structured parking can add tens of thousands of dollars per unit to a housing project (Reid et al., 2020). This cost burden can make affordable housing infeasible in areas where it is often most needed. Structured and underground

Parking requirements encourage car use over other travel modes and can make infill development and building reuse cost prohibitive.

parking also increases the use of concrete, which has higher embodied carbon than other building materials, such as the structural timber used in most low-rise multi-unit construction.

OREGON PARKING REQUIREMENTS

Oregon made recent changes to its laws and land use rules to reduce or eliminate minimum parking mandates statewide.

- ORS 197A.425(1)(b)(B): Prohibits requiring parking for ADU development.
- ORS 197A.430(3): Limits parking requirements for single room occupancy developments.
- ORS 197A.445: Removes minimum parking requirements for converting commercial buildings to housing.
- SB 1537: Allows up to 10 mandatory design or development standard adjustments for housing. A full adjustment to minimum parking requirements may be included.
- OAR 660-012-0400: Limits parking mandates for cities in metropolitan areas.
- OAR 660-046-0010: Limits and reduces parking mandates for middle housing based on community size and housing type.

The research that studies the relationship between parking and travel behavior primarily focuses on the impact that free or unconstrained parking has on vehicle ownership (Cao & Cao, 2014; Chatman, 2013; Currans et al., 2020, 2023; Kim, 2024; Weinberger, 2012). Within the literature, several studies also look at the effect of parking on vehicle trip generation and travel mode choice, while only a handful estimate the effect of parking on VMT. (Currans et al., 2023; Guo, 9/2013a). Currans et al (2023) examine how parking affects VMT, both directly and indirectly through vehicle ownership finding that the effect is primarily indirect through VMT. Furthermore, Currans et al (2023) find that households with unconstrained parking conditions (i.e., ratio of more than one parking space per dwelling unit) are estimated to own 1.14 times more vehicles than households with constrained conditions, and that each additional vehicle an average household owns is associated with an additional 17 miles of total household VMT. Guo (2013a) examined the impact of having access only to on-street parking (e.g. constrained parking) on vehicle trips and VMT, finding that having access only to on-street parking is associated with a statistically significant reduction in vehicle trips and a reduction of 14.3 kilometers (almost 9 miles) in total daily kilometers travelled. The results from these studies and the literature reviewed that does not address VMT are summarized in Exhibit 8.

Exhibit 8. Summary of reviewed literature on parking requirements, supply and pricing

Study	Study Area	Parking Measure	Outcome Variables	Findings
Studies that include impact on VMT				
Currans et al., 2023	California	Off-street parking supply	Vehicle ownership and VMT	<p>Unconstrained parking (>1 parking space per dwelling unit) was associated with a statistically significant increase in vehicles owned; households with unconstrained parking are estimated to own 1.14 times more vehicles.</p> <p>Additional vehicle ownership was associated with a statistically significant increase in total VMT; each additional vehicle in the average household is associated with 17 more miles of total VMT.</p>
Guo, 2013a	New York City region	Off- and on-street parking supply	Vehicle trip generation, Mode choice, and VMT	<p>Having only on-street parking was associated with statistically significant reduction in vehicle trips and with 14.3 fewer kilometers travelled.</p> <p>Additionally, having only on-street parking reduced the likelihood of choosing to drive for a trip by about 50%.</p>
Studies with impacts on vehicle ownership, mode choice and trip generation				
Cao and Cao, 2014	Minneapolis-St. Paul	Off-street parking supply	Vehicle ownership	The study finds that large backyards and abundant off-street parking are associated with a statistically significant increase in auto ownership.
Chatman, 2013	Northern New Jersey	Off-street parking supply	Vehicle ownership, and travel mode choice	Scarcity of off-street parking reduced the probability of commuting by single-occupied vehicles to 57% and the average number of vehicles per adult by 13–19%.
Currans et al., 2020	San Francisco, California & Los Angeles, California	Off-street parking supply	Vehicle trip generation	<p>Increasing the number of parking spaces from 1 to 2 per dwelling unit was estimated to increase vehicle trips per dwelling unit by 0.26 trips in the morning peak period and 0.18 trips in the afternoon peak period.</p> <p>Estimates the elasticity between parking spaces per dwelling unit and number of vehicle trips to be between 0.61 and 0.78 for the morning peak period (e.g. a 7.8% increase in vehicle trips from a 10% increase in parking spaces), and between 0.61 and 0.70 for the evening period (e.g. a 7.0% increase vehicle trips from a 10% increase in parking spaces).</p>

Guo, 2013b	New York City	Off-street parking supply	Vehicle ownership	<p>Estimates that when on-street parking becomes almost unavailable (i.e. no parking spaces on the street), average car ownership would decline by 8.8%.</p> <p>This suggests that 1 out of every 11 cars owned by the households in the study area could be explained by the presence of available on-street parking.</p>
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Study	Study Area	Parking Measure	Outcome variables	Findings
Millard-Ball et al., 2022	San Francisco	Off-street parking supply	Vehicle ownership, and vehicle trip generation	<p>The ratio of parking spaces per dwelling unit was associated with a statistically significant increase in vehicle ownership, with a one-standard-deviation increase in the ratio associated with a 14 percentage point increase in the likelihood that the household owns a car.</p> <p>The ratio of parking spaces per dwelling unit is also associated with a statistically significant increase in vehicle use. A one-standard-deviation increase in the ratio is associated with a 20% increase in the likelihood that a household's driving behavior falls into a more frequent category.</p>
Weinberger, 2012	New York City	Off-street parking supply	Vehicle ownership, and travel mode choice	<p>Finds that off-street parking is correlated to driving to work both indirectly by its contribution to car ownership and directly by easing car use.</p> <p>More off-street parking (spaces per dwelling unit) is associated with a statistically significant increase in vehicle ownership and the share of driving in commute travel modes.</p> <p>The effect of off-street parking on vehicle ownership was higher than all but two other factors examined and higher than all but one other factor on the share of driving in commute travel modes.</p>

Despite the consistent evidence that parking requirements and unconstrained parking leads to higher vehicle ownership and more vehicle trips, a survey of local governments in California reveals that introducing parking pricing and parking reform were the least preferred strategies for reducing local VMT and greenhouse gas (Baek & Kim, 2023). The aversion to parking reform is likely due to the concern that reducing or eliminating parking requirements could increase street congestion as drivers search for available spaces. However, research suggests that most households and neighborhoods already have sufficient parking, even an over-supply of parking. When accounting for actual garage use, more than 75 percent of households have enough off-street parking to accommodate all their vehicles. Including both off-street and on-street spaces, households have on average 1.6 more parking spaces than vehicles and that on-street parking in predominantly single-unit neighborhoods has vacancy rates between 71 percent and 89 percent even during peak demand (Volker & Thigpen, 2022).

On average, households have 1.6 more parking spaces (on and off street) than vehicles available to them

Co-Benefits

Reducing or eliminating parking requirements has many co-benefits in terms of increasing housing production, improving air quality, reducing heat island effects, and increasing road safety. Minimum parking requirements for new housing effectively trade “bedrooms for people” for “bedrooms for cars,” restricting the type of housing that can be built and the amount of new housing that can be built on a parcel of land. Studies of parking reform in Buffalo, NY and Seattle, WA both showed that 60 to 70 percent of new homes built since parking reforms would have been illegal under the previous parking requirements (Gould, 2023; Spivak, 2022).

In addition to enabling higher housing production, eliminating parking requirements can lead to further greenhouse gas emission reductions by reducing cruising or circling for parking spaces. Studies have found that free or underpriced public and residential parking encourages people to drive to destinations and once at the destination to circle looking for a parking spot. Reducing or eliminating parking requirements to encourage alternate transportation can further reduce emissions by eliminating emissions from cruising (ICF Consulting et al., 2021; U.S. Dept. of Transportation, 2025).

Parking requirement reform can also benefit community health and safety. In some communities, developers meet minimum parking space requirements with surface parking lots. These large open areas of pavement contribute to the heat island effect, increasing ambient temperatures due to pavement and other infrastructure absorbing the sun’s heat, which can exacerbate health issues related to excessive heat (U.S. Dept. of Transportation, 2025). Minimum on-street parking requirements are associated with minimum street-width requirements and cruising for parking and double-parking behaviors. Cruising and double parking can have adverse effects on road-safety for people walking or biking. Removing on-street parking can allow communities to repurpose parking spaces or reduce lane widths to provide protected bike lanes or expanded sidewalks to improve safety for people

walking and biking (Guo, 2013b-01-02; ICF Consulting et al., 2021; U.S. Dept. of Transportation, 2025).

Building

The design, materials, appliances, and energy systems in buildings directly affect greenhouse gas emissions. Some aspects of how buildings are designed and constructed are governed by development standards, while others are regulated by building codes. Still others, such as solar orientation or appliance choices, are at the discretion of architects and developers in the absence of specific local or state standards.

Generally, new construction is more energy efficient in operation than older construction, and as a result has lower operating greenhouse gas emissions. This is in part driven by improvements in building materials and construction and in part by building codes. The evolution of Oregon's statewide building codes, particularly in response to two recent Governor issued Executive Orders,⁴ have made new residential construction significantly less energy intensive than older, existing housing. A study by the University of Oregon compared new residential construction energy use intensity (measured per square foot) under the most recent Oregon Residential Specialty Code (ORSC) to that from new construction under older versions of the codes (University of Oregon, 2023). The study found that the energy use intensity under the 2023 code was 12.5 percent lower than under the 2021 version of the code and 42.6 percent lower than under the 2005 code, on average across state climate zones.

Below we highlight findings from the literature related to building components that have the greatest effects on greenhouse gas emissions.

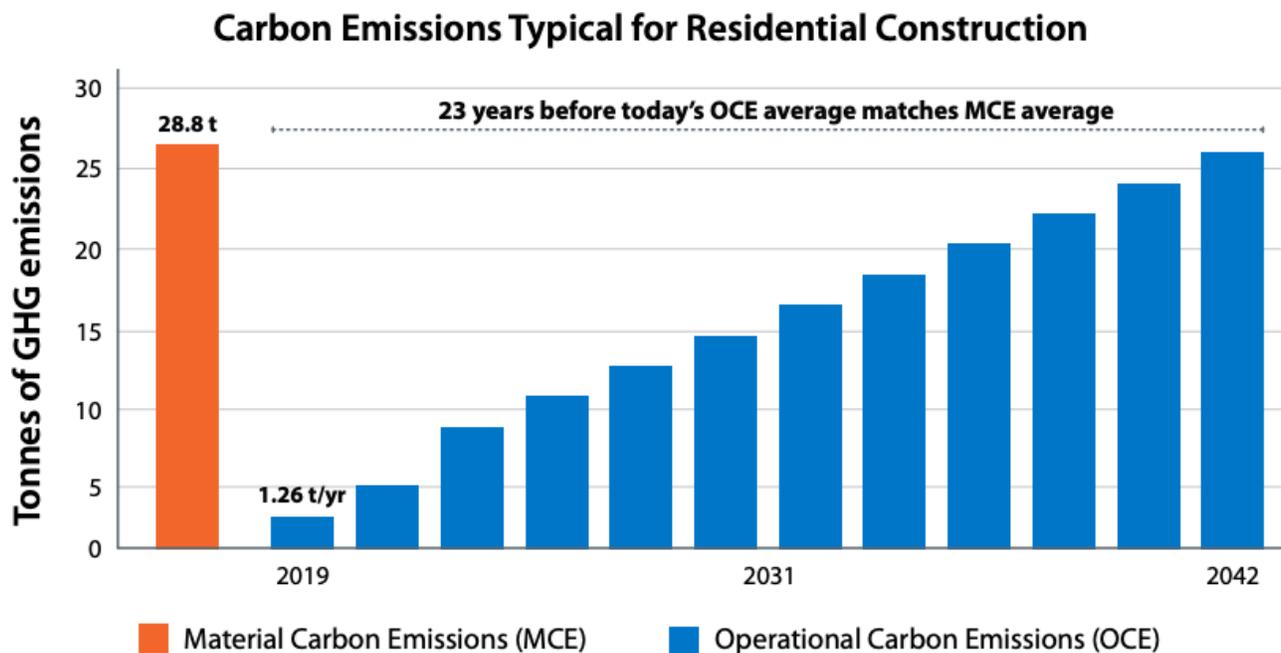
Low-Energy Design

Thoughtful design choices can dramatically cut a home's energy needs. For example, passive solar design (orienting and designing a house to capture winter sun and shade summer sun) can supply a substantial portion of heating demand. Researchers at University of Oregon found that even in cold, cloudy climates, untapped passive solar could provide about one-third of residential heating needs (Rempel et al., 2021). South-facing windows with proper overhangs, thermal mass (like concrete or earthen floors) to store heat, and high insulation help maintain comfortable temperatures with minimal mechanical heating or cooling. Efficient layouts that minimize wasted space and consider natural ventilation and daylighting further reduce energy use. Daylighting (ample natural light) cuts electric lighting demand, and designs that enable cross-breezes reduce the need for air conditioning. In all housing types, these low-tech strategies lower operational emissions by reducing heating, cooling, and lighting requirements.

Building Materials

A significant source of emissions from housing comes from the embodied carbon in the materials used in residential construction, particularly steel and concrete (Weir et al., 2023). An analysis by the U.S. Department of Energy estimates that the carbon emissions from materials in typical residential construction are equal to 23 years of cumulative operational carbon emissions of the home, as shown in Exhibit 9. Although carbon emissions from materials used in residential construction are a significant portion of a building's total carbon emissions, local governments have more limited options to regulate or incentivize this aspect of building design compared to other policy levers.

Exhibit 9. Carbon emissions typical for residential construction



Note: This graph is based on a case study in British Columbia from Builders for Climate Action using the Material Carbon Emissions (MCE2) estimator tool.

Source: U.S. Department of Energy (2022). New Residential Construction Carbon Emissions, <https://www.nrel.gov/docs/fy23osti/83049.pdf>

One potential way to reduce emissions is with the use of cross-laminated timber (CLT), a manufactured wood product whose structural qualities make it suitable for some larger scale buildings that would otherwise use concrete and steel. A meta-study of CLT studies found the potential to reduce greenhouse gas emissions by 40 percent by using CLT instead of traditional materials in large multi-story buildings (Younis & Doodoo, 2022). Oregon is a leader in construction using and manufacturing CLT and other mass timber products. Oregon is also the first state to adopt code provisions allowing wood buildings up to 18 stories (*Oregon Structural Specialty Code (OSSC) 2019, Appendix P, 2019*).

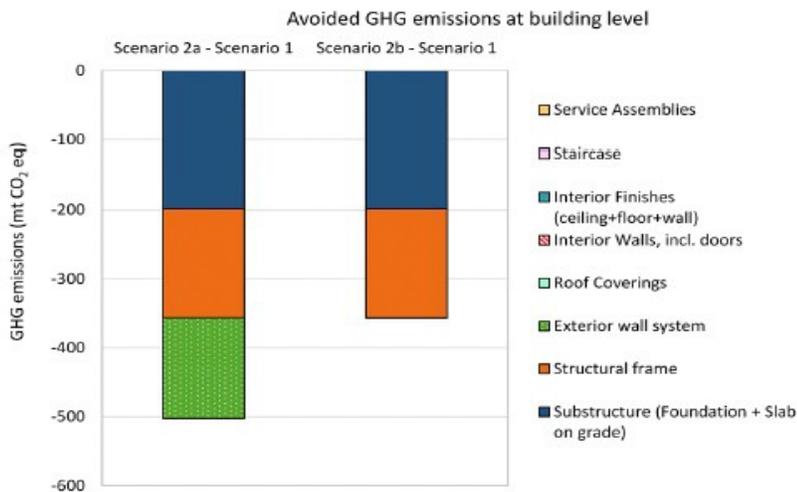
Energy Efficiency and Weatherization

A study by the Rocky Mountain Institute found that building emissions could be reduced by 50 percent with deep energy retrofits (Clark et al., 2023). Deep energy retrofits go beyond typical weatherization measures in existing buildings to remove fossil fuel systems (such as natural gas or oil for heating and cooking) and install energy-efficient upgrades. This approach to energy efficiency achieved lower embodied carbon footprints even compared to typical new multi-unit construction built to more recent energy standards (Clark et al., 2023). Oregon’s TIGHGER Report also cites weatherizing existing residential buildings as a top policy in terms of total reduced greenhouse gas emissions (Zelenka & Baker, 2023).

Adaptive Reuse

Adaptive reuse of older buildings into residential uses may save substantial amounts of embodied carbon and emissions, as opposed to new construction. A study of the energy and greenhouse gas emissions impacts of repurposing non-residential buildings to residential uses in California found that repurposing a building, compared to building a new building, results in about 56 percent less embodied energy, 34 to 48 percent fewer CO_{2e} emissions, and 72 percent less materials by mass (Gursel et al., 2023) as shown in Exhibit 10. A report prepared for Oregon’s Parks and Recreation Department estimates that 47 percent of upper stories in downtowns across the state are currently vacant, providing an opportunity to convert these spaces into residential uses in walkable neighborhoods (University of Oregon IPRE, 2022).

Exhibit 10. Greenhouse gas emissions avoided by selecting Scenario 2 (repurposing) over Scenario 1 (construction of new apartment building) in California case study



Source: (Gursel et al., 2023)

Household Appliances

Heating and cooling appliances, which are often powered using natural gas, contribute a larger share of

a household's energy demand and greenhouse gas emissions than other household appliances. The Energy Information Agency (EIA) estimates that space heating consumes an average of 28.8 million BTU annually per household in Oregon and water heating 16.1 million BTU annually (EIA, 2020), together accounting for 67 percent of an Oregon household's energy consumption annually.

Common household appliances, like refrigerators, dishwashers, stoves, clothes washers and dryers contribute to the energy demand of a household, generating greenhouse gas emissions indirectly through electricity and natural gas use. Older or less efficient household appliances tend to consume more energy, and transitioning to energy-efficient appliances, such as those certified by ENERGY Star, can reduce energy consumption, greenhouse gas emissions, and the utility bills for a household. Estimates of household energy demand attributable to appliances—excluding heating, water heating, and air conditioning—range from 13 percent to 33 percent nationally, with Oregon-specific estimates at 31 percent (EIA, 2020; NH State Energy Office, n.d.; Penn State, n.d.).

Upgrading household stoves and clothes dryers offer the most potential for reducing residential energy use and associated greenhouse gas emissions, as these appliances are typically powered by natural gas. Gas stoves not only emit carbon dioxide during operation but also leak methane, another greenhouse gas. One study estimated that unburned methane emissions from gas-powered stoves in the US are 28,000 metric tons per year (Lebel et al., 2022). Transitioning to induction cooktops can improve energy efficiency by threefold compared to gas burners, particularly when powered by increasingly decarbonized electricity sources, and are up to 10 percent more efficient than conventional electric ranges (US DOE, 2023).

Clothes dryers are estimated to account for 27 million metric tons of CO₂e annually in the United States. Switching to an efficient ENERGY STAR dryer can reduce emissions by 16 percent, and switching to an electric dryer can reduce emission up to 91 percent (Zhu & Miller, 2025). However, the reduction possible by moving to an electric dryer is highly dependent on the fuel that powers the electrical grid, and in some cases, where the grid is powered by high-carbon emitting fuels such as coal, switching from a gas-powered dryer to an electric dryer can lead to an increase in emissions.

The NREL ResStock data provides estimates of the change in emissions that would result from differences in energy consumption in 2030 for various energy-efficiency measures that a household could take. The data estimates packages of energy-efficiency measures, including an Appliance package which replaces a household's refrigerator, dishwasher, clothes washer and clothes dryer with energy efficient Energy Star appliances, and individual packages that replace non-electric range and ovens with induction or conventional electric range and ovens. The estimated one-year emissions reductions in 2030 that would result from the Appliance package is only in the tens of kilograms of CO₂e emissions per year.

While this reduction might make a meaningful reduction in a household's utility costs, it is less than 0.01 percent of a household's total annual emissions, which are in the metric tons per year (see Exhibit 7). This is another example of a strategy to reduce greenhouse gas emissions that on its own has minimal impact, but when layered with additional energy-efficiency changes in a household could

more meaningfully reduce a household's operational greenhouse gas emissions.

Co-Benefits

At the building scale, measures to reduce greenhouse gas emissions offer health and economic co-benefits to the residents. Low energy design paired with energy efficient appliances can offer significant cost savings on utilities. Electric appliances also reduce harmful emissions from gas-powered appliances. Combined with low-carbon and healthier building materials, these building interventions improve indoor and outdoor air quality (Rajpurohit et al., 2022).

Climate Action Planning in Oregon

As discussed in Section 2, many communities in Oregon are developing policies and plans to reduce their local greenhouse gas emissions, reduce environmental impacts of the built environment, transition to more sustainable energy sources, and improve resiliency to climate change. While these plans are independent of the state’s housing production strategy requirements, they can provide insights into how jurisdictions are evaluating and adopting actions and policies that directly connect land use planning and housing production with climate impacts. To help inform DLCDC’s revisions and enhancements to the menu of actions for Housing Production Strategies, this study includes a review of eight local climate action plans for actions and policies that affect housing.

Local Climate Plans

For this study, we surveyed publicly available plans for Oregon cities that were adopted within the last eight years. The plans represent a range of communities of different sizes and contexts from the Portland metro region, the Willamette Valley, the Bend metro area, and southern Oregon. Except for Sisters, all of these cities are required to adopt a Housing Production Strategy. We did not find any adopted plans from cities in eastern Oregon or coastal regions, though some are currently in progress.

Information about the plans included in this review are summarized in Exhibit 11.

Exhibit 11. Summary of reviewed climate-related plans

CITY	REGION	POPULATION	PLAN TITLE	ADOPTION YEAR
Ashland	Southwest	21,061	Climate & Energy Action Plan	2017
Bend	Central	104,544	Community Climate Action Plan	2019
Eugene	Willamette Valley	177,899	Climate Action Plan 2.0: A Roadmap for Eugene's Climate Journey	2020
Gresham	Metro	114,247	Climate Action Plan	2024
Milwaukie	Metro	21,594	Climate Action Plan	2018
Salem	Willamette Valley	175,535	Climate Action Plan	2021
Sisters	Central	2,979	Environmental Sustainability Plan	2023
Tualatin	Metro	27,383	Community Climate Action Plan	2024

Source: EConorthwest

Key Strategies and Commitments

Each of these plans includes policies and strategies related to housing, specifically, or to components for buildings, generally. While the level of detail for goals and actions varied, there were shared themes across the plans that highlight where cities are focusing their climate actions related to the built environment.

Promote Energy-Efficient and Resilient Buildings

Each of these climate action plans laid out goals related to upgrading the energy-efficiency of existing buildings. There is wide variation across the communities in the estimates of how much building energy use contributes to overall local greenhouse gas emissions (from 25 percent in Ashland to 64 percent in Milwaukie). Actions aimed at existing buildings create voluntary programs to encourage efficiency improvements that lower ongoing energy costs for owners or tenants. Many cities are also creating requirements related to efficiency as part of their development code for new buildings.

Most building efficiency policies focus on providing information and incentives to help individual homeowners weatherize their homes, or for multiunit building owners to upgrade insulation and HVAC systems. These actions range from community outreach (all cities) to establishing revolving loan programs (Bend) that can fund building investments, especially for low-income and moderate-income building owners.

Other examples of actions that rely on voluntary changes include programs that encourage residents to change how or when they use energy. Several cities are working with local utility providers to create demand response programs. These programs provide financial incentives (such as rate reductions or rebates) to customers to reduce their energy use overall or to shift their energy use to non-peak times.

Cities are also adopting actions that will update local building codes to meet net zero or various green building standards. Gresham and Salem are working on voluntary, stretch development standards. Ashland will establish minimum energy efficiency standards specifically for affordable housing that benefits from the City's affordable housing incentives. Tualatin will establish a local requirement that failed gas-powered appliances must be replaced with electric alternatives.

Diversify Housing Types

Most of the climate action plans also laid out goals to support more dense and diverse housing including townhomes, multiplexes, and multi-unit apartment buildings. House Bill 2001 requires all of these cities (except Sisters) to allow middle housing types. Some cities are also incentivizing vertical multi-unit development through zoning and regulatory incentives.

Many cities mentioned removing zoning barriers to smaller, attached, or ADU housing, such as permitted uses and setback requirements. Most of these actions did not specify clear requirements or

outcomes, and some were more exploratory (Tualatin). The most common regulatory incentive cited in the action plans was adjusting SDCs to scale by unit size to encourage smaller and attached housing types (Bend, Eugene, Milwaukie). Eugene also mentioned establishing a loan product specifically for attached housing.

Increase Compact Development and Low-Carbon Travel

All of the plans discuss the need for increasing mixed-use areas and strategically locating housing downtown, near jobs, and other daily needs. Communities identified a wide range in estimates of how much transportation contributes to overall local greenhouse gas emissions (from 12 percent in Tualatin to over 50 percent in Salem and Eugene).

Many of the plans list extensive actions related to transportation planning, from improved street design and connectivity, transit investments, and infrastructure for electric vehicles. Actions focused on increasing land use diversity range from updating comprehensive plan policies to promote infill development and walkable neighborhoods (Ashland, Milwaukie, Salem, Sisters), exploring density increases in downtown zones (Tualatin), prioritizing development in downtown and key corridors (Eugene), and allowing more uses in industrial and commercial areas (Eugene). Salem identified specific regulatory changes to support compact development, including eliminating parking minimums citywide and providing SDC exemptions for development within a quarter mile of the core transit network.

Implications for Housing Production Strategies

Oregon communities that are investing in climate action planning have already identified the importance of neighborhood-scale and building-scale interventions on meeting their local greenhouse gas emissions reductions goals. Some cities (Gresham, Milwaukie, Tualatin) have estimated the potential greenhouse gas emissions reductions related with each of their actions, either on an annual or cumulative basis. Most cities, however, discuss climate benefits in more general terms. Most plans focus on sector-based emissions, though a few are also thinking about the embodied carbon aspects of housing and land use.

Only a few cities have described clear outcomes and metrics that allow them to measure progress toward their climate goals. Bend, for example, has linked increased ADU production and smaller housing overall to the goal of reducing the city's average housing size to 1,600 square feet. The Housing Production Strategy framework requires the adoption of realistic actions that cities will implement within the six or eight years. The orientation towards implementable actions may help advance cities' climate goals for actions that have both housing production and climate benefits.

There is already overlap between climate action plans and the HPS menu of actions to support co-implementation and co-benefits. Several of the actions identified in this review are also actions in the HPS menu, including creating tax exemptions for multiunit housing and scaling SDCs by unit size or

waiving them for smaller housing types. Local climate action plans show a growing recognition that housing and climate objectives are not in competition, but are instead deeply interconnected. Integrating climate-informed housing actions into Housing Production Strategies, such as supporting infill development, minimizing parking mandates, and scaling system development charges by unit size, can help jurisdictions deliver on both their housing goals and their climate commitments. The recently updated HPS menu includes designation of actions that this study concluded were “climate-smart” housing actions to support local governments in meeting the HPS requirements to plan for climate adaptation, mitigation, and resilience.

Conclusions

Key Findings

Most of the reduced emissions related to housing will come from state-level policies about decarbonizing the energy system. Oregon’s clean energy target is designed to reduce emissions from energy sources by 80 percent by 2030. While this work is critical, it is also important for local governments to consider energy efficiency measures, such as supporting smaller, attached housing in neighborhoods designed to support walking, biking, and transit to help reach the state’s climate goals. Local actions are essential not only to complement statewide efforts but also to address emissions that state policy cannot fully reach—such as those from transportation patterns, land use decisions, and the physical form of new housing. By shaping where and how housing is built, local governments can drive down vehicle dependence, reduce infrastructure emissions, and ensure that the benefits of clean electricity are maximized through efficient, compact development.

Smaller, attached housing offers significant and consistent reductions in greenhouse gas emissions. Compared to large, single-unit homes, smaller homes consume much less energy and use less materials per unit. These energy and emissions benefits increase when housing is attached, and are highest for multi-unit buildings with five or more units. Because these climate benefits derive from the housing itself, they are more predictable than policies that support changes in travel or consumption behavior.

The benefits of increased density depend on how dense a neighborhood is to start. The literature shows that the relationship between population density and reduced greenhouse gas emissions is not linear. The benefits of increased density are often not realized below a certain threshold and are strongest in places that already have higher densities.

Neighborhood-scale policies work best in combination. The effect of changes in the D-variables of the built environment (density, diversity, design, destination access, and distance to transit) on reducing greenhouse gas emissions are relatively small when evaluated in isolation. The benefits are highly dependent on local context and the interplay between these elements in a community.

Land use policies can have positive effects on both sector-based and consumption-based emissions. Planning policies that encourage smaller housing in compact neighborhoods support reduced greenhouse gas emissions from building operations and the transportation people need to meet their daily needs. These policies can also reduce the embodied carbon in building materials and in the amount of infrastructure needed to serve these neighborhoods. Studies of household carbon footprints also show that people who live in compact neighborhoods also produce fewer emissions across all consumption patterns, beyond the gains from driving less.

Policy Implications

Oregon communities are working hard to plan for housing to fill current shortages, accommodate future growth, increase choice and affordable options, and better connect residents to community amenities. These goals also have the potential to help communities meet local and statewide goals to reduce greenhouse gas emissions by creating compact and connected neighborhoods where residents have multiple low-carbon options to meet their daily needs.

The existing literature on greenhouse gas emissions and land use policies suggest several directions and considerations for local governments engaged in housing and climate-related planning, especially related to the HPS menu of actions.

- **Housing type matters.** Housing type plays a critical role in determining the operational and embodied greenhouse gas emissions associated with residential development. Attached housing types, such as duplexes, townhomes, and multi-unit buildings (especially those over 5 units), typically have lower energy demands than detached single-unit homes. This is largely due to shared walls, floors, and ceilings, which reduce heat loss and improve overall energy efficiency. In addition to form, the size of housing has a strong influence on emissions. Smaller homes consume less energy to heat, cool, and maintain, and they require fewer materials during construction, which lowers their embodied carbon footprint. Policies that encourage or incentivize smaller, attached housing—particularly when located in areas that reduce car dependence—can offer some of the most reliable and measurable reductions in emissions from the residential sector.
- **Compact walkable neighborhoods are key.** Designing neighborhoods to include all the D-variables—density, diverse uses, design for low-carbon transportation, and access to destinations and transit—will improve the potential for lowering greenhouse gas emissions. High density housing in auto-oriented environments is less likely to support people walking, biking, or taking transit.
- **Infill development offers the greatest benefits.** Some cities are accommodating growth by designating new higher density areas at the edge of their Urban Growth Boundaries, or in new master planned areas that are currently undeveloped. While this is valuable, literature suggests that the greatest climate gains will come from focusing housing production in areas that are already dense, with diverse uses, are designed for low-carbon and active transportation, and provide good access to daily needs. Encouraging infill development is more likely to lead to reduced emissions than expansion-oriented development.

As with any of the HPS actions, how policies are designed and implemented determines their effect on the outcomes cities are trying to achieve. In the case of climate benefits, designing actions to specifically encourage or incentivize smaller or attached housing, or locate housing in compact, mixed-use areas will determine the magnitude of the potential reductions in greenhouse gas emissions.

As Oregon communities consider actions to include in their Housing Production Strategies, it is

essential to recognize that no single policy will achieve all desired outcomes on its own. Communities must balance a range of goals, including housing affordability, equitable access, infrastructure efficiency, and climate mitigation, when designing and implementing strategies. Many of the most effective actions provide multiple co-benefits. For example, encouraging smaller, attached housing in compact neighborhoods can reduce greenhouse gas emissions, lower utility costs for residents, preserve open space, and support walkable communities. By taking a holistic approach and selecting policies that provide overlapping benefits, communities can develop strategies that are both practical and transformative, meeting the program's requirements to align housing production with broader environmental, social, and economic objectives.

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