The Influence of Development Characteristics on the Ecological Footprint of an Urban Household

prepared by
Signe Gilson for Richard Gelb,
Seattle Office of Sustainability and Environment

March 19, 2004

The resources provided by the earth to feed, house, transport and otherwise support the earth's population are finite and the earth's capacity to absorb the wastes produced by our consumption is limited. Our resource use is affected by our personal consumption choices, but also by the characteristics of the built environment in which we live. The purpose of this paper is to summarize research findings on the relationship between urban development characteristics and household resource consumption using the concept of an "ecological footprint."

SUMMARY

Neighborhood land use development patterns influence a household's ecological footprint primarily by affecting fossil fuel consumption. Private vehicles and the fossil fuels they consume account for the majority of a household's land use related (i.e., housing, transportation, infrastructure) ecological footprint. Land use characteristics associated with reduced private vehicle use are:

- Land use diversity (mixed use neighborhoods)
- Higher population density
- Dense and highly connected transportation networks

Residential space heating accounts for the second highest use of fossil fuels in communities where energy for space heating is fossil fuel derived. Residential development characteristics most likely to reduce this resource use are:

- Higher proportion of townhouses and walk-up apartments
- Smaller residences

CALCULATING AN ECOLOGICAL FOOTPRINT

Mathis Wakernagel and William Rees of the University of British Columbia, coined the term, and developed the ecological footprinting technique described in their book *Our Ecological Footprint: Reducing Human Impact on the Earth*, 1995. The technique has been adapted and applied by many including the World Wildlife Fund which measured the resource use of every country in the world and compared that resource use with the resources available to us (Living Planet Report 2002).

The concept of an ecological footprint is based on the following premises:

1. A given population's consumption of food, housing, transportation, infrastructure, consumer goods, and services can be measured.

2. The population's consumption can be translated into a land area equivalent (e.g., acres of cropland occupied, acres of forestland cut, acres of land occupied by buildings) necessary to produce, grow, manufacture, transport and dispose of the food, housing, transportation, infrastructure, consumer goods, and services consumed.
3. The total number of acres used to produce the resources consumed by the population and to dispose of the wastes produced equals that population's ecological footprint.

Table 1 shows the categories of consumption that are translated into land area equivalents in a typical ecological footprint analysis. Consumption is translated into land area using coefficients that reflect the average yield of cropland, forestland, and pasture land. The coefficients convert pounds of crops consumed into acres of cropland farmed; board feet of forest products used in housing construction into acres of forestland harvested; and pounds of animal products consumed into acres of pasture land needed to raise the animals. Goods and services consumption are also translated into land area equivalents based on the resource consumption of the major inputs such as metals, wood products, and the fossil fuels consumed during manufacture.

Energy consumed within each of the consumption categories is translated into a land area equivalent, "fossil fuel land," by determining the amount of forested land needed to absorb the CO2 emitted by fossil fuel combustion. This method is based on the premise that if we consume fossil fuels (a non-renewable resource), we are responsible for the pollutants or waste products thereby generated. CO2 is a waste product and pollutant when emitted by fossil fuel combustion because it is a greenhouse gas and thereby contributes to global warming. However, given enough time and resources CO2 is absorbed by an average forest at a rate of approximately 1.8 tons of carbon per hectare per year (Wackernagel, 1996, page 121). For example, the CO2 emitted by the average US resident who drives about 14,000 miles per year requires 4 acres of average forest to absorb this waste product (Merkel, 2003; page 93).

Two other possible methods to determine the ecological footprint of energy consumption yield roughly the same footprint. One approach is to calculate the land area needed to grow fuel crops to replace fossil fuel stocks as they are depleted. Ethanol and methanol are fuels produced from plant materials such as corn and wood. Using this method, the energy footprint of an individual or population would be the acres of land needed to produce enough crops to manufacture enough crop-based fuel to supply the population's energy consumption.

A third approach is to calculate the land area needed to rebuild natural capital at the same rate as fossil fuel is being consumed. This method is based on the premise that if a society depletes non-renewable resources, it should "replace" them with an equal value of manufactured or enhanced natural assets.

TABLE 1
Consumption and Resource Use Typically Included in an Ecological Footprint Analysis

CONSUMPTION CATEGORIES	PRODUCTIVE LAND CATEGORIES*				
	Cropland	**Pastureland**	**Forestland**	**Built up land**	**Fossil fuel land (land area required to sequester CO2 produced by fossil fuel combustion:****
Food	Acres used to grow crops	Acres used to graze animals			Fossil fuel energy used to produce and transport crops and farm animals
Housing			Acres used to grow timber to produce wood-based building materials.	Acres occupied by residential buildings	Fossil fuel energy used to: manufacture and transport building materials and to construct and operate (heat, cool, provide electricity) residential buildings
Transportation and Infrastructure				Acres occupied by infrastructure, roads, parking lots	Fossil fuel energy used to transport people and goods and to construct and operate infrastructure
Goods and services	Acres used to produce raw materials to manufacture crop-based consumer goods (e.g., textiles, rubber)	Acres used to produce raw materials to manufacture animal-based consumer goods (e.g., leather)	Acres used to produce raw materials to manufacture wood products (e.g., paper, furniture) used in goods and services industries	Acres occupied by public and private buildings and services (schools, parks, airports, shops, offices, etc.)	Fossil fuel energy used to manufacture and transport goods and services; and to operate the public and private facilities that provide them.

Source: Wackernagel and Reese, 1996.

Notes:
* The resources included in a particular footprint analysis vary depending on the subject and purpose of the analysis
* * Wackernagel and Rees (Wackernagel, 1996) considered three methods for converting fossil fuel consumption into acres of productive resources consumed. The other two methods are described in the text. Non-fossil fuel energy sources such as hydropower are not included in this example. The hydropower footprint consists of the land drowned by the impoundment and the land occupied by transmission facilities.

Ecological Footprint Example

The ecological footprint measured by any particular analysis will vary depending on the categories included, data available, and the coefficients used to translate product and service consumption into land area consumption. The footprint calculation in Table 2 shows the ecological footprint of the average US resident to be approximately 24 acres (Merkel, 2003).

TABLE 2
United States Footprint Averages (acres/person) *

Consumption Category	Acres consumed to supply consumption	Portion of footprint represented by each consumption category
Transportation Car Other	4.4 acres 4.0 acres 0.4 acres	17 percent
Housing construction and operation (heating, maintenance)	5.1 acres	22 percent
Food production and transport	5.5 acres	24 percent
Goods and Services (consumer products, health care, utilities)	8.6 acres	37 percent
TOTALS *	**23.6 acres***	**100 percent**

Source: *Radical Simplicity Small Footprints on a Finite Earth*, Merkel, 2003
Notes:
* The ecological footprint measured in any particular analysis varies depending on the consumption categories included, the data available, and the coefficients used.

Land Use Related Footprint Categories

The construction and operation of a typical household in the United States consumes resources in all of the ecological footprint categories: food, housing, transportation, infrastructure, consumer goods, and services. The quantity of resources consumed by a particular household and the distribution of consumption among categories is determined in part by personal preferences, but consumption patterns also vary with respect to dwelling types, and in response to the development characteristics of the neighborhood in which the household is located.

TABLE 3
Single-Family Household Consumption of Land Use Related Resources

LAND CATEGORIES	**LAND USE RELATED CONSUMPTION CATEGORIES***			
	Housing	**Transportation**	**Infrastructure**	**TOTALS RESOURCE USE**
Fossil Fuel Land: Operating Energy**	31 percent *includes energy consumed by: heating, lighting, appliances, hot water*	41 percent *includes fossil fuel consumed to power private and public passenger vehicles*	< 1 percent	**84 percent fossil fuel land**
Fossil Fuel Land: Embodied Energy**	6 percent *includes energy consumed by: raw materials extraction, processing, transport, fabrication; house construction, repair, demolition and disposal*	4 percent *includes energy consumed by: raw materials extraction, processing, transport, fabrication; vehicle manufacture, repair and disposal*	< 1 percent	
Forest land: Wood Products	15 percent *wood required for house construction*	NA	NA	**15 percent forestland**
Occupied Land	1 percent *land occupied by the house*	(area occupied by roads is included as infrastructure)	1 percent	**2 percent occupied land**
TOTALS Consumption Type	**53 percent**	**45 percent**	**3 percent**	

Source: Study of Canadian households by Lyle Walker (Walker, 1995).

Notes
* "Land use related" includes the typical ecological footprint categories except "food" and "goods and services."
** Embodied energy and resources of a commodity refers to the total quantities of energy and materials that are used during the lifecycle of that commodity for its manufacture, transport, and disposal.

Private business decisions and public policy can affect the size and composition of an urban household's footprint by their decisions affecting the mix of dwelling types available, the characteristics of the transportation network, and the population density and land use mix of a neighborhood. The footprint categories most influenced by these development patterns are housing, transportation, and infrastructure (all major consumption categories except "food" and "goods and services"). These are referred to as the land use related consumption categories.

Consumption in the land use related categories translates into an ecological footprint made up of forestland, built up land, and fossil fuel land. Table 3 shows the single-family household's resource use in the land use related consumption categories (Walker, 1995). When combined, fossil fuel consumption accounts for 84 percent of the resource use within these three categories of household consumption. Thirty-seven percent of the fossil fuel use is attributed to private passenger vehicle operation and 31 percent is the result of fossil fuel energy (oil and natural gas) used to heat and provide a portion of the household operating energy. Walker studied Canadian households but the household fuel consumption characteristics are comparable to Seattle's.

It is interesting to note that the most tangible portion of a household's land use related footprint, the land physically occupied by the dwelling, makes by far the smallest contribution to the overall ecological footprint.

URBAN DEVELOPMENT CHARACTERISTICS AND HOUSEHOLD ECOLOGICAL FOOTPRINT SIZE

The Walker study described above indicated that fossil fuel consumption represents 84 percent of the single family household's land use related ecological footprint. The majority of this is consumed by private vehicles and to operate (heat, light, etc.) the household.

Urban development characteristics that reduce the number and distance of a household's private vehicle trips and thereby reduce fossil fuel related household consumption are:

- Land use diversity (mixed use neighborhoods)
- Increased population density
- Dense and highly connected transportation network

Household characteristics that result in less fossil fuel consumption to heat and provide household electricity are:

- Higher proportion of townhouses and walk-up apartments
- Smaller houses

Land Use Diversity (mixed use neighborhoods). Land use diversity together with transportation network density (see below) can effectively reduce the distance between destinations and thereby increase the feasibility of alternative transportation modes (Walker and Reese, 1997; page 102). Distance between trip origin/destinations is reduced by the physical proximity of residential, commercial and retail uses, and together with increased route options, encourages pedestrian modes.

A study of San Francisco neighborhoods concluded that the built environment affects residents' travel habits though the effect is not always understood (Cervero, 1997). The authors believe that the combination of higher densities, diverse land uses, and pedestrian-friendly environments together can reduce vehicle miles traveled, and increase use of transit and pedestrian modes. Several specific design elements of the built environment seemed to be particularly relevant to non-work trips. Notably, neighborhoods with high shares of four-way intersections and limited on-street parking abutting commercial establishments tended to average less single-occupant vehicular travel for non-work purposes (Cervero, 1997).

Pedestrian-friendly environments and the presence of convenience stores within a quarter mile of residences appeared to induce commute trips via transit and non-motorized modes. The study authors suggest that plentiful neighborhood retail shops and "pedestrian-oriented" designs are significant factors in encouraging people to commute by transit and non-motorized modes (Cervero, 1997). They believe that nearby retail uses allow workers to shop while en route from transit stops to home.

Higher Population Density and Road Network Density. A highly connected transportation network as indicated by the number and proximity of intersections, reduces the route distance for all modes of travel by increasing the number of route options. The grid network is the most highly connected street pattern.

A recent study of the link between land use patterns and transportation in the Puget Sound region, found that as population and transportation network densities increase, the proximity and connectivity of trip ends increases. Higher population and road network densities reduce the distances traveled because; 1) route distances are shortened and route options increased by the dense and highly connected road network, and 2) walking becomes potentially more viable (Frank, 2000).

Traffic congestion, though maybe not a desirable goal, can reduce vehicle miles traveled since pedestrian modes may become more efficient. However, a free flow of traffic results in greater fuel efficiency and lower emissions. Thus, a certain amount of congestion may be desirable from the standpoint of trip reduction, but result in increased adverse health issues and increased fuel consumption (Anderson, 199; page 30).

Dwelling Types. Second to fossil fuel consumption used to power vehicles, the next greatest land use related contributors to the urban household's ecological footprint are the energy required to operate the household, and the forest products consumed in building construction (see Table 3).

Dwelling types that share walls and floors between units, such as townhouses and walk-up apartments, draw less energy for space heating and cooling because of the insulating effect of the shared walls. Townhouses and walk-up apartments also tend to have less space per capita and for that reason also consume less energy for heating. Detached single family houses consume the most operating and embodied energy per unit of floor space when other factors are held constant. (Walker and Rees, 1997).

The per household ecological footprint of a townhouse is 78 percent of the ecological footprint of a detached single family residences, and the footprint of a walkup apartment household is 38 percent of a single family detached household (Walker, 1995; page 78).

The characteristics of each housing type (floor space, lot size, and number of occupants) measurably affect consumption related to house construction and operation and transportation. Similarly, there is a link between lot size and the energy, materials, and land required for infrastructure. Lot size determines the frontage which in turn dictates the amount of linear infrastructure (e.g., electric lines, communications cables, water and sewer line required to service the lot) (Walker and Rees, 1997; page 105 – 106).

CONCLUSION

A combination of personal consumption choices, private business decisions affecting land use mix and dwelling types, and public policy decisions that affect urban development patterns can dramatically reduce an urban household's footprint. Living in a compact dwelling, driving an energy-efficient car, and using pedestrian modes when feasible, can significantly reduce a household's transportation and housing footprint. Coincidentally, such a lifestyle could entail quality of life improvements as well.

Sources:

Anderson, William, Pavlos Kanaroglou, and Eric Miller, "Urban Form, Energy and the Environment: A Review of Issues, Evidence, and Policy," *Urban Studies Volume No. 1, pages 7-35,* 1996.

Cervero, Robert and Kara Kockelman, "Travel Demand and the 3D's: Density, Diversity, and Design," *Transportation Research D, Volume 2*, pages 199-219, 1997.

Frank, Lawrence; Brian Stone, Jr., and William Bachman; "Linking Land Use with Household Vehicle Emissions in the Central Puget Sound: Methodological Framework and Findings*," Transportation Research Part D 5* pages 173-196, 2000.

Merkel, Jim, *Radical Simplicity: Small Footprints on a Finite Earth,* 2003.

United Nations Environment Program, *Living Planet Report 2002.*

Van Diepen, Albertine and Henk Voogd, "Sustainability and Planning: Does Urban Form Matter?" *International Journal Sustainable Development, Volume 4, No. 1*, 2001.

Wackernagel, Mathis and William Rees, *Our Ecological Footprint: Reducing Human Impact on the Earth,* 1996.

Wackernagel, Mathis, et. al., "Tracking the Ecological Overshoot of the Human Economy," *Proceedings of the National Academy of the Sciences,* July 9, 2002.

Walker, Lyle, "The Influence of Dwelling Type and Residential Density on the Appropriated Carrying Capacity of Canadian Households," 1995.

Walker, Lyle and William Rees, "Urban Density and Ecological Footprints – An Analysis of Canadian Households" *Eco-City Dimensions: Healthy Communities, Healthy Planet*, Ed. Mark Roseland, 1997.