

Framework for eco-mobility in multi-functional neighborhood

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Abstract

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Automobile centric transportation system in North American urban sprawl with sporadically dispersed amenities result in high trip length and consequently elevated Carbon emission that warrants major remodeling at rudimentary level. This study develops a framework that amalgamates eco-mobility with multi-functional neighborhood system and proves the application of framework on different Neighborhood Scenarios (NS) through reduction of environmental, social and economic impact of the sustainable mobility-amenity nexus. The goal is to create a scalable, holistic approach to eco-mobility framework within a cluster of amenity-rich neighborhoods.

The methodology employed in this research work begins with development of an Eco-Mobility Strategic Framework (EMSF) focusing on three strategies – walking, cycling and public transportation, which are inspected (individually or in combination). A base case scenario for a neighborhood called West-5 at London (ON), where eco-mobility and multi-functional neighborhood strategies are yet to be applied, is examined. A contemporary multi-functional urban planning strategy called 15-minutes city is employed in this study for six different Neighborhood Scenarios (NS) at seven different Degree of Amenity Availability (DOAA) where amenities such as living, working, supplying, caring, learning and enjoying/leisure are taken into account. Sustainability of combining EMSF with 15-minute neighborhood is scrutinized with respect to environmental (e.g., annual CO₂ emission and annual energy consumption), social (e.g., travel time) and economic (e.g., net annual cost) pillars – namely Sustainability Transportation Indicators (STI). Finally, Decision-Making Metric (DMM) is proposed where effectivity of EMSF at multi-functional Neighborhood Scenarios (NS) under different DOAA are measured and quantified using two metric – Framework Performance Coefficient (FPC) and a Decision-Making Metric Value (DMMV) that combines the FPCs altogether with respect to their importance weight to the policy makers.

Results, in a broad sense, demonstrate that application of Eco-Mobility Strategic Framework (EMSF) in multi-functional neighborhoods mark into average reduction in annual CO₂ (STI₁), annual energy consumption (STI₂), annual travel time (STI₃) and annual net cost (STI₄) of 97%, 95%, 83%, 48% respectively. However, a closer inspection reveals that lower degree of EMSF such as walking only or walking & cycling only strategies reduce environmental indicators with respect to base case scenario. However, higher degree of EMSF yields better results for social and economic indicators. This contrast is addressed in the Decision-Making Metric (DMM) where average Decision-Making Metric Value (DMMV) is 0.19 indicating that integration of eco-mobility and multi-functional neighborhood results into overall reduction of 81% impact from environmental, social and economic sustainability combinedly.

This study aids the urban planners, policy makers and community members by simplifying the policy selection process by developing a flowchart for mobility on neighborhood: Amenity-Mobility Integration (Mon-AMI). Scalability of MonAMI is ensured through using a procedure of interpreting the Eco-Mobility Strategic Framework (EMSF) and multi-functional neighborhood scenarios into a simple trip length, number of trips, modal ratio components which are easily measured. Both existing and proposed neighborhoods are benefited from Mon-AMI that aids in selecting sustainable strategies regarding mobility and amenities.

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Dedication

My journey towards the MASc have been built upon the constant love, commitment, and encouragement of my family, to whom this thesis is dedicated. Their unwavering confidence in my skills has motivated me to overcome every obstacle. In addition, I dedicate this work to my friends and colleagues, who have been a constant source of encouragement and support. Last but not least, I dedicate my accomplishment to everyone who works to promote building engineering knowledge and innovation, hoping that our work will help create robust and sustainable infrastructure for coming generations.

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List of Abbreviations

DMM = Decision Making Metric

DMMV = Decision Making Metric Value

DOAA = Degree of Amenity Availability

EMSF = Eco-Mobility Strategi Framework

EV = Electric Vehicle

FMC = 15-minute City

FPC = Framework Performance Coefficient

GHG = Greenhouse Gas

kW-H = kilo watt hour

NC = Neighborhood Cluster

NS = Neighborhood Scenario

NU = Neighborhood Unit

PV = Photovoltaic

SDGs = Sustainable Development Goals

STI = Sustainable Transportation Indicator

1. Introduction

1.1. Background

A typical North American urban neighborhood requires long hours of driving using fossil fuel-based automobiles from home to work or other amenities, resulting in substantial CO₂ emission coupled with wasted time on roads. Canada produced 708MT of CO₂ equivalents in the year 2022 which was 1.3% more than that of the year 2021 and 22% of this emission i.e., 156MT of CO₂e are emitted from transportation sector [1] [2]. The World Bank reported that 56% of the world population are living in cities and by 2050 this figure is expected to double indicating that 70% of world population are going to live in cities [3]. United Nations states that cities consume 75% of world's energy while emitting 70% of global greenhouse and World Bank also reports that fossil fuel-based automobiles are the principal contributors of urban Greenhouse Gas (GHG) emission [4] [5]. As on July 1st of 2023, 29.8 million i.e., 75% Canadians live in metropolitan areas [6]. Multi-modal mobility plays the central role in contributing towards a sustainable society that fights global societal threats of climate change [7]. Studies show that walkable mixed-use neighborhoods have higher level of social capital – social network and interactions inspiring trust and reciprocity among citizens - in comparison to car-oriented sub-urbs [8]. This study aspires to examine the possibility of reducing environmental, social and economic impact of sustainable transportation system by introduction of multi-functional neighborhood such as 15-minute city.

1.2. Problem

Road transportation system in Canada generated 84% of the Canada's greenhouse gas [2]. Volatile organic compounds (VOCs), nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO) and sulphur oxides (SO_x) are emitted as a result of greater reliance on private vehicles owned by dwellers of urban neighborhood [9]. By employing cleaner manufacturing methods, renewable energy sources, and policies or incentives to reduce industrial emissions, many towns are already making significant progress. Reducing emissions will also improve urban air quality and city people's health by lowering local pollution from transportation and industry [10].

Disparity between the availability of amenity in neighborhood which influences the average trip length of dwellers and availability of sustainable transportation i.e., eco-mobility infrastructure, is a problem that warrants attention for further research work. Sustainable development goals (SDGs) set by United Nations (UN) includes 17 goals where SDG-7 (affordable and clean energy), SDG-11 (sustainable cities and communities) and SDG-13 (climate action) lies within scope of this study. However, strategies that integrate communities and CO₂ emission from transportation modes as source of emission requires special attention. Several studies have been conducted on integrating multi-functional neighborhoods and on one particular mode of sustainable transportation (e.g., walking or cycling or public transportation), but combined studies involving these two strategies and developing a framework including them is scarce. Quantifying the effectiveness of such a framework by means of sustainable development pillars (e.g., environmental, social, economic) and presenting it to the policy-makers and the community in a simple comprehensible way is another challenge from technical perspective.

This study is going to examine neighborhoods of different geometry and amenity availability i.e., multi-functional neighborhood(s) that includes different degree of sustainable transportation i.e., eco-mobility and combine these two strategies into a single quantifiable framework, effectiveness of which can be measured and used as a decision-making tool for the policy makers. This thesis proposes a methodology that examines the combined effect of amenity-mobility framework, measures the framework's effectivity and conveys the result to policy makers with a single digit.

1.3. Research objectives and questions

As part of a broader research work on resilient and sustainable community development, this research work looks at communities from amenity and mobility perspective. The goal here is to set strategies that reduces sustainable development indicators such as CO₂ emission and energy consumption and also travel time and cost. With this goal, the study will look into neighborhood scenarios of different geometry and amenity availability while introducing the eco-mobility strategies to examine the effect of the integrated strategies on the sustainability indicators.

1.4. Scope of the study

This research work aims to develop a framework that integrates two strategies - multi-functional urban neighborhoods with eco-mobility – to reduce greenhouse gas emission. Following figure (figure-1) shows the scope of this research work and topics discussed in it.

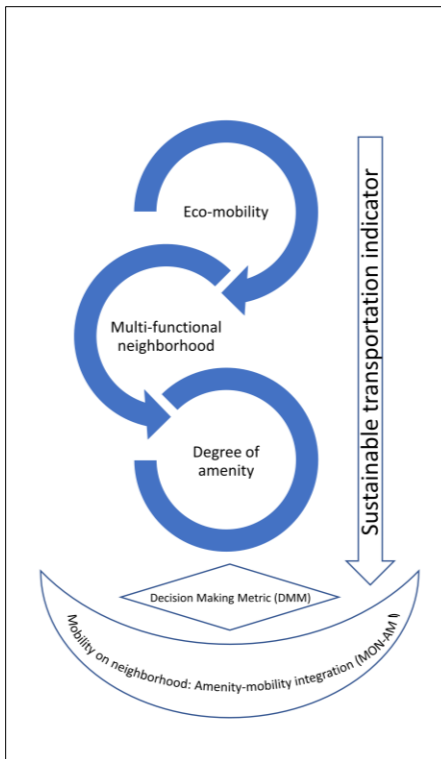


Figure 1 Scope of the study delineating Amenity-mobility integration in multi-functional neighborhood

The concept of 15-minute city will be applied in context of a Canadian urban neighborhood where spatial redistribution of amenities coupled with introduction of eco-mobility strategies such as walking, cycling, public transportation is to be examined as an integrated framework. As a measure of effectivity of the framework, this study will measure environmental, social and economic pillars of sustainability as indicators. In order to make the framework scalable and popular among urban planners, the goal is to develop a framework that is easily computable with data (e.g., traffic, demographic, geometric) from readily available sources. This study will examine a base case neighborhood in Canadian urban scenario.

Qualitative aspects of amenity-mobility framework are to be quantified and examined in this research work. A North American neighborhood in Canadian urban context is scrutinized where data pertaining to multimodal transportation (e.g., trip length, number of trips, modal ratio etc.), community (e.g., demographic, vehicle ownership, propensity to use sustainable modes etc.) are available or collected from primary or secondary sources. Sustainability performance will be evaluated by the measurement and analysis of land-use and transportation indicators, including travel time, modal split, trip duration, and greenhouse gas emissions. Eco-mobility strategies (i.e., walking, cycling and public transportation) and privately owned automobiles are considered within the scope of this research work. Only the urban neighborhood scenarios perused in this study. Instead of inter-city or intra-city transportation system, this research work scrutinizes neighborhood scale transportation system and also does not consider automobile-based ride sharing as a separate mode of transportation.

In order to postulate a scalable framework for stakeholders (e.g., policymakers, urban planners, community members etc.) around the globe, the scope of this thesis will seek to present a combined flow chart titled “mobility on neighborhood: amenity-mobility integration (Mon-AMI)” that includes a data driven eco-mobility strategic framework (EMSF) and a decision-making metric (DMM). With this scope, this research work will focus into the dynamics of multifunctional neighborhood with sustainable mobility for creating sustainable and low-carbon emitting community.

1.5. Thesis organization

This study looks into amenity-mobility duo in context of Canadian urban neighborhood. Amenity in context of multi-functional neighborhood such as 15-minute city and mobility in context of eco-mobility are perused in this study.

Chapter 2 of this research work contains the literature review that examines the concept of 15-minute city and eco-mobility independently. It also scrutinizes the literature that integrates these two strategies into a single framework plan.

Chapter 3 of this thesis contains the methodology that proposes a framework that combines the spatial re-distribution of amenity with mobility. Several 15-minute city or neighborhood scenarios are generated based on a base case neighborhood where different degrees of amenity are available. Eco-mobility strategies are applied and their effectivity is measured using different sustainable indicators. Finally, a Decision-making metric is formulated that quantifies and unifies different indicators into a simple number.

Chapter 4 of this study applies the newly developed methodology in context of different neighborhood scenarios at different degree of amenities availability. This chapter also measures and quantifies the strategies and provides a comprehensible decision-making metric.

Chapter 5 of this thesis contains the discussion about the results obtained from previous chapter and postulates a scalable flowchart titled “Mobility on neighborhood: Amenity-Mobility Integration (Mon-AMI)” that can be applied to other urban neighborhoods around the globe.

Chapter 6 is the final chapter of the thesis contains the conclusion that describes the inference drawn from this research work on amenity-mobility integration in neighborhood scale.

2. Literature review

2.1. Multi-functional neighborhood

2.1.1. Basic concept of city, neighborhood and urban sprawl

City as a functional entity comprising an urban transportation system that includes infrastructure, rolling stock and traffic flows and the transportation system in a city is characterized by high concentration of human activities within a limited space (e.g., commercial and business district) [11]. City can also be defined as a relatively large, dense and permanent settlement of heterogeneous individuals where large number brings individual variability, density involves diversification and specialization and heterogeneity breaks down the rigid social structure [12]. Another literature describes city as a physical entity, where consumption of goods and services take place, where employment occurs and workforce works [13].

Communities in urban context are known as neighborhoods. They are known as geographical subarea of city where residents share spatial proximity and some degree of mutual circumstances, needs, priorities and access to broader metropolitan area and the systems to have an impact on their lives [14]. Place and human activities are interlinked in the neighborhood [15]. A Quebec, Canada based research work defined neighborhood as a living area, a place of work, a place of utility (e.g., grocery stores, medical clinics etc.), a place for socialization [16].

In contrast to the ancient Greek concepts, livable criteria such as job opportunities, efficient transport system and sound urban finance has gained more weightage to become a good city in the mind of dwellers [17]. Neighborhoods include bundle of spatially based attributes associated with clusters of residences, sometimes in conjunction with other land use [18]. Classic definition of neighborhood unit entails the presence of ideal residential units with school, churches and recreational areas at the center of neighborhood. Dwellers should be able to reach these features through a quarter-mile walk with commercial areas nearby [19]. Neighborhood unit is the new frontier for changing the functional and spatial structure of urban areas [20].

Starting from early 20th century, the North American cities are creating single-purpose districts while segregating land-use and regulating deleterious industries [21]. This lead to the concept of urban sprawl that describes low density development in the outskirts of cities that comprises of single detached houses and high dependency on automobiles with major environmental and socioeconomical implications [22] [23]. Urban sprawl portrays suburbanization process where percentage of built up area, dispersion of the built up area and low density are the key dimensions for measuring the degree of its application [24]. However, lack of mixed land use and homogenous developments are few of the criticisms that urban sprawl confronts. On the contrary, mixed land-use promotes active mode of transportations (e.g., walking and cycling) and lower vehicle-miles that contribute toward achievement of cleaner environment and aesthetic urban scenario [25].

2.1.2. Basic concept of multi-functional neighborhood

A multi-functional neighborhood is an antonym to the popular zoning concept in North America and can be defined as a neighborhood where synergy between various types activities

exist through spatial combination of separate land units with different functions or through function assigned to same land unit but to be executed at different time or integrated functions to be executed at same land unit at same time [26]. Multifunctional neighborhood is also defined as urban locations where supplying, living, enjoying/leisure, working, and occasionally light industrial uses coexist in a small geographical area. The concept moves away from typical North American zoning laws and introduces poly-centric city strategies that aim to lessen reliance on automobiles and promotes active mode of transportation [27].

The concept of mixed-use neighborhoods gained pace in the 1980's where environmental quality, equity and efficiency driven communities brought advantages over the classic urban sprawl. Optimum use of infrastructure, greater range of options for household design, increase in affordability and equity by mixing housing type, reduction of car dependence by establishing housing near commercial and civic activities, alleviate the environmental consequences associated with automobile use by reducing the need for car ownership by establishing amenities near to residences are few of the advantages of multi-functional neighborhoods [21]. Following figure (figure-2) shows a conceptual example of multi-functional neighborhood (e.g., 15-minute city).

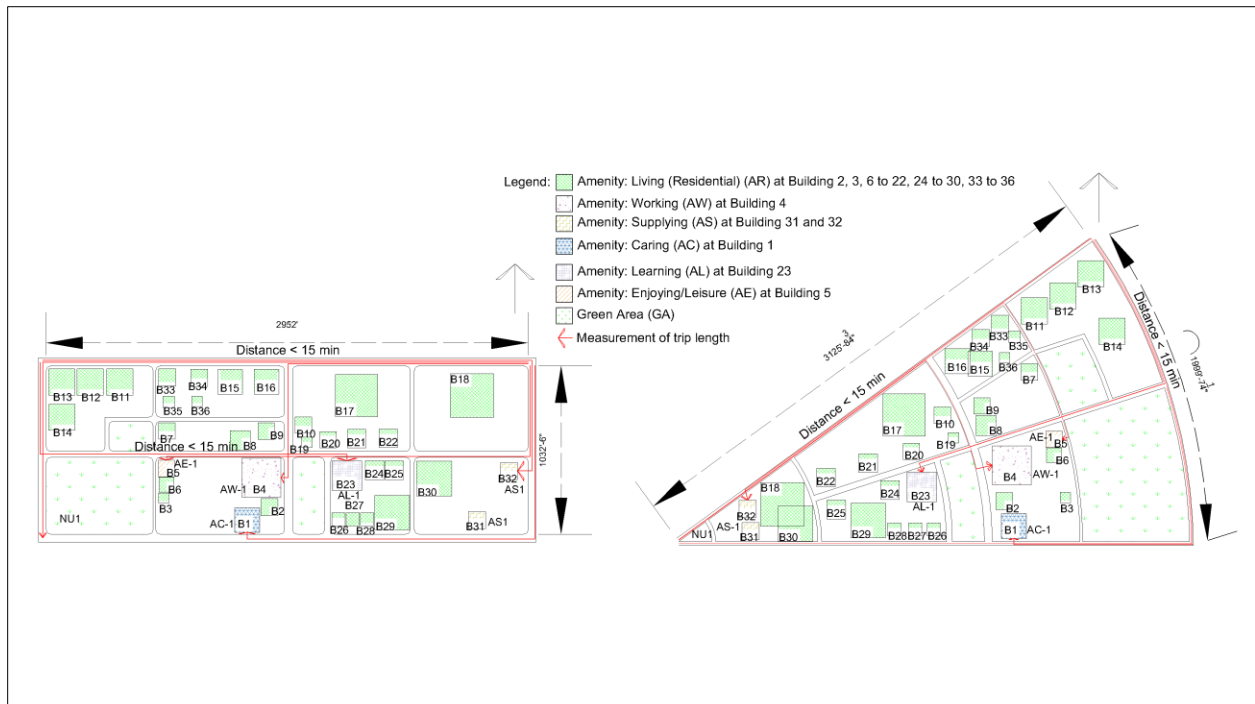


Figure 2 Conceptual pictorial representation of a multi-functional neighborhood, i.e., 15- min city (rectangular and radial road patterned multi-functional neighborhood of 70 acre/0.28 km²) [28]

For example, the city of Portland, Oregon at USA has gone through a policy change where the city planned to take a multinucleated urban form that includes multi-modal transportation system and mixed-use regional and town centers [25]. While urban sprawl areas cause higher vehicular emissions due to lower proximity to important amenities (e.g., work place, public transport etc.), the concept of multi-functional neighborhood is gaining popularity around the globe [29]. The theory of n-minutes city develop living zones of n-minute radii where

dwellers are able to meet their demand within a n-minute walk from their residences, brining sustainability to the urban environment [30]. Policy makers are also able to use the n-minute city as a tool to achieve the sustainable development goals 11 (SDG-11) that create inclusive, safe, resilient and sustainable cities [31].

2.1.3. Multi-functional neighborhood: chrono-urbanism and 15-minute city

15-minute city concept was first launched by Carlos Moreno in 2016. However the concept of multi-functional neighborhood in the shape of 20-minute neighborhood was already being implemented in Portland, Oregon of USA since early 2000's [32].

Chrono-urbanism - an urban planning approach visualized by Swedish geographer Torsten Hägerstrand - urges that concentration must be shifted towards the travel time to improve the experience of city dwellers [33]. Chrono-urbanism visions a peaceful city life where long-distance commutes, bad traffic conditions and running-in-a-hurry type lifestyle will be eliminated and cities are rearranged in small nuclei with neighborhoods containing essential amenities to fulfill recurrent needs [34]. Chrono-urbanism describes cities from a time and proximity standpoint which gives birth to a new urban planning concept called 15-minutes city (FMC) [35]. A study made at Calgary in Canada also showed that distance of business center from residences has the highest impact on GHG emission from transportation standpoint [36].

Rooted in the principles of chrono-urbanism, the concept of the 15-minute city (FMC) reimagines traditional mono-functional urban centers as polycentric, human-scaled cities. It is structured around four key dimensions: (i) proximity – ensuring daily needs are accessible within a short distance; (ii) diversity - promoting a mix of land uses and services; (iii) density - supporting vibrant, efficient urban forms; and (iv) ubiquity or digitalization - utilizing technology to enhance accessibility and connectivity [37] [38]. FMC concentrates on urban life planning instead of city planning and it describes an urban environment where residents can meet their essential needs within a short trip from home using Carbon free mobility or active modes of travel i.e., walking and cycling [39].

Design process of an energy efficient neighborhood starts from optimizing it's site layouts, road layouts and partition of land [40]. Energy consumption and corresponding Green House Gas (GHG) emission of a neighborhood is greatly impacted by the function served by the buildings operating in a neighborhood [41]. Mixed used neighborhoods also known as “live, work, play” community are considered more environment friendly than single-use neighborhoods [42]. The theory of 15-minutes city states that six essential social functions or amenities i.e., (i) living (e.g., residential detached or attached units), (ii) working (e.g., commercial buildings), (iii) supplying (e.g., grocery stores, pharmacies), (iv) caring (e.g., hospital, health care centers), (v) learning (e.g., educational institutions, schools) and (vi) enjoying/leisure (e.g., parks, movie theatres) should be available within a short distance i.e., 15-minutes walking or wheeling distance or 1 km radius [39] [43]. All of these six amenities should demonstrate the basic characteristics (e.g., proximity, diversity, density and ubiquity) described earlier.

2.1.4. Advantages and disadvantages of 15-minute city

Apart from one obvious benefit of 15-minute city concept being the reduction of long trip length and corresponding decrease in travel time to amenities, there are other advantages stemming out of this concept that are described below,

- Reduction in CO₂ emission and energy consumption due to reduction or elimination of vehicle miles or vehicle kilometers. Decrease in traffic congestion, increase in green spaces, boost in economic front and potential for employment are few other advantages of 15-minute city [38].
- Public health is benefited due to enhanced use of active mode of transportation i.e., walking and cycling [33].
- Increased social interaction and cohesion in neighborhood is another benefit of 15-minute city [31].

On the contrary, the critics of 15-minute city concept have pointed out following disadvantages or drawbacks that are summarized below,

- Implementation of 15-minute city concept by spatially redistributing the amenities requires major policy change, political affiliation and acceptance from community members for both existing as well as new neighborhoods [32].
- Introduction of amenities and special transportation features in a neighborhood can cause a hike in real-estate price resulting in gentrification [32].
- For public transportation, the last millimeter or mile issue coupled with discomfort for people with special need or disability are a major drawback for 15-minute city that promotes active mode of transportation [32].

2.1.5. Research works pertaining to multi-functional neighborhoods in context of North America

Similar principles pertaining to urban sustainability have been implemented in a neighborhood called Olympic village at Vancouver, British-Columbia in Canada [44]. The city of Montreal also intends to achieve carbon neutrality by the year 2050 and inspire to achieve their goal by implementing 15-minute city policies such as convenient access to a wide spectrum of amenities and services by the residents at a close proximity [45]. Paris has already implemented the multi-functional neighborhood concept called 15-minute city where spatial reallocation of amenities is complemented by infrastructure development for active mode of transportation and public transit [38] [46]. Superblocks in Barcelona, Spain is also another example for execution of sustainable strategies in urban neighborhood [47]. Similar examples in Melbourne, Australia and Milan, Italy exists where multi-functional concepts are being implemented [48] [49].

The multi-functional neighborhoods result into modified traffic flow i.e., trip length, number of trips generated and modal share. Multifunctional neighborhoods also lead to higher land-use mix, a higher density of amenities and improved accessibility that causes reduced vehicle kilometers traveled (VKT) and increased use of walking, cycling, and public transportation. Introduction of amenities in the neighborhood promotes non-motorized travel

while other factors such as socioeconomic factors, land use mix and accessibility to amenities are confirmed. Studies highlight measurement sensitivity the results mostly rely on the geographical scale employed in the research as well as the operationalization of employment to residential ratios [50].

Recent research demonstrates that neighborhoods may be multifunctional in many ways at different times of day (e.g., work place during daytime is converted to leisure place at evening) by detecting functional mixing and temporally multilayered uses using land-use inventory. Urban multifunctional features (e.g., home-based businesses and informal retail) are frequently under represented on standard zoning maps. For policy makers and urban planners, quantifying temporal and functional mixing is especially important because daytime multifunctionality (e.g., work and supply amenities) would have different mobility and emissions effects than mixed neighborhoods [51].

The literature on planning and policy also connects multifunctionality to public health, economic condition, and resilience. By focusing demand for small local businesses and encouraging chance encounters that create social capital, mixed neighborhoods can boost local economies. These effects are frequently measured by pedestrian density, street-level business survival and qualitative evaluations of vibrancy. Simultaneously, multifunctionality interacts with the quality of the public realm (e.g., parks, street design) as well as the transportation system. While poorly planned public spaces and transit can reduce the advantages of functional mixing, well designed public spaces and transit can enhance them. Nature-based multifunctionality also demonstrates that including green infrastructure in mixed neighborhoods may provide a number of co-benefits, including flood prevention, amenity and microclimate management [52].

The literature pertaining to multi-functional neighborhoods also show significant trade-offs and contextual limitations despite widespread excitement. One issue is equity: gentrification, or the displacement of lower-income households, and rising property values are frequently brought on by redevelopment that produces multipurpose, high-amenity neighborhoods. This can undermine the socioeconomic variety that once made the area alive. Another issue is that sustainability is not ensured by multifunctionality alone. If mixed uses (such as big surface parking and arterial surroundings) continue to be automobile oriented, the potential benefits of improved travel behavior may be outweighed by a continuous reliance on automobiles. As a result, design and governance are just as important as the land-use mix [53].

Multi-functional neighborhoods have unique possibilities and challenges in North American cities. Functional zoning and sub-urbanization in the 20th century influenced a large portion of North America, creating monofunctional sub-urban areas with low densities and a reliance on automobiles. However, mixed use redevelopments have become more popular in recent decades. Infill projects, transit-oriented developments (TODs), and downtown revitalizations have brought multi-functionality back to many inner sub-urban areas and urban cores. According to comparative research, without intentional design and policy interventions, North American urban form larger block sizes, lower densities and larger trip lengths that often makes it more difficult to create walkable mixed-use neighborhoods. According to recent empirical study, it is more difficult to achieve the 15-minute scale that is typical in European

cities in many North American situations. A somewhat longer realistic accessibility objective (e.g., 20 to 30 minutes) may be more suitable north American sub-urban areas, unless substantial retrofitting is carried out. These results suggest that North American multifunctionality strategies need to pay more attention to densification around transportation and street retrofitting [54].

In context of Canadian metropolitan areas, policy changes that may promote multi-functional neighborhood transitions include zoning change, motivations for ground-floor retail, parking maximums rather than minimums and incentives for mid-rise housing. In order to prevent mixed projects from turning into gated communities, it is crucial to coordinate parking regulations, pedestrian walkway design and small business assistance. Mixed developments centered on strategically located transit stoppages are the most effective in decreasing driving and boosting the number of people using public transportation. However, successful transition from single-use neighborhood to multi-functional one is influenced by market conditions, political leadership and financial resources [53].

Scale and measurement are still areas of current research. Strong policy recommendations still need separating selection effects, socioeconomic confounders and service accessibility, even though evidence suggest that multi-functionality has a causal impact on fewer automobile trips and shorter travel times [55].

The concept of multi-functional neighborhood has recently been extended to modern planning frameworks including equitable accessibility and the 15-minute city. The 15-minute cities reframe multi-functionality as an integrated approach for everyday amenities within walking distance. In order to provide equal access to necessary amenities, it is recommended to combine multi-functionality with progressive housing and transportation investment. Furthermore, environmental studies are increasingly examining whether multifunctionality results in quantifiable greenhouse gas reductions at the local or metropolitan level. The preliminary data is supporting the idea that low-carbon emitting transportation system must be combined with land-use interventions [56].

In summary, different literature demonstrates compelling theoretical and empirical justifications for multi-functional neighborhoods as a tool for sustainable development of neighborhoods. If properly planned, multi-functional neighborhoods reduce travel times, encourage active modes of transportation, brighten up streets and offer a number of other benefits. However, accurate measurement, complementing housing and transportation regulations and clear equality protections are necessary for multi-functionality to be effective [27].

2.2. Eco-mobility

2.2.1. Basic concepts of transportation system

Transportation system provide opportunities for the mobility of people and goods, but over the long term it influences patterns of growth and the level of economic activity through the accessibility it provides to land [57]. Another definition of transportation system describes it as a coordinated set of modes, facilities and services designed to move people and goods safely and efficiently from one location to another [58]. Importance of research work on transportations

system is described in the book *Directions in engineering research: An assessment of opportunities and needs* (1987) where it was predicted that United States' supremacy in economy and defense will be compromised if it fails to progress in transportation [59]. The same literature describes important issues pertaining to transportation system such as protecting the environment, reducing life-cycle costs, conserving scarce energy and material resources etc. Beside the classic elements such as node (e.g., location), link (e.g., infrastructure that connect the nodes), hub (e.g., large nodes that handles substantial amount of traffic) etc., contemporary transportation system comprises of gateways that function as the compulsory passage or junction between different modes of traffic [60].

2.2.2. Sustainable mobility

The Brundtland report published by United Nations in 1987 defined sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs [61] [62]. United Nations declared 26th November as World Sustainable Transport Day and also defined sustainable transport as “the provision of services and infrastructure for the mobility of people and goods - advancing economic and social development to benefit today's and future generations - in a manner that is safe, affordable, accessible, efficient, and resilient, while minimizing carbon and other emissions and environmental impacts” [63]. Transport Canada defines sustainable transportation system as one that integrates and balances social, economic and environmental objectives [64].

In line with the SDG goal 11 for sustainable cities and communities, Government of Canada has set goals to ensure that Canadians live in healthy, accessible and sustainable cities and communities. One of Canada's specific goals pertaining to SDG-11 is that 22% of commuters adopt shared or active transportation by 2030. Canadian Indicator Factor (CIF) set for measuring the SDG achievement progress measures the percentage of people living within 500 meters of public transportation stoppage (e.g., Canadian average is 74.6% of population where urban dwellers are 81.1% and rural dwellers are 9.7%) and also the percentage of people using active or shared transportation for commuting [65, p. 11].

2.2.3. Eco-mobility planning

Transportation planning is a process which consists of well-defined tasks that must be accomplished before the final set of information is presented to those who must decide which course of action is best for an agency, region or community [66]. Eco-mobility aspires to shift the focus from privately owned automobiles to integrated sustainable modes comprising walking, cycling, wheeling and public transportation. Automobile-dependency describes unavoidable reliance on automobiles (e.g., cars, scooters, motorcycles) for everyday commutes and it stems from absence of safe and efficient alternative mode of transportation [67]. Eco-mobility encompasses walking, cycling, public transport, and shared light electric vehicles. It encourages travel through integrated and socially inclusive transportations alternatives which are environment friendly and discourages dependency on privately-owned vehicles [68]. Few examples of eco-mobility around the globe are Leipzig, Germany which is entirely run by renewable energy; Portland (OR), USA have implemented transportation policies where walking, cycling, transit and use of shared vehicle is given priority over privately owned cars; Kochi,

India where e-bus and e-rickshaw project have been introduced to fill up the “first and last mile connectivity” coupled with public transport system; Burgas, Bulgaria where Intelligent Transport System (ITS) have been launched and Almada, Portugal with solar pavements have been installed [69]. Household travel survey 2016 showed that dwellers of London, Ontario, Canada vastly rely on convenience (82%) and travel time (75%) while choosing transportation mode although weather (35%), parking availability (29%), bus waiting time (24%) are also important issues to Londoners for choosing mode of transportation [70].

2.2.4. Eco-mobility modes

2.2.4.1. Eco-mobility: walking

Neighborhoods that offer short distance to destination, presence of other people in destination or streets, aesthetic window display, proper width of sidewalk, separated sidewalk from motorway and cycling path, safe traffic crossing, relatively smaller motor traffic on the street, presence of other pedestrians on the sidewalk (familiar faces), noiseless, clean, well-maintained street attract more senior adults to walk [71]. On the contrary, early darkness and absence of greenery during winter, rain puddles and mud caused by snow, busy traffic on the motorway and careless cyclists, cracks and unevenness in sidewalk, disappearance of local shops from community discourage people from walking. However, objective of walking activity influences the decision making process of pedestrians where recreational objectives and positive perception regarding the destination make people walk through conventionally “less walkable” neighborhoods [72] [73]. Concerning the density of the neighborhood, it is observed in Minneapolis and St. Paul, USA that less concentrated areas promote leisure walking while dense areas promote travel walking [74]. In context of Canada, guideline prepared by City of Ottawa describes design and development strategies to encourage dwellers to use walking and/or cycling and/or public transportation as chosen mode. Few examples of walking related parameter is that minimum width of sidewalk should be no less than 2 meters, maximum slope of ramp should be 1:20, if grade separation is required then elevated connection is preferred over below grade, use of different material or color to make pedestrian routes more visible and so on [75]. Extreme weather condition in North America also has profound effect on walking decision of adults (e.g., 46.51% and 55.16% Americans deter from their daily activity due to snowing or raining respectively) [76].

2.2.4.2. Eco-mobility: cycling

Cycling not only offers an air and noise pollution free environment but it also has environmental benefits for urban scenario [77]. Physical environment (e.g., accessible cycling lanes), health consciousness, consideration for climate change, distance to work/School were few of the important factors for choosing cycle as a mode for urban dwellers across Sweden [78]. However, urban cyclists have a negative attitude when the cycling path is on-street, increased frequency of pedestrians and cyclists, increased volume and speed of motorized traffic, safety issues and dark roads, air pollution, noise pollution, rain and cold temperature, perception of risk appears [77]. A study conducted in US found that sociodemographic factors such as age, income, gender did not have a direct effect on cycling [79]. For example, dwellers of London, Ontario, Canada in “Household travel survey 2016” expressed that adding more bike lanes, separating the

bike lanes and adding multi-use pathway (72%), bike parking (69%), and bike sharing service (54%) are few of the potential place of improvement for cycling sector [70].

Canadian Bikeway Comfort and Safety (Can-BICS) classification system takes five types bikeway facilities found in Canada and classifies them into three categories – High, medium and low comfort. Cycle track, local street bikeway and bike path are considered high comfort while multi-use path and painted bike lanes are considered as medium and low comfort respectively [80]. Canada has 18,700km of bicycle path mapped by Can-BICS where 13% are high, 27% are medium, 26% are low comfort and remaining 33% are non-conforming. Following the Ontario Bikeway Design Manual, the bike riders can be categorized into three categories - Utilitarian (or destination-oriented), touring and recreational. Utilitarian trips are those for which the purpose is to reach a particular destination and are often repetitive (average trip length 1 to 15 km) (e.g., trips to places of employment/school, shopping, the bank, any other trips that are necessary as part of an individual's daily activities); Touring trips takes longer time and travels longer distance than other two categories and generally takes place between urban areas, town, cities, villages etc. (average trip length is very long); Recreational trips are taken to enjoy the scenery, the ride or company of other cyclists (average trip length 1 to 100 km) [81].

2.2.4.3. Eco-mobility: public transportation

Public transportation is an excellent sustainable transportation tool for populated urban area but may prove to be expensive for an area with low population density [78]. Dwellers of London, Ontario, Canada in “Household travel survey 2016” expressed that adding new routes (71%), late night bus schedule (63%), increased frequency (75%), rapid transit implementation (70%), financial incentive (64%) and early morning service (64%) are few of the potential place of improvement for transit sector [70]. The city of Ottawa, Ontario, Canada has proposed following guidelines as part of transit-oriented development,

- Land use guideline (e.g., transit stoppage within 600m of infrastructure, discourage non-transit supportive infrastructure, create multi-purpose destination and mixed land-use)
- Layout related guideline (e.g., short block lengths, create pedestrian and cycle shortcuts, locate buildings close to each other, higher density and mixed-use buildings new transit stoppage, orient buildings towards transit stations)
- Built form related guideline (e.g., human scale sidewalks by stepping the building back, architectural variety at the lower levels of buildings to make it more appealing to pedestrians)
- Pedestrians and cyclists related guidelines (e.g., safe, continuous pedestrian connections, appealing pedestrian routes, inclusion of amenities in grade-separated walkways, ensure adequate width for pedestrian walkways, design infrastructure for cycle)
- Vehicles and parking related guidelines (e.g., provide park and ride service, encourage sharing of parking space, place parking spot at the rear side of building, include pedestrian linkage at parking space etc.)
- Streetscape and environment related guidelines (e.g., provide quality benches, bicycle racks, provide sitting area at every 50m along the sidewalk, plant shading trees etc.) [82].

Elements that have been mentioned in various publications as influencing eco-mobility modes are compiled in the following table (table-1),

Table 1 List of important factors influencing eco-mobility modes (as mentioned in literature)

Eco-mobility mode and influencing factor	
1.	Walking
a.	Land use (e.g., proximity to amenities or destinations) [38]
b.	Pedestrian walkaway infrastructure (e.g., availability and width of pedestrian walkways, maintenance, convenience and accessibility) [83]
c.	Safety & Security (e.g., good street lighting, low traffic speed, crosswalks, pedestrian signals, visible policing, crime rates) [71]
d.	Street Connectivity (e.g., network of streets, access to public transit, accessible walking routes, barriers to walking) [82]
e.	Comfort and appeal (e.g., presence of green, shades and shelters, street furniture, air quality, noise level, aesthetic and attractive city scape) [82]
f.	Traffic calming measures (e.g., speed bumps, pedestrian islands, narrow roads) [84]
g.	Community & Culture (e.g., pedestrian friendly policy, community engagement) [85]
2.	Cycling
a.	Bike infrastructure (e.g., dedicated bike lanes, shared roads, intersection design, bike parking) [86]
b.	Safety (e.g., traffic conditions, crash data, lighting, signage) [87]
c.	Accessibility (e.g., connectivity, barriers to cycling, public transit integration) [88]
d.	Comfort and Maintenance (e.g., road and surface quality, weather protection, gradient and terrain) [89]
e.	Culture and Community Support (e.g., cycling culture, community program, education) [90]
f.	Land Use and Urban Design (e.g., mixed use development, density, proximity) [91]
g.	Environmental and Health Factors (e.g., air quality, noise levels) [92]
h.	Policy and Governance (e.g., bike friendly policies, traffic calming measures, enforcement) [93]
i.	Aesthetics and appeals (e.g., greenways, street vibrancy) [94]
3.	Public Transportation
a.	Ridership Level (e.g., utilization of total capacity deployed by the city authority, public acceptance) [95]
b.	Service Coverage (e.g., geographic area coverage, population served) [96]
c.	Frequency (e.g., time interval between vehicles) [97]
d.	Reliability [98]
e.	Travel time [99]
f.	Safety records [100]
g.	Cost and financial performance [101]
h.	City dwellers satisfaction (e.g., comfort, cleanliness, overall experience) [102]

2.2.5. Research works pertaining to eco-mobility

A combination of transportation methods and services known as eco-mobility reduces their negative effects on the environment while enabling accessible, safe and egalitarian travel in cities. In the concept, modal shifts (walking, cycling and public transportation), vehicle efficiency (electric vehicles, low-carbon fuels), vehicle sharing and micro-mobility (bikeshare, e-

bikes, e-scooters) and enabling policies and technologies (parking management, mobility as a service, smart infrastructure) are all bundled under an integrative sustainability lens. Eco-mobility involves technical and socio-institutional shift. To achieve long-term emissions reductions and health advantages, technology solutions must be combined with land-use, governance and behavioral changes [103].

Inclusion of electric vehicles (EVs) impacts the energy consumption of a neighborhood quite significantly. Inclusion of EV related loads on the electrical grid result in higher local energy consumption and more demands on the distribution network. A recent study on EV charging at households in Sweden showed that the inclusion of EVs increased household electricity consumption [104]. For example, research work conducted in the UK found that the local utility grid's requirement for power increased significantly when all fossil-fuel based vehicles were converted to EVs [105]. Cost, range and ease of recharging have significant impact on EV popularity [106]. EVs lower carbon emissions, but they result in higher electricity consumption at neighborhood level resulting in increased load on the power generation system. The neighborhoods total energy consumption rises as a result of the extra energy used for vehicle charging and supporting auxiliary infrastructure (e.g., transformers and chargers). Additionally, local demand peaks are made worse by the timing and clustering of charging (e.g., evening time peak demand period), necessitating the local grid to deliver more electricity per unit time.

The potential for active transport (e.g., walking and cycling) to yield significant environmental and public health benefits is important evidence in favor of eco-mobility. An increased use of active mode of transportation result in significant physical benefits. When relatively small percentages of motorized trips switch to active modes, quantitative health impact assessments demonstrate significant increases in DALYs (disability-adjusted life years) or decreased death. The advocacy of compact, walkable urban design as a fundamental component of eco-mobility is supported by this research [107].

Due to its ability to facilitate short urban excursions and first/last mile links to public transportation, micro-mobility (e.g., shared bicycles, e-bikes, dock less and docked e-scooters) has gained significant attention in recent eco-mobility discussions. Studies demonstrate that the manufacturing and fleet management of micro-mobility units (vehicle lifespan, collection/redistribution logistics, and charging practices) frequently dominate their life cycle greenhouse gas (GHG) contribution. Micro-mobility is expected to reduce congestion and net greenhouse gas emissions when it replaces private automobiles/vehicles or taxi rides, but it has little to no effect when it replaces walking, bicycling, or public transportation. Thus, fleet operations and modal substitution patterns are critical to micro-mobility's overall sustainability. In order to maximize net benefits, recent LCA-informed studies suggest design and policy changes (e.g., longer device life, effective rebalancing, integration with transportation) [108].

The literature on eco-mobility comes to the conclusion that institutional coordination and policy combinations are more important than individual initiatives. When demand-management tools (e.g., parking pricing, congestion charging), infrastructure investments (e.g., protected bike

lanes, pedestrianization), regulatory measures (e.g., zoning, parking maximums), and incentive programs (e.g., subsidized transit, micro-mobility integration) are combined, they result in more significant and long-lasting changes than when they are done separately, according to reviews of policy packages. Creation of integrated policies that combine eco-mobility initiatives with investments in affordable housing, public transportation and focused assistance for underprivileged populations [109].

By increasing system efficiency, technological enablers such as linked infrastructure and mobility data platforms such as route optimization for shared fleets, intelligent signal timing for active users, and dynamic parking management, are positioned as multipliers for eco-mobility. According to research on “eco-efficient mobility” in smart city scenarios, data-driven operations that minimize empty runs, maximize charging for low-carbon power, and manage multimodal trip chains produce the greatest environmental results [103].

For transit dependent urban dwellers, eco-mobility initiatives might increase access to amenities, but they can also have some disproportionate effects. For example, investment on infrastructures pertaining to active mode of transportation may be focused in areas with political capital, while micro-mobility fleets may be disproportionately situated in higher-income districts. Emphasizes must be given on integrating eco-mobility with inclusive housing and anti-displacement strategies since gentrification and displacement following streetscape and transportation investments are known threats. Evidence also shows accessibility trade-offs. Policy design must offer a variety of low-carbon mobility alternatives since micro-mobility and cycling may be less practical for older persons or individuals with impairments [109].

Measuring modal substitution and causal effects properly is a significant methodological problem. Numerous studies use trip logs or rider questionnaires, which are prone to self-selection bias (cyclists choose to reside in bike-friendly neighborhoods). Assumptions about device longevity, energy grid mix and operational logistics have an impact on life-cycle evaluations of developing modes. Although local mode adjustments can lower urban emissions, studies provide a compelling estimate of the GHG savings from integrated eco-mobility packages at the city or regional level across decadal timeframes. Filling up these gaps is essential to a thorough policy review [110].

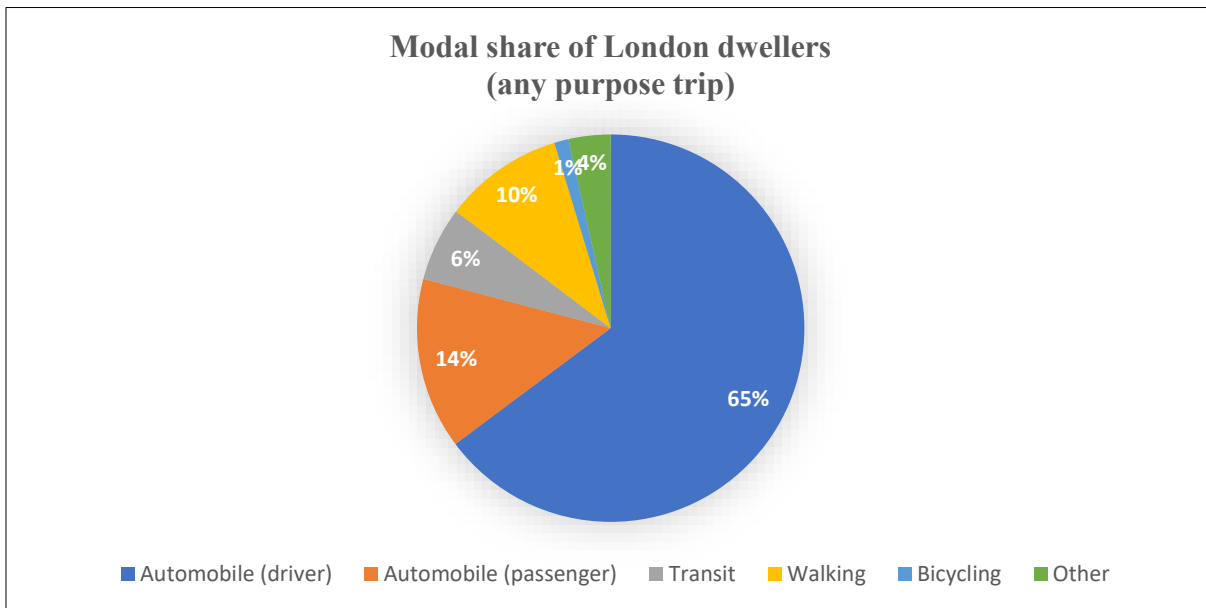
In order to implement eco-mobility strategies and extract the optimum result from these strategies, firstly, as the foundation of eco-mobility, top priority must be given to establishment of safe, interconnected networks for bicyclists and pedestrians as well as first-rate public transportation. Second, include shared services and micro-mobility as feeders to transit rather than as alternatives to non-motorized modes; control fleet operations and deployment to guarantee extended device lifespans and effective logistics. Third, put demand-management strategies into place (such as congestion pricing and parking reform) to deter unwarranted automobile use. Fourth, to guarantee that benefits are widely distributed, incorporate equity measures like as subsidies, fair fleet allocation and affordable housing regulations. Lastly, incorporate monitoring and standardized assessment into the program design so that treatments may be modified in response to social and environmental consequences that can be assessed [111].

Although there is a lot of data, the area of eco-mobility is still developing. Active travel and public transportation focused approaches for better health and lower emissions are well supported by research. The most promising path to system-level decarbonization and equitable access is to combine infrastructure, regulatory, pricing and social policies in integrated policy mixtures [107].

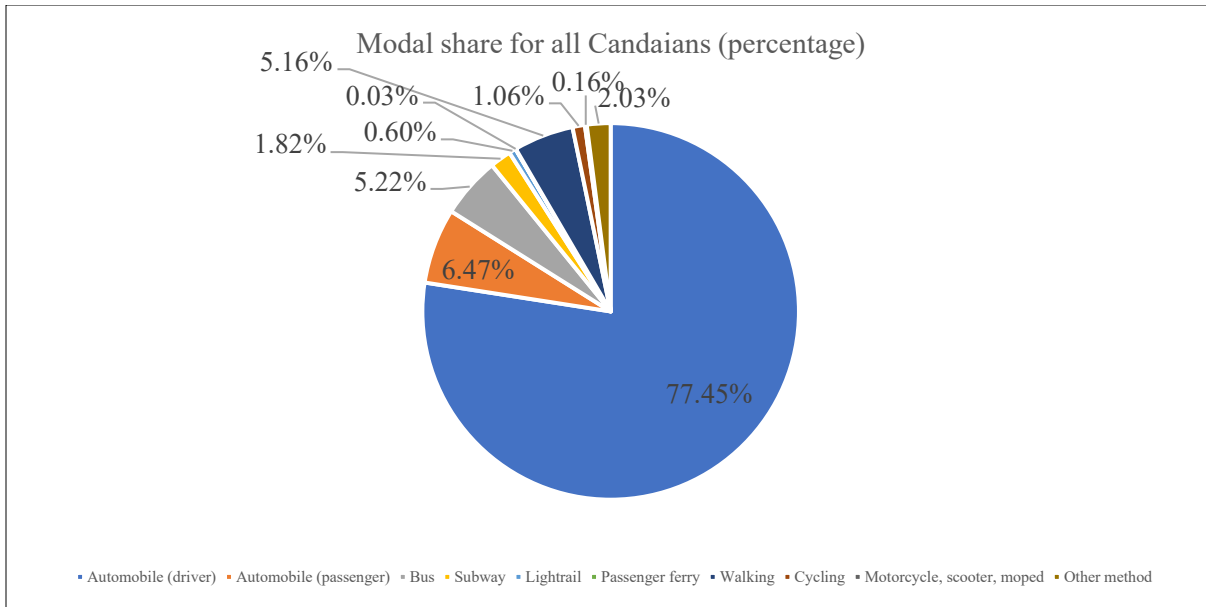
2.3. Modal share in Canada

As per report published by Statistics Canada on 2022, about 13.05 million Canadians commuted every day of which 10.9 million (83.5%) used automobiles and 1.8 million (13.8%) used sustainable transportation (i.e., public transit and active modes). Bus users (5.21%) had an average commute time of 40.9 minutes while walking mode (5.16%) and cycling mode (1.06%) users commuted for 12.5 and 20 minutes respectively [112].

However, this modal share is slightly different for London, Ontario. Household travel survey 2016 conducted at London depicts that 64.8% city dwellers used automobile (as drivers) and 17.4% used sustainable transportation. Percentage of transit, walking and bicycle mode users are 6.2%, 10% and 1.2% respectively [70]. Comparing this data with other cities in Canada, it is observed that 5% of Waterloo dwellers, 7% of Hamilton dwellers and 14% of Ottawa-Gatineau dwellers use public transit as their choice of mode [70]. Following figure (figure-3) delineates pictorial representation of modal share in London (ON) dwellers and overall modal split of Canadians.



(3.a) Modal share for London dwellers (Data Source: 2016 London Household Travel Survey Summary Report)



(3.b) Modal share for commuting Canadians (DOI:<https://doi.org/10.25318/9810045701-eng>)

Figure 3 Modal share of London dwellers for any purpose trip and Canadians commuting

The same survey found that 4%, 17%, 20% and 9% city dwellers holds a poor attitude towards automobile, bus, bicycle and walking related infrastructure [70].

2.4. Research works pertaining to the amenity-mobility integration

A combination of residential, commercial, leisure and supply related land uses within a small physical footprint characterizes multifunctional neighborhoods. A low-carbon and health-promoting substitute for reliance on cars is eco-mobility, which includes walking, bicycling, public transportation, and micro-mobility. The existence and accessibility of amenities are important factors that influence travel behavior, according to research on land-use mix. Density, diversity and geometric designs of neighborhoods significantly decrease automobile trip length and boost non-motorized trips when facilities are positioned within short walking or cycling distances [113]. The functional availability of schools, supermarkets, medical facilities, and recreational facilities within a 10 to 15-minute catchment is crucial to promoting eco-mobility, according to accessibility-based frameworks that have reframed this connection [38]. By suggesting that daily demands be met by active modes, the 15-minute city idea clearly connects the supply of multifunctional amenities to sustainable transportation results.

This integrated approach is further strengthened by health and environmental impact studies. Community facilities that encourage active modes of transportation instead of driving have significant public health advantages by promoting physical activity and lowering exposure to air pollutants [107]. In order to ensure that eco-mobility modes enhance sustainable travel rather than replace it, amenity clustering and integration with transit might influence replacement patterns.

The interdisciplinary synergy known as science of cities or urban data science is principally interdisciplinary synergy between different scientific fields such as urban planning,

geoinformatics, computer science, Physics etc. and has contributed in advances achieved in the research field on multimodal mobility [7]. Public amenities coupled with safe and clean streets are imperative for boosting cities and making it more attractive to the dwellers as well new habitats and investors [114]. Urban scholars and policy makers have agreed on the importance of city beautification and inclusion of amenities in the city for economic growth [115]. For example, Oklahoma City (OK), Camden (NJ), San Antonio (TX) in USA, Glasgow in Scotland, Bilbao in Spain are investing to city beautification to attract economic development. A study conducted in Bogota, Columbia found that high income dwellers are more likely choose active mode over automobile due to inclusion of amenities in the neighborhood while decision to walk for low income dwellers depends on reasons other than presence or absence of amenity [116]. Another study conducted in Vienna, Austria found that establishing bike sharing stations (BSS) near the public transportation infrastructure improves access to the amenities, complementing the multi-functionality of the neighborhood [117]. A study conducted on 31 neighborhoods in Toronto, Canada found that inclusion of amenities (e.g., 3 additional grocery store, schools, restaurants) increases the walk score by more than 50 points in a scale of 100 [118]. Active mode of transportation (e.g., walking and cycling) contributes in reducing carbon emission and also reduce traffic congestion while improving air and noise quality. For example, a case study at Klang valley, Malaysia found that walking and cycling reduces GHG emission by 14.52% for short car trips under 4 km and 3.66% for walking trips under 2km [119]. Another case study at Boston show that between 2015 and 2024, 2616.44 tons of oil equivalent, 7614.98 tons of CO₂ and 16.43 tons of NO_x emission is reduced through the introduction of bike sharing [120]. Replacing the traditional fossil fuel based fleet of bus with electric buses in Madrid, Spain will result in CO₂ emission reduction up to 92.6% [121]. Introduction of 15-minute city features in Barcelona, Spain found that 32% users were loyal automobile users who did not take advantage of walkable and transit friendly areas [122]. Following figure (figure-4) shows the conceptual representation of eco-mobility strategies and multi-functional neighborhood.

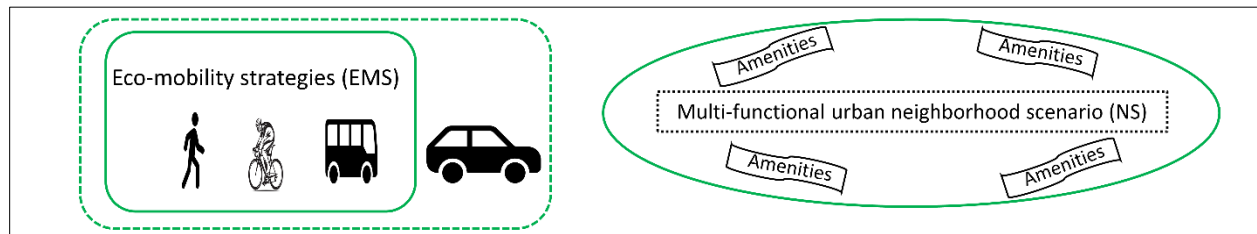


Figure 4 Conceptual representation of eco-mobility strategies and multi-functional neighborhood

All these studies considered either amenity availability or mode of transportation as variables and point of interest and examined the effect of change on environment. It is obvious that these two strategies are individually effective enough to reduce carbon emission and bring positive changes to the environment while achieving the sustainability goal for the neighborhood. However, the novelty of this research work is that it combines the amenity availability in neighborhood i.e., multi-functionality with eco-mobility. Examining the combined effect of these two strategies and aiding the decision-making process for selection of strategy or combination of strategies is going to be the contribution of this study.

This research aspires to integrate multi-functional neighborhood with eco-mobility and proposes an integrated framework. A method of computing the combined effectiveness of

introducing eco-mobility strategies in a neighborhood comprising various degree of amenities will be described in this research work. Utilizing only the traffic, geometric and demographic data of the neighborhood, this research work undertakes to develop a framework followed by a decision-making metric that will help the policy makers to take informed decisions based on simple comprehensible analysis. In order to safeguard the sustainable features of the urban neighborhood development strategies i.e., eco-mobility and amenity distribution, this research work will examine the environmental, social and economic pillars of sustainable development.

With the view of quantifying and measuring the sustainable development pillars, annual CO₂ emission and annual energy consumption as environmental indicator, annual travel time as social indicator and annual net cost as economic indicator are computed in various research works [123] [124] [125] [126].

Multi-functional neighborhoods with plenty of amenities are frequently linked to more expensive housing, which raises issues of gentrification and unequal access. In order for eco-mobility frameworks to be successful, policies must guarantee that cheap housing and amenities are distributed fairly close to walkable, transit-rich districts [127].

According to the literature, eco-mobility and amenity availability are mutually reinforcing. This means that while sustainable mobility systems increase access to these amenities without requiring fossil fuel-based private vehicles, multifunctional neighborhoods with a variety of nearby amenities lower the bar for being prone to selecting public transportation and active transportation. Following sub-section depicts the framework that have already been proposed in different research works that involves amenity-mobility duo.

2.4.1. Transportation-land use interaction

Miller and Soberman in their paper titled “Travel demand and urban form” published in office of scientific and technical information (OSTI) at US department of energy (DOE) at 2003 described the transportation and land use duo as a two-way-chicken-and-egg-relationship. The link between land use in urban setting and transportation is delineated in figure 4. This research work was conducted in context of Ontario. Urban planners or city engineers and policy-makers have the challenge of first comprehending this interplay and then using that knowledge to steer the metropolitan’s development in ways that the community’s demands are fulfilled as much as possible. A land use pattern where a variety of activities (housing, shops, schools etc.) coexist, in other words multi-functionality, within manageable walking or cycling distances, as well as neighborhood infrastructure (e.g., road pattern and building design) that supports and promotes active modes, can be viable alternatives to motorized travel.

This model describes private automobiles as principal mode of transportation for North American city dwellers. However, it is also described by Miller and Soberman that competitive, high-quality transit can only be offered at a reasonable cost in areas where land use patterns support it and the construction of such transit supportive built forms is only possible if the right kind of transit service is available. Observing the adverse effects of private automobiles on environmental, social and economic sustainability of the urban neighborhoods, an “automobile taming” approach is proposed instead of taking an anti-automobile one. This framework also

proposes non-motorized forms of transportation for making shorter trips as an alternative to the automobiles. Following figure (figure-5) delineates the transportation-land use interaction flowchart.

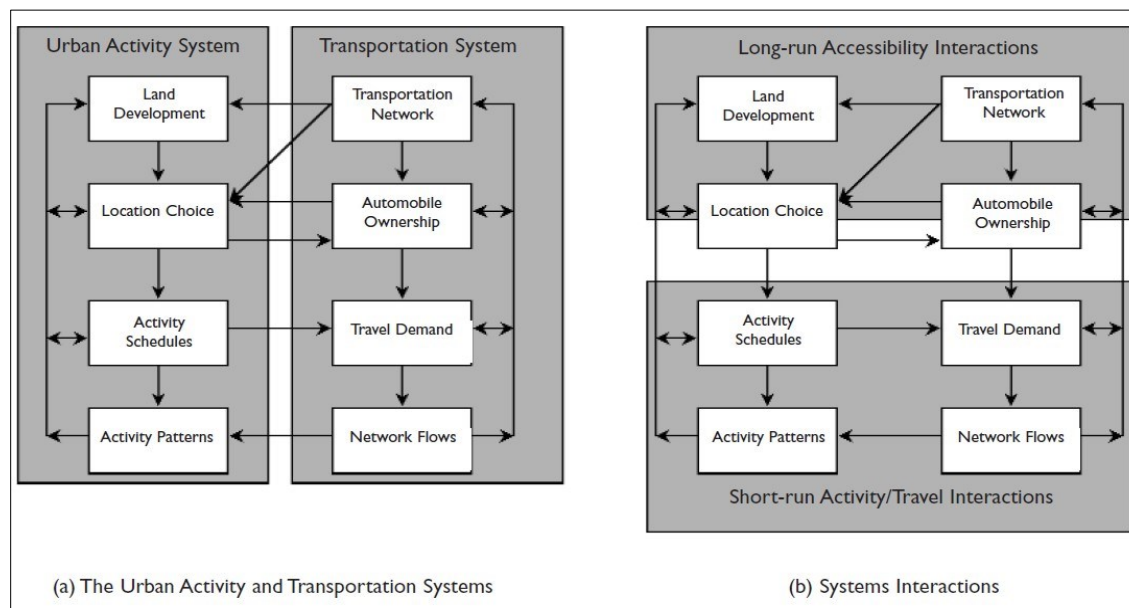


Figure 5 The transportation-land use interaction proposed by Miller and Soberman (2003)

As determinant for selecting public transportation, parameters such as travel time, convenience, cost of door-to-door journey, transit route layout, service quality, cost on board, level on integration with other modes have been listed as impact factors [128]. Also, parameters such as auto ownership, number of trips, modal ratio are used as input for this model.

It was observed in this research work that average emission per household and car ownership growth is higher in sub-urban areas while transit use is higher in denser part of the urban areas. Finally, this research work concluded that location and density of employment is more important than performance of the transportation system. It can be inferred from this model that multi-functionality carries more weight in the mind of Ontario dwellers than availability or convenience of transportation mode.

2.4.2. Physical activity through sustainable transportation approach (PASTA)

A paper titled “Towards a Comprehensive Conceptual Framework of Active Travel Behavior: a Review and Synthesis of Published Frameworks” by Thomas Götschi, Audrey de Nazelle, Christian Brand and Regine Gerike published at Current Environmental Health Reports (2017) describes a framework titled PASTA.

Physical activity through sustainable transportation approaches project (PASTA) is a European multi-national interdisciplinary research work. The general PASTA framework investigates travel behavior pertaining to active modes (e.g., walking and cycling). The socio-spatial structures capture the temporal scale to a large degree. For example, the trips (highest resolution layers) represent more short-term phenomena, while the city or the society (larger

layers) reflect longer-term processes (i.e., changes in factors or periods over which factors affect each other) [129]. Following figure (figure-6) represent a flowchart for PASTA from this paper.

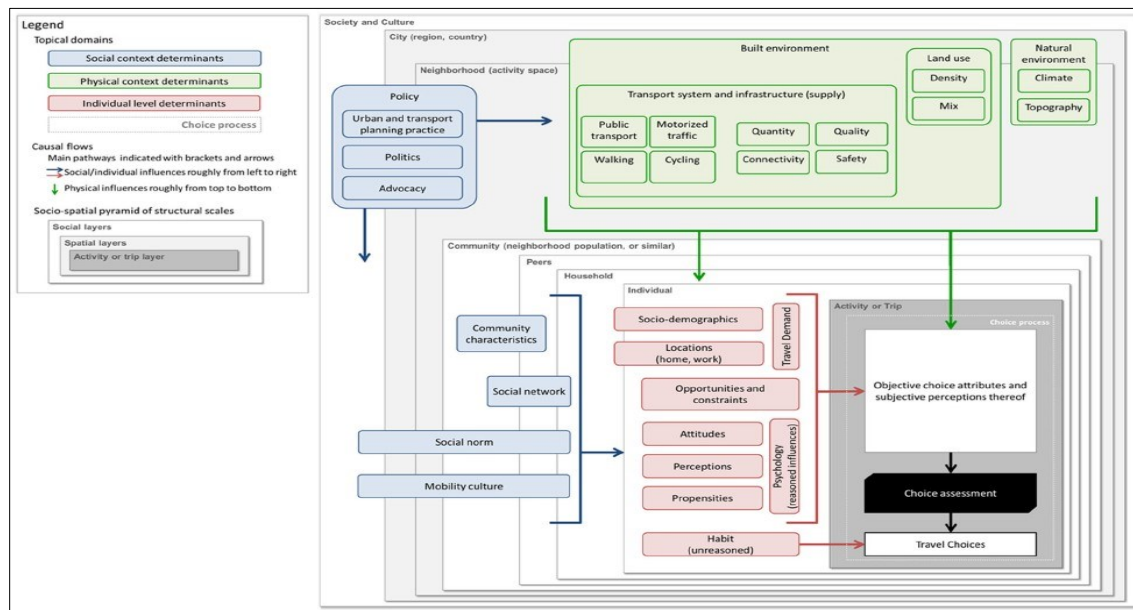


Figure 6 PASTA conceptual framework on active travel behavior (Götschi et al., 2017)

PASTA framework predicts the travel behavior of city dwellers pertaining to active mode where the inputs include inputs such as land use (e.g., mix and density), transport system and infrastructure (e.g., public transport, walking, cycling and motorized traffic) and natural environment (e.g., climate and topography). Alongside this input data the PASTA framework also takes input from community demographic data and finally comes up with travel choice as the final output.

From different types and categories of sustainable mode of transportation or eco-mobility, PASTA framework investigates only two modes of travel. This model is more content into studying travel behavior of dwellers but it does not investigate the result or effectivity of choosing active mode of transportation. It takes input from neighborhood scale data and available modes of transportation as well.

2.4.3. 15-minute city and its dimensions

In a paper titled “Introducing the 15-Minute City: Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities” by Carlos Moreno, Zaheer Allam, Didier Chabaud, Catherine Gall and Florent Pratlong published at Smart Cities (2021) described framework for 15-minute city depicting four dimensions – density, proximity, diversity and digitalization. Following figure (figure-7) describes the dimensions of 15-minute city framework as described by Moreno et al., Smart City (2021).

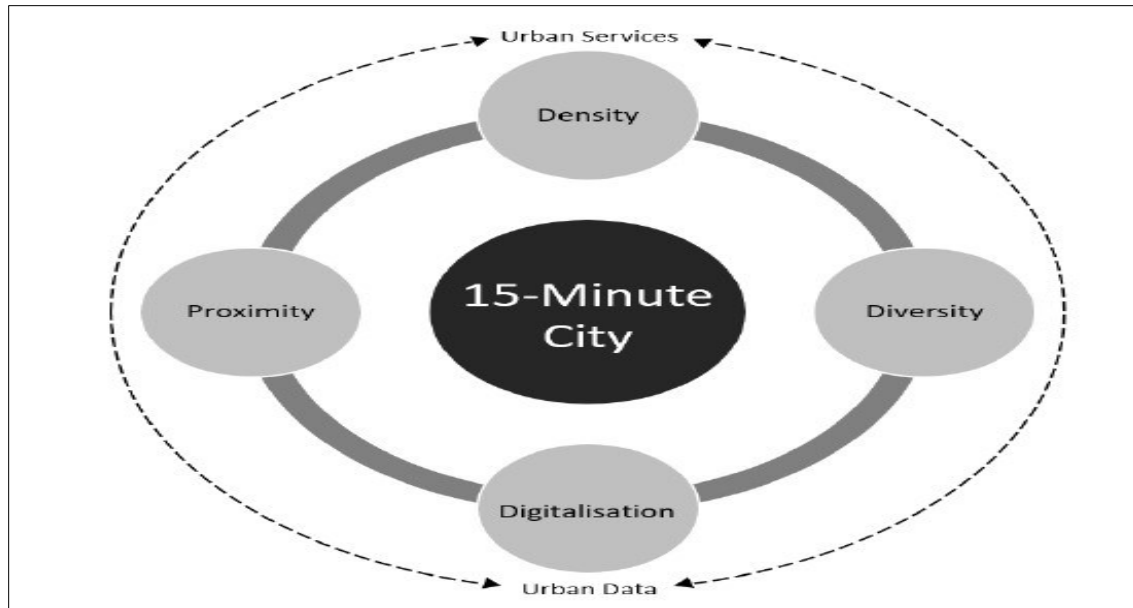


Figure 7 Framework for 15-minute city proposed by Moreno et al., *Smart Cities* (2021)

Density is depicted as number of people per square kilometer and an optimal density promotes local solutions such as energy generation, food supply and multiple use of available space. Density in context of sustainable city is an important dimension and it takes into account how many people a particular region can support comfortably in terms of resource consumption and urban service delivery.

Proximity describes the 15-minute city from both temporal and spatial perspective and contributes in reducing travel time for commuting while reducing environmental and economic impacts as well. Concept of 15-minute city permits multimodal usage of basic infrastructures that results in to inhabitants ultimately benefitting from improved service supply in both public and commercial businesses due to the proximity of necessary services.

Diversity in context of 15-minute city is described from two perspectives – amenities in mixed use neighborhood and diversity in culture and people. In order to maintain economically dynamic urban fabrics, provide enough housing for all urban inhabitants, encourage inclusion, and support environmental practices, mixed-use communities are essential. Adopting mixed-use communities is crucial to achieving a 15-Minute City model because it allows for the construction of bike lanes and walking streets while also guaranteeing that the ideal density and closeness of necessary facilities are met.

The concept of digitalization is very important for a 15-minute city due to its ability to integrate the other three dimension altogether. The successful implementation of various technologies is necessary to implement the concept of Smart City idea. This is comparable with 15-Minute City. For example, by focusing on solutions like bike sharing and the installation of sensors to guarantee cyclists safety and security, digital tools and solutions guarantee that bicycling experiences are improved [130].

The dimensions described by Moreno et al., *Smart City* (2021) chiefly focuses on amenity availability in a neighborhood. However, the same literature accepts the fact that success

of the model for bringing sustainability to the neighborhood depends on reduction of trip lengths and introduction of non-carbon emitting modes of transportation.

2.5. Research question

In order to enjoy the sustainable benefits of implementing amenity-mobility duo in community level, multi-modal transportation system must be coupled with multi-functional neighborhood. However, literature review presented above depict that independent study on these two topics are rich yet integrated studies involving these two strategies are scarce. There are studies that include one mode of eco-mobility (e.g., walking or cycling or public transportation) but in reality, this is hardly the scenario. Usually, a combination of strategies is found in North American scenario, whether the strategies are fully implemented or not, that warrants different research and investigation. This poses a research question regarding combined effect of all eco-mobility modes i.e., walking, cycling and public transportation and method for measuring their effect on sustainability of the neighborhood. Also communicating these technological terminologies and numbers to the policy-makers and community members in a comprehensible poses another challenge. From the research gaps observed in previous sub-section, following research questions warrant answers,

- (i) What types of strategies should be implemented to reduce CO₂ emission and introduce sustainable transportation system for an urban neighborhood?
- (ii) What types of strategies should be implemented to spatially redistribute the amenities in a multi-functional neighborhood?
- (iii) If amenities are re-distributed in neighborhood, then will it be efficient from environmental (e.g., CO₂ reduction and energy consumption reduction), social (e.g., travel time reduction) and economic perspective (e.g., fuel cost reduction)?
- (iv) Will area and geometric shape of the neighborhood effect environmental, social and economic factors?
- (v) How will the policy makers select the suitable strategy that suits their environmental, social and economic goal?

2.6. Objectives

Building on the 15-minute city concept, this research advances the idea of self-sufficient, energy-efficient neighborhoods by integrating spatial planning with eco-mobility and resource distribution. As part of a larger research project examining the impact of localizing all essential amenities within walkable neighborhood boundaries in North American car-dependent contexts, this study focuses on all six amenities individually and in combination. This discourse assesses not only the spatial accessibility of amenities within a 15-minute walking radius but also explores the role of no-or-low-emission mobility, including walking, cycling and public transit, in reducing travel-related energy use and GHG emissions. By addressing both spatial proximity and energy implication, the work extends the conventional 15-minute city framework toward a model of neighborhood-level self-sufficiency supported by functional complementarity across adjacent urban zones. The objective of this thesis is to develop a comprehensive framework that integrates eco-mobility and multi-functional neighborhoods, using the principles of the 15-minute city as a guiding concept. This framework is applied to the Canadian context to assess its potential for

reducing greenhouse gas emissions while improving the sustainability and livability of communities.

(i) Develop an Eco-Mobility Strategic Framework (EMSF) delineating elements in neighborhood transportation system design which have impact on walking, cycling and public transport.

(ii) Analyze the EMSF with respect to Sustainable Transportation Indicator (STIs) in context of multi-functional Neighborhood Clusters (NCs) where different degrees of amenities are available (DOAA).

(iii) Develop guideline(s) containing Decision Making Metric (DMM) and recommendations re-inventing an existing Neighborhood Cluster (NC) into a multi-functional Neighborhood Cluster (NC).

A pictorial description of the objectives mentioned above is given below (figure 8).

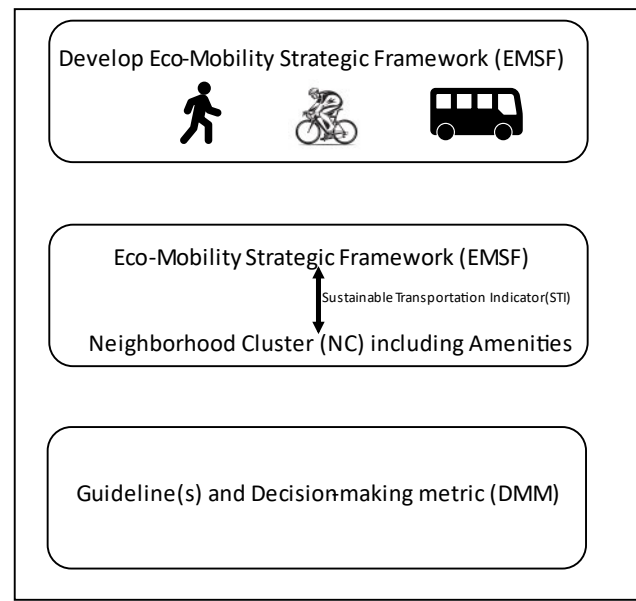


Figure 8 Objectives of the research work integrating amenity and mobility

The remaining sections of this study is organized as follows: chapter 3 describes methodology which contains four sub-sections describing the process of achieving the aforementioned goals; chapter 4 presents the results obtained from application of the Eco-Mobility Strategic Framework (EMSF) on different multi-functional neighborhood cluster scenario; finally a comprehensive guideline for EMSF is described at the discussion section in chapter 5 and takeaways as well as limitations of this study is summarized at the conclusion in chapter 6.

3. Methodology

This research is based on an advanced high performance community – West-5, located 11 Km from London city center in Ontario province of Canada and It is located in a 6b climate zone where average winter temperatures lie between -20 and -18 °C [131]. It is the largest smart community in North America developed by Sifton in partnership with s2e technologies and London Hydro. The goal of the project is to achieve net zero energy status while making it an EV friendly neighborhood [132]. Plans of West-5 conforms to “The London Plan” framework which endorses sustainable development [133]. For this research work, West-5 is considered as a sample Neighborhood Unit (NU) with an approximate land area of 70-acre ($=0.28$ km²) and capacity of 2000 dwellers. It is employed as the basis to extract various assumptions and metrics.

In line with the objectives of this research (stated above, see section 2.6), the methodology has four sections. First section describes the base case scenario i.e., West-5 where amenities are not available and Eco-Mobility Strategies (EMS) are not implemented. The second section covers the procedure for development of Eco-Mobility Strategic Framework (EMSF), third section depicts the procedure for analyzing the application of EMSF in several multi-functional Neighborhood Scenarios (NS) with respect to Sustainable Transportation Indicators (STIs), fourth and the final section articulates the procedure of developing a quantifiable measure for EMSF (i.e., Decision-Making Metric (DMM)) assessing the impact of EMSF within different neighborhood scenario using Sustainable Transportation Indicator (STI) that represent the environmental, social and economic pillars of sustainable development of multi-functional urban neighborhood and eco-mobility i.e., environment friendly transportation system within. A quick summary of the methodology is presented in figure 9.

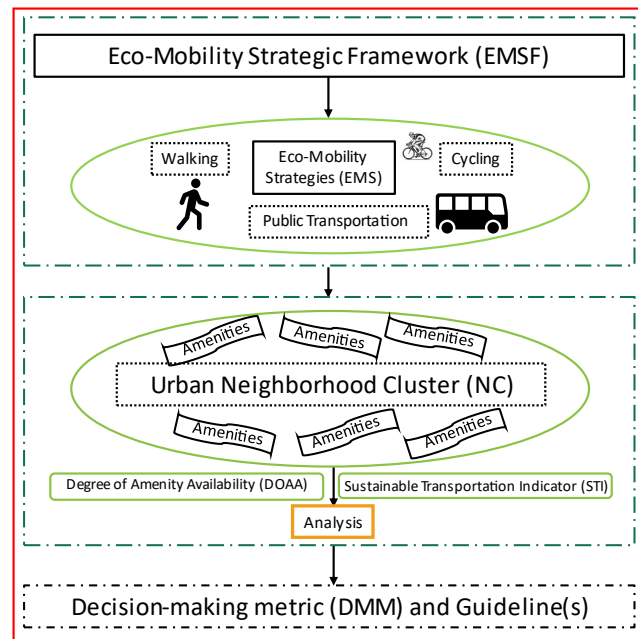


Figure 9 Methodology describing the link between EMSF, NC, STI and DMM

The methodology introduces Eco-Mobility Strategic Framework (EMSF) and apply this framework to different neighborhood scenarios (NS), characterized by different Degree of Amenity Availability (DOAA). DOAA spatially re-distributes the amenities in the neighborhood alongside the introduction of EMSF resulting in improved sustainability indicators such as CO₂ emission, energy consumption, travel time and cost of fuel. Sustainable Transportation Indicators (STIs) are employed to quantify and measure the effectivity of EMSF with respect to the base case scenario using Decision Making Metric (DMM) and Framework Performance Coefficient (FPC). The goal is to find a scalable Eco-Mobility framework that can be replicated in other urban neighborhoods globally.

3.1. West-5 as base case scenario

West-5 is considered as the base case for this research work. West-5 is an automobile based North American urban neighborhood where eco-mobility related strategies are yet to be implemented, and amenities are not available within walkable distance. This study explores amenity availability around West-5 and determine the trip lengths coupled with modal share from residence to those amenities. In the end, indicators pertaining to sustainability of current automobile-based transportation scenario of West-5 are measured to record the base case condition of a North American neighborhood. Figure 10 illustrates the map of West-5 as shown in the website of the developers.



Figure 10 West-5 (base case) plan view (showing both existing and future buildings)

In order to analyze and comprehend the base case scenario at West-5, traffic related data are required to determine the Sustainable Transportation Indicators (STI) which are described in following section.

3.1.1. Traffic data for base case scenario at West-5

Traffic related data used in this research work is collected from Household travel survey 2016 conducted at London, Ontario [70]. West-5 is located at Riverbend neighborhood located in the London Census Metropolitan Area (CMA). Following table (table-2) depicts base case i.e., West-5 traffic data used in this research work,

Table 2 Traffic data of base case scenario at West-5

Description	Data	
Trip Length (km)	Purpose of trip (Amenity type)	Trip Length (km)
	Home to work (AW)	9.1
	Home to school (AL)	4.2
	Home to supply (AS)	10
	Home to care (AC)	4.9
	Home to leisure (AE)	6.5
Modal Share (%)	Mode	Share (%)
	Automobile (driver)	64.80
	Automobile (passenger)	14.30
	Transit	6.20
	Walking	10.00
	Cycling	1.20
	Other	3.50
Number of daily trips	3.4 trips/person	
Number of daily trips by purpose	Purpose of trip (Amenity type)	Number of trips (Percentage)
	Home to work (AW)	0.85 (25%)
	Home to supply (AS)	0.73 (21.49%)
	Home to care (AC)	0.73 (21.49%)
	Home to school (AL)	0.36 (10.53%)
	Home to leisure (AE)	0.73 (21.49%)

Details about the Sustainable Transportation Indicators (STI) are described in section 2.3.3. These STI values calculated for base case scenario are considered as the core base case information for comparison with other frameworks.

3.2. Methodology for development of Eco-Mobility Strategic Framework (EMSF)

Three strategies of eco-mobility – Walking (W), Cycling I and Public Transportation (PT) are studied in this research work. From hereafter, the combination of these three eco-mobility strategies have been called as Eco-mobility Strategies (EMS). Following figure (figure-11) shows a representative figure of EMS.

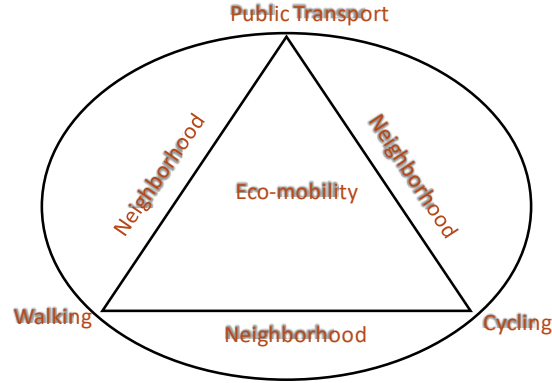


Figure 11 Tripod of Eco-mobility strategies introducing eco-mobility in a neighborhood

This study considers 5 design standards chosen from different literatures for each of the Eco-Mobility Strategies (EMS) (e.g., City of Ottawa guideline [75] [134], research papers [43] [135] [136], Ontario and other different North American standards for improving accessible built environment standards [137] [138], Bikeways Design Manual by Ministry of Transportation, Ontario, Canada and other countries manuals [80] [81] [139]) and the standards are described in table 3. Effect of implementing Eco-Mobility Strategies (EMS) on Sustainability Transportation Indicators (STIs) are measured in terms of traffic data/response i.e., change in modal share, speed, trip length.

Table 3 Design standards for Eco-Mobility Strategies (EMS)

Eco-Mobility Strategy	Parameter	Quantifiable design standard for EMS
1. Walking(W)	(i) Sidewalk dimension	(i) Minimum sidewalk width = 2m; Maximum ramp slope = 1:20 [134] and Design Speed = 1.2 m/s [43]
	(ii) Sidewalk availability	(ii) Sidewalk available at both sides of the road. [134]
	(iii) Pedestrian protection from weather effects	(iii) Minimum 1.83m wide glass or steel canopy covering at least 80% of the building frontage length in retail and commercial façade [137] and tree spacing 9 to 14m (large size) or 6 to 10m (medium size) or 6 to 8m (deciduous tree) [134] [135])
	(iv) Promote accessibility, connectivity and continuity	(iv) Distance from one intersection to other = 50 to 100m or 100 to 150m (if signalized intersection) [134])
	(v) Rest area (e.g., bench)	(v) Bench spacing = 30m to 50m [138] [75])
2. Cycling (C)	(i) Bikeway dimension	(i) Bike path width (1-way = 2m or 2-way = 4m); Grade = 3-5%; Design Speed = 35kmph [81].
	(ii) Bikeway quality	(ii) High Comfort – cycle track or local street bikeway or bike path [80].
	(iii) Bike Parking	(iii) Convenient and attractive bicycle parking near to building entrance with weather protection features [75].

Eco-Mobility Strategy	Parameter	Quantifiable design standard for EMS
3. Public Transit (PT)	(iv) Bicycle amenities	(iv) Provision for cycle amenities such as shower facilities, changing room, lockers for employees in commercial places [75].
	(v) Lighting for bikers	(v) Lighting (Minimum 10 lux to Maximum 20 lux) [81].
	(i) Encourage transit supportive land use	(i) Establishing transit stop/station near transit supportive amenities (e.g., townhouses; apartments; child care facilities; hotels; medical clinics; restaurants; affordable housing; libraries; recreational and cultural facilities; fitness clubs; movie theatres; call centers; offices; high schools and post-secondary institutions) and create multi-purpose destinations [75].
	(ii) Distance of transit stop/station from amenity	(ii) Distance of transit stop/station from amenity $\leq 500\text{m}$ [139].
	(iii) Automobile parking	(iii) Parking lots are to be located at the rear side of the building leaving the front side free and adjacent to pedestrian walkways and near to transit stations [75].
	(iv) Park and ride facilities	(iv) Provide opportunities for park and ride facilities at the transit stations [75].
	(v) Lower waiting time for bus*.	(v) Lower headway for buses (i.e., waiting time is half of headway) [136]; Design speed = 45 km/hr.

The eco-mobility strategies are perused in this study with respect to Sustainable Transportation Indicators (STIs) by looking into the degree of implementation of these strategies into different neighborhood scenarios and availability of different amenities. EMS application is measured using the criteria mentioned in table 4.

Application of each of these Eco-Mobility Strategy (EMS) in the neighborhood result in reduction of trip length and consequently CO₂ emission, energy consumption, travel time and fuel cost. Meanwhile it is assumed that average speed, unit cost of fuel and fuel consumption rate are not affected by application of EMS. Trip lengths are measured for different Neighborhood Scenario (NS) from the design scenarios while modal share related information is collected from surveys done in London. The base case scenario is named as Eco-Mobility Strategic Framework - 0 (EMS_{F0}). Full application of walking only, walking & cycling and finally walking, cycling and public transportation related strategies are named as EMS_{F1}, EMS_{F2} and EMS_{F3}. Modal share for EMS_{F0-3} is different and influences the sustainability indicators.

Table 4 Cases describing Degree of Eco-Mobility Strategic Framework (EMSF) application

EMSF case scenarios	EMS chosen	Description
EMSF ₀	None	- Base case scenario with automobile-based transportation system. - No EMS is fully developed and related guidelines are not implemented in the neighborhood.
EMSF ₁	Walking (W) strategy only	One EMS is fully developed and related guidelines have been implemented in the neighborhood.
EMSF ₂	Walking (W) and Cycling (C) strategy	Two EMSs are fully developed and related guidelines have been implemented in the neighborhood.
EMSF ₃	Walking (W), Cycling (C) and Public Transportation (PT) strategy	All three EMSs are fully developed and related guidelines have been implemented in the neighborhood.

Partial implementation of Eco-Mobility Strategies (EMS) such as implementing 50% of walkability, cycling and public transportation related strategies may also take place depending on the decision-making process, budget of the concerned metropolitan authorities and community preferences. Current research does not look into such partial implementation scenarios and only looks into cases where strategies are fully implemented or not i.e., all or nothing approach, as a proof of concept.

3.3. Methodology for application and analyzing the Eco-Mobility Strategic Frameworks (EMSF)

This section explains the Eco-Mobility Strategic Framework (EMSF) analysis process. Several multi-functional Neighborhood Scenarios (NS) are developed containing one or multiple neighborhood unit(s) in a cluster followed by development of different Degrees of Amenities Availability (DOAA) in these neighborhoods. Sustainable Transportation Indicators (STIs) are developed to quantify and measure the effect of EMSF on specific performance criteria. Performance criteria such as CO₂ emission, energy consumption, travel time and fuel cost are quantified by using the STIs and their effectivity with respect to the base case scenario are measured using Decision-Making Metric (DMM) containing the Framework Performance Coefficient (FPC).

3.3.1. Development of multi-functional Neighborhood Scenarios (NS)

The effect of a neighborhood geometric shape and its dimensions on trip lengths are investigated in this work. Multiple neighborhood scenarios of different shape (e.g., rectangular or radial road pattern) and dimension (e.g., Area equal to or half of or ten times more than base case at West-5) are developed. Three rectangular neighborhood layouts with different area and three radial neighborhood layouts with same area are designed and analyzed. The Neighborhood Scenarios (NS) are as presented in table 5.

Table 5 Neighborhood Scenarios

Neighborhood Scenario (NS)	Geometric shape	Neighborhood Unit (NU) & Neighborhood Cluster (NC)	Area of each Neighborhood Unit (km ²)	Combined area of each Neighborhood Cluster (km ²)	Comparison with Base case neighborhood (Percentage)
(i)	(ii)	(iii)	(iv)	(v)	(vi)
NS-1 (Fig. 6)	Rectangular	1 NU	0.1289	Not Applicable	45.5%
NS-2 (Fig. 7)		1 NU	0.2833	Not Applicable	100% (equal)
NS-3 (Fig. 8)		1 NC (=10 NUs)	Not Applicable	2.833	1000% (ten times larger)
NS-4 (Fig. 9)	Radial	1 NU	0.1288	Not Applicable	45.5%
NS-5 (Fig. 10)		1 NU	0.2833	Not Applicable	100% (equal)
NS-6 (Fig. 11)		1 NC (=10 NUs)	Not Applicable	2.833	1000% (ten times larger)

NS-1, 2 & 3 have rectangular (Figure 12, 13 & 14) and NS-4, 5 & 6 are radial (Figure 15, 16 & 17) road pattern. NS-2 (Figure 13) and NS-5 (Figure 16) have the same area as West-5 i.e., 0.2833 km². However, NS-1 (Figure 12) and NS-4 (Figure 15) are developed to peruse the effect of EMS when the neighborhood is significantly smaller. NS-3 (Figure 14) and NS-6 (Figure 17) are neighborhood cluster which have been developed based on NS-2 (Figure 13) and NS-5 (Figure 16) respectively. One Neighborhood Cluster (NC) has ten Neighborhood Units (NUs). Different neighborhood scenarios are presented at figure 12 to 17,

- Legend:
-  Amenity: Living (Residential) (AR) at Building 2, 3, 6-22, 24-30, 33-36
 -  Amenity: Working (AW) at Building 4
 -  Amenity: Supplying (AS) at Building 31-32
 -  Amenity: Caring (AC) at Building 1
 -  Amenity: Learning (AL) at Building 23
 -  Amenity: Leisure/Enjoying (AE) at Building 5
 -  Green Area (GA)

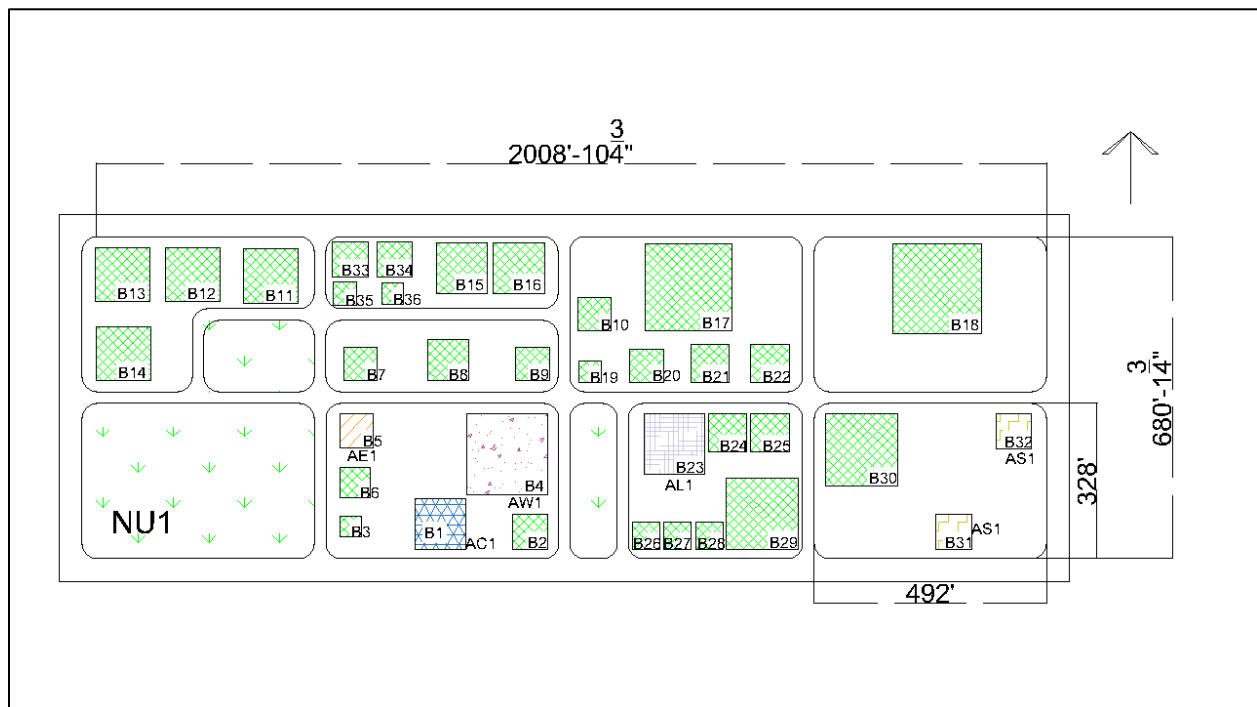


Figure 12 NS-1 (1 NU, Rectangle shape, Area = 31.85 acres/ 0.1289 km²)

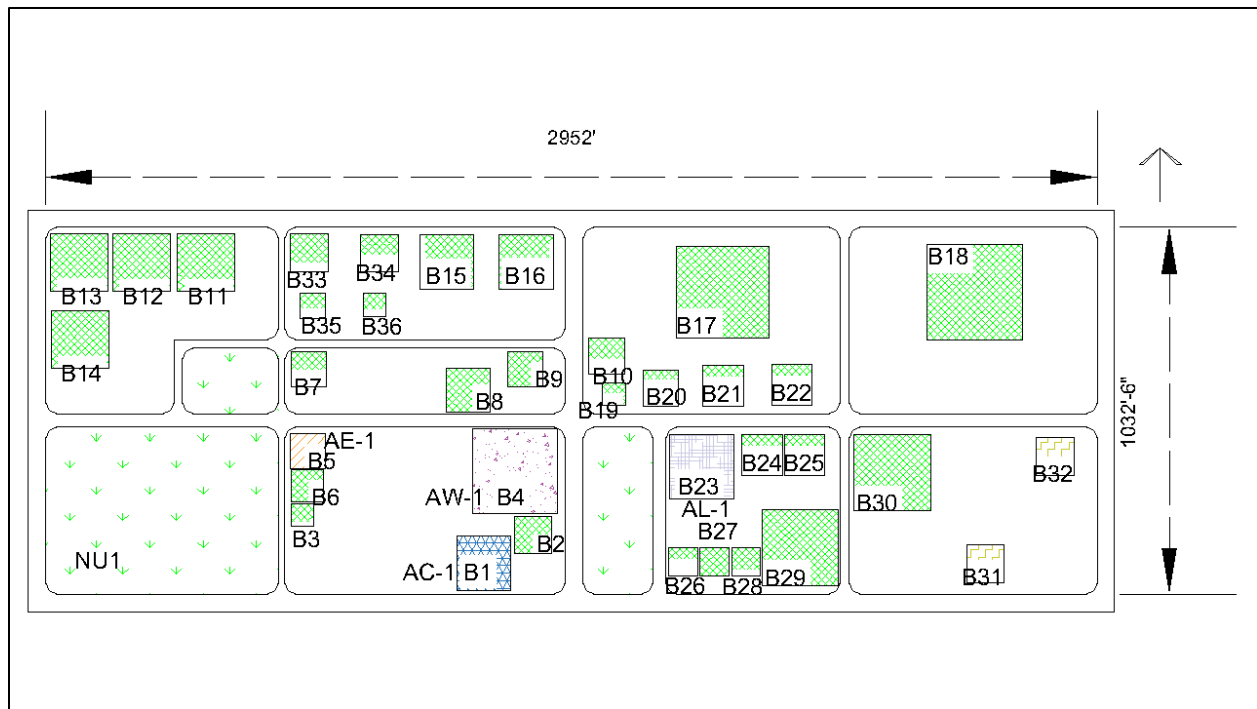


Figure 13 NS-2 (1 NU, Rectangle shape, Area = 70 acres/0.2833 km²)

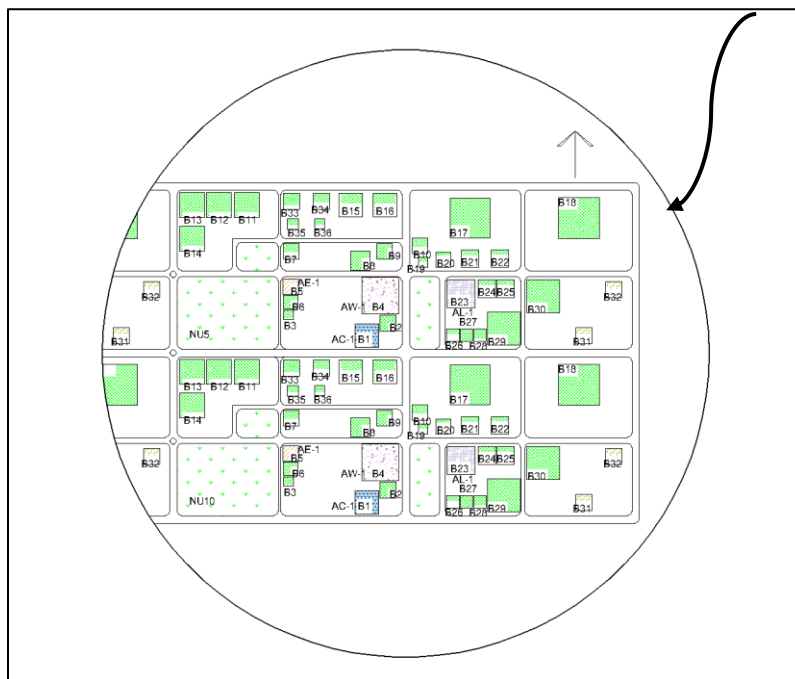
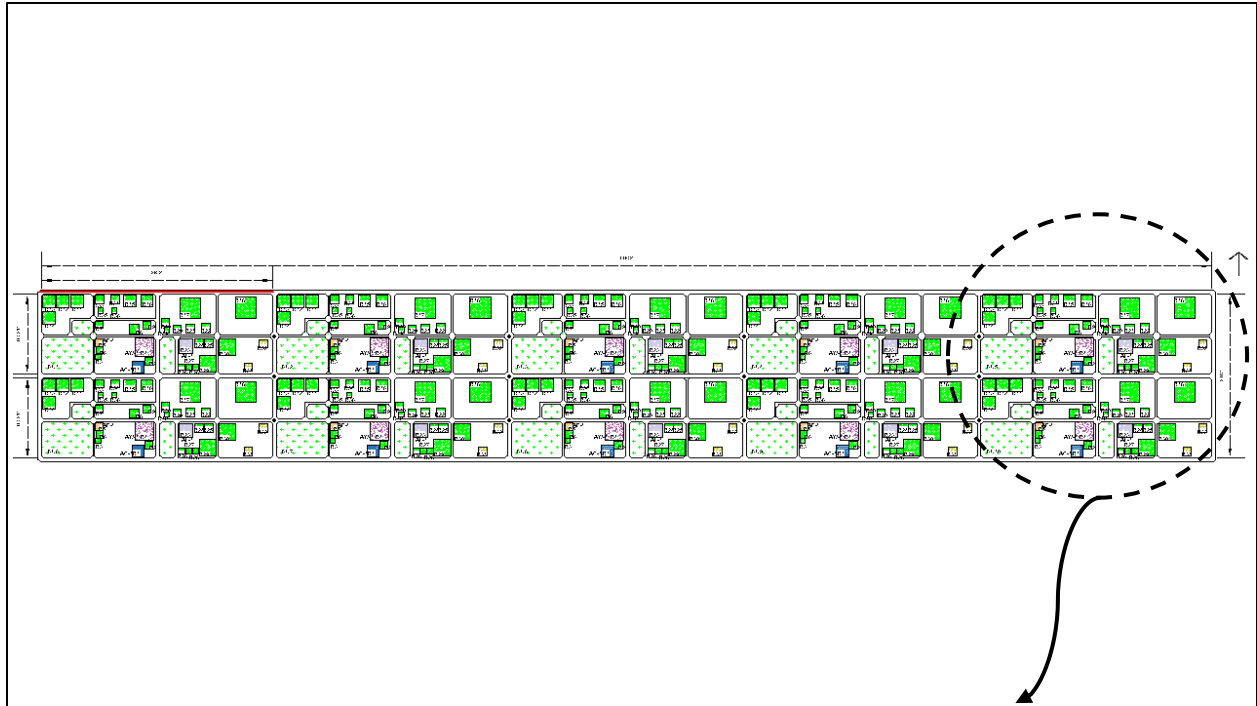


Figure 14 NS-3 (10 NUs = 1 NC, Rectangle shape, Area = 700 acres/2.833 km²)

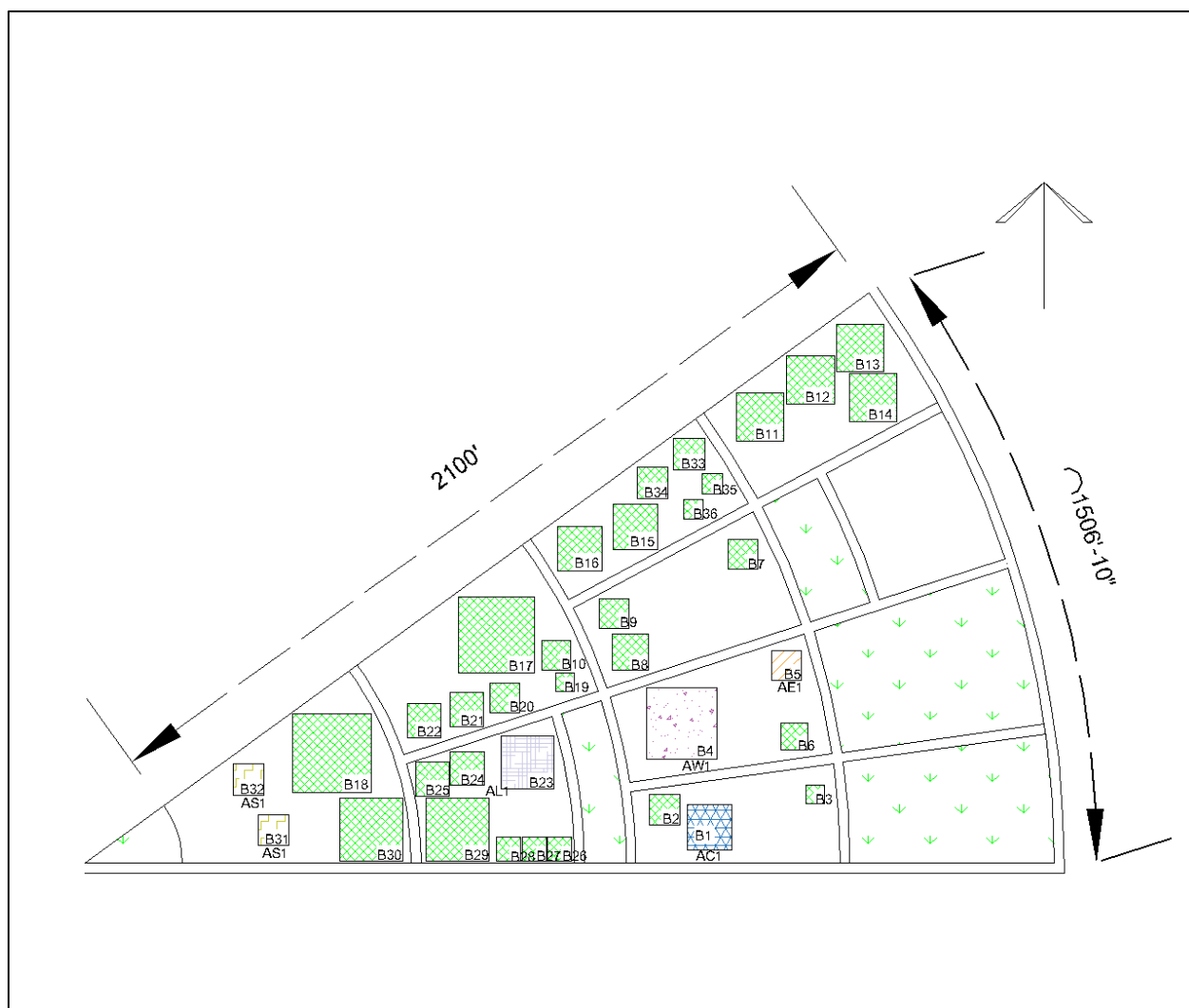


Figure 15 NS-4 (1 NU, Radial shape, Area = 31.83 acres/0.1288km²)

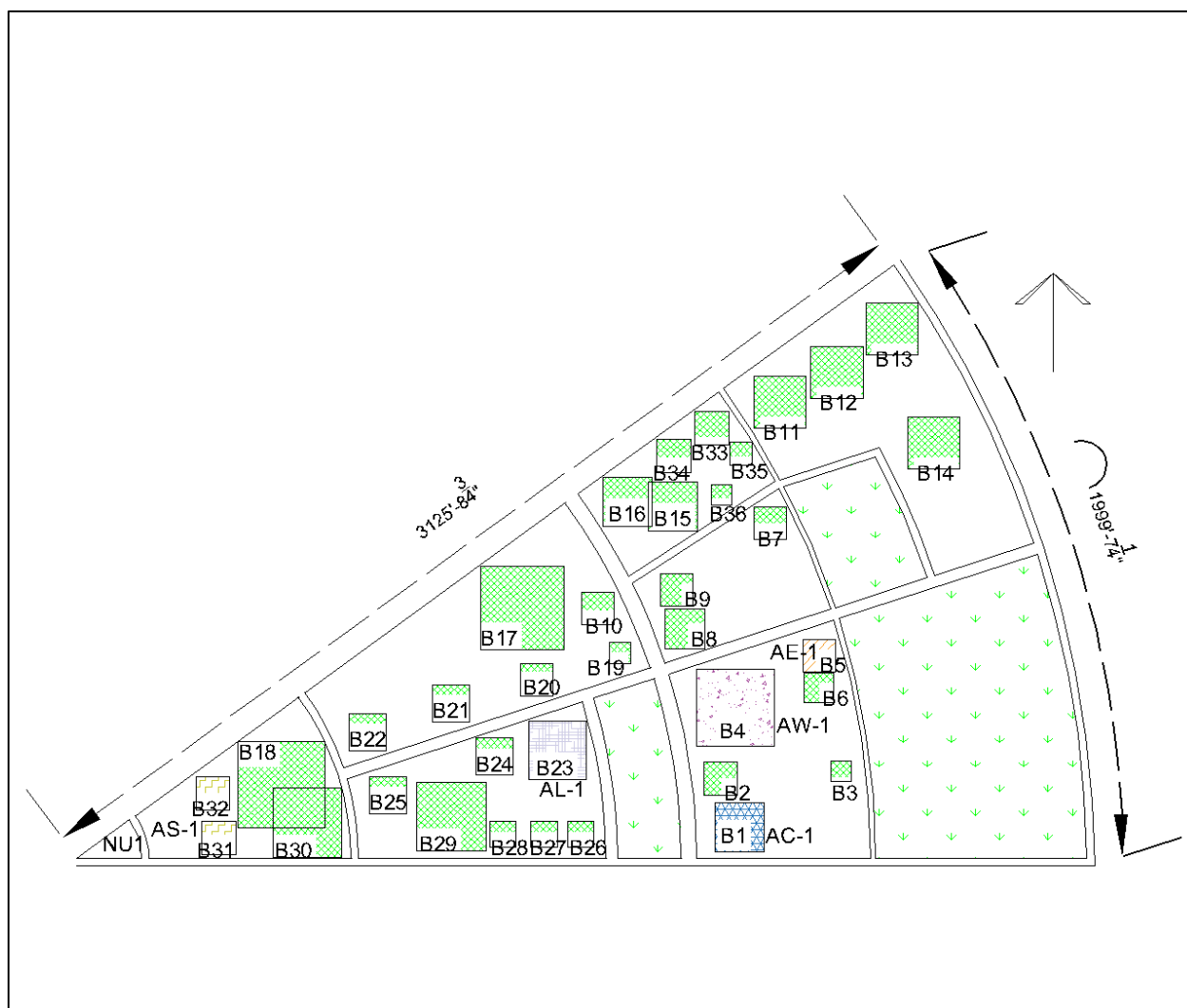
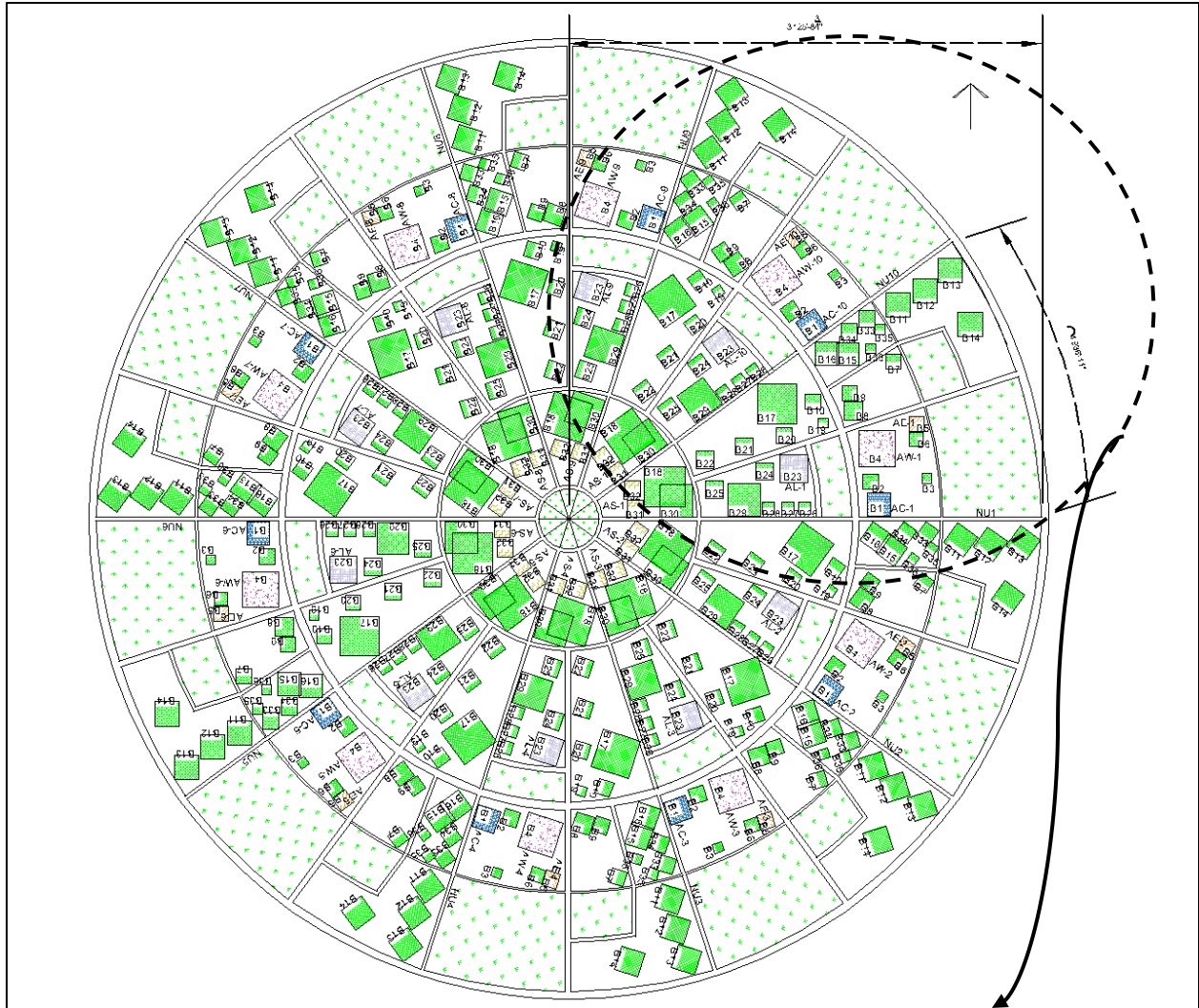


Figure 16 NS-5 (1 NU, Radial shape, Area = 70 acres/0.2833 km²)



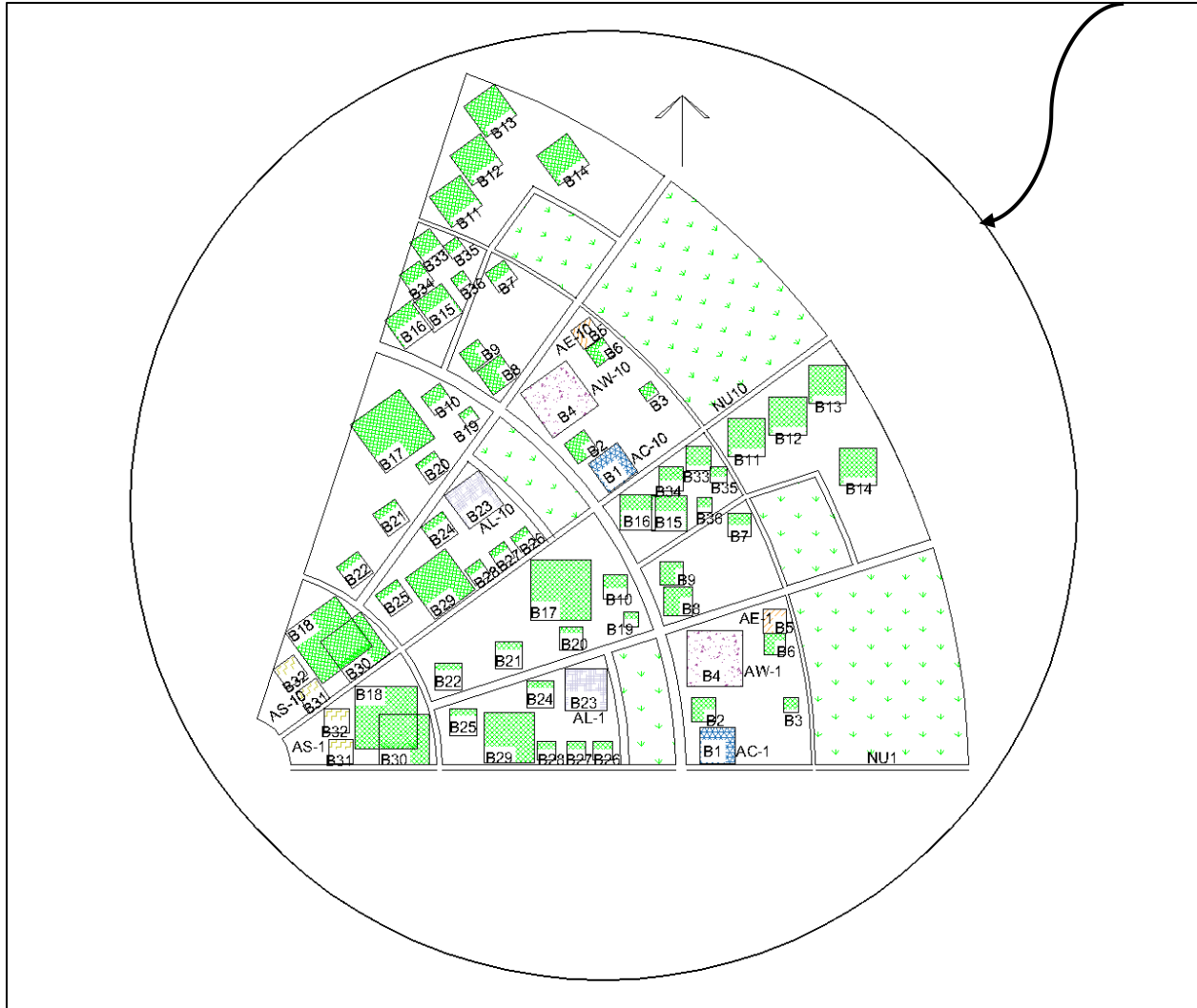


Figure 17 NS-6 (10 NUs = 1 NC, Radial shape, Area = 700 acres/2.833 km²)

Mirroring the base case scenario of West-5 which has 36 buildings, each of the Neighborhood Units (NUs) in the aforementioned scenarios has 36 buildings. These buildings have different geometry and operational purposes (e.g., town houses, apartment buildings, mixed use, retail, health centers). The building blocks in NS-2, 3, 5 & 6 represent the equivalent building roof areas of West-5 while building blocks in NS-1 & 4 have half the buildings areas of West-5. The scenarios have been created using Google Earth Pro and AutoCAD.

3.3.2. Defining Degree of Amenity Availability (DOAA)

15-minute City (FMC) stratifies amenities into 6 categories (mentioned in table 6) and this study applies them in the neighborhood scenarios as different Degree of Amenity Availability (DOAA). Seven DOAA scenarios are investigated in this study where trips from residence to all five– amenities - working (AW), supplying (AS), learning (AL), caring (AC) and leisure/enjoying (AE) amenities are individually and combinedly perused. Table 6 depicts all the degrees of amenity availability perused in this study,

Table 6 Degree of Amenity Availability (DOAA) in Neighborhood Cluster (NC)

DOAA _k Scenario	Number of available amenities in neighborhood (k)	Amenities	Trip Length (TL) from AR
DOAA ₂	2	AR and AW	TL _{AW} X (k-1)
DOAA ₂	2	AR and AS	TL _{AS} X (k-1)
DOAA ₂	2	AR and AL	TL _{AL} X (k-1)
DOAA ₂	2	AR and AC	TL _{AC} X (k-1)
DOAA ₂	2	AR and AE	TL _{AE} X (k-1)
DOAA ₃	3	AR, 33% AW and 67% AS	(33% X TL _{AW} + 67% X TL _{AS}) X (k-2)
DOAA ₄	4	AR, AW, AS and AL	(TL _{Avg} of AW, AS & AL) X (k-3)
DOAA ₆	6	AR, AW, AS, AL, AC & AE	(TL _{Avg} of AW, AS, AL, AC and AE) X (k-5)
*Amenities: (i) Living (Residential) [AR], (ii) Working [AW], (iii) Supplying (AS), (iv) Caring [AC], (v) Learning [AL] and (vi) Leisure/Enjoying [AE]			

Average trip length from residential unit to other amenities for different Degree of Amenity Availability (DOAA_{k=1-6}) is measured based on the different Neighborhood Scenarios (NS_{j=1-6}) where different degrees of Eco-Mobility Strategic Framework (EMS_{F=0-3}) have been applied.

DOAA scenarios presented in table-6 are also examined for four different scenarios – 0%, 33%, 66% & 100% - describing utilization of neighborhood-amenities by dwellers. These four scenarios describe the percentage of dwellers who avails newly introduced amenities located inside the neighborhood. When 0% of the dwellers use the newly introduced amenities inside the neighborhood then base case scenario prevails.

3.3.3. Defining Sustainable Transportation Indicators (STIs)

United Nation identifies economic, social and environmental factors as three pillars of sustainable development [140]. With the view of quantifying and measuring the sustainable development pillars, annual CO₂ emission and annual energy consumption as environmental indicator, annual travel time as social indicator and annual net cost as economic indicator are selected and computed in this research work [123] [124] [125] [126].

In line with these pillars, 4 indicators have been defined in this research as measure of impact on sustainability of transportation i.e., Eco-Mobility Strategies (EMS). Four Sustainable Transportation Indicators (STI) perused in this study delve into different pillar of sustainable development. Annual CO₂ emission (STI₁) & annual energy consumption (STI₂) are

environmental indicators, annual travel time (STI₃) is a social indicator and annual net cost (STI₄) is an economic indicator. Carbon dioxide emission and energy consumption are two different environmental indicators. Carbon dioxide emission represents the mass of carbon dioxide released from the fossil fuel-based vehicles operation and upstream fuel production per unit of use. Energy consumption measures the quantity fuel or electricity a vehicle uses (e.g., liters of fossil fuel or kilowatt hours of battery energy). Improvements in fuel efficiency (e.g., lower energy consumption) but reduction of carbon emission depends on the carbon concentration of the fuel or electricity used. Depending on the average carbon intensity of the electrical grid, the life-cycle GHG emissions of model year 2024 battery electric vehicles (BEV) sedans and sports utility vehicles (SUV) in the US are 66%–70% and 71%–74% respectively lower than traditional fossil fuel-based vehicles [141].

Equations for calculating Sustainable Transportation Indicators (STIs) are presented below,

Annual Carbon Dioxide Emission (kg/year) (STI₁) = Daily Average Trip Length/person (km/person/day) X Number of daily trips (trips/person/day) X Average CO₂ emission (kg/km) X 365 days (Equation 1)

Annual Energy Consumption by EV (kW-Hr/year) (STI₂) = Daily Average Trip Length/person (km/person/day) X Number of daily trips (trips/person/day) X Average energy consumption by EV (kW-Hr/km) X 365 days (Equation 2)

Annual Travel Time (Hours/year) (STI₃) = Daily Average Trip Length/person (km/person/day) X Number of daily trips (trips/person/day) X 365 days / Average speed (km/hr) (Equation 3)

Net Annual Cost of fuel (C\$/year) (STI₄) = {Base case daily neighborhood trip length (km/person/day) - Modified case daily neighborhood trip length (km/person/day)} X Fuel consumption rate (Liter/km) X Cost of fuel (C\$/Liter) X Number of daily trips (trips/person/day) X 365 days (Equation 4)

Total Sustainable Transportation Indicator (STI) for a certain Eco-Mobility Strategic Framework (EMSF) is computed from equation 5,

Total STI for EMSF_i = STI_{l=1to4} for automobile + STI_{l=1to4} for walking + STI_{l=1to4} for cycling + STI_{l=1to4} for public transportation (Equation 5)

EMSF₀ i.e., base case of this study comprises of automobile-based neighborhood while introduction of other strategies in the neighborhood i.e., EMSF_{1to3} reduces modal share of automobile and increase modal share of other modes i.e., walking, cycling and public transportation.

STI types and equations to calculate them are described in table 7,

Table 7 Definitions and equations for Sustainable Transportation Indicators (STI)

Indicator no (STI _i) (i)	Indicator type (ii)	Indicator name (iii)	Equation for STI (v)
STI ₁	Environmental	Annual Carbon Dioxide Emission (kg/year)	$\text{Daily Average Trip Length/person (km/person/day)} \times \text{Number of daily trips (trips/person/day)} \times \text{Average CO}_2 \text{ emission (kg/km)} \times 365 \text{ days}$
STI ₂	Environmental	Annual Energy Consumption by EV (kW-Hr/year)	$\text{Daily Average Trip Length/person (km/person/day)} \times \text{Number of daily trips (trips/person/day)} \times \text{Average energy consumption by EV (kW-Hr/km)} \times 365 \text{ days}$
STI ₃	Social	Annual Travel Time (Hours/year)	$\text{Daily Average Trip Length/person (km/person/day)} \times \text{Number of daily trips (trips/person/day)} \times 365 \text{ days} \div \text{Average speed (km/hr)}$
STI ₄	Economic	Net Annual Cost of fuel (C\$/year)	$\{\text{Base case daily neighborhood trip length (km/person/day)} - \text{Modified case daily neighborhood trip length (km/person/day)}\} \times \text{Fuel consumption rate (Liter/km)} \times \text{Cost of fuel (C\$/Liter)} \times \text{Number of daily trips (trips/person/day)} \times 365 \text{ days}$

The individual components for STI equations 1 to 4 are calculated using the methodology mentioned in table 8,

Table 8 Calculation method for determining components of STI equations

Component no	Component Name	Expression of equation or Calculation method	Function in STI
Component-1	Daily Average Trip Length/person (km/person/day)	For EMSF₀: Base case scenario where trip lengths are collected from London Household Travel Survey 2016 or measured from average value of distance to difference amenities from West-5 using google map. For EMSF₁₋₃: Trip lengths are measured from Neighborhood Scenario, NS_{j=1-6} using AutoCAD. Average Trip Length is considered for calculation which is mean value of maximum and minimum trip length/distance between residential units and amenities. The minimum trip length is taken as zero. Average trip length = $\{(\text{TripLength}_{\text{MAX}} + \text{TripLength}_{\text{MIN}}) \div 2\}$ where TripLength_{MIN} is zero.	STI – 1, 2 & 3
Component -2	Number of daily trips (trips/person/day)	For EMSF₀: Number of daily trips by purpose (i.e., from residence to different amenities) is collected from London Household Travel Survey 2016.	STI – 1, 2, 3 & 4

Component no	Component Name	Expression of equation or Calculation method	Function in STI
		For EMSF₁₋₃: Number of daily trips by purpose (i.e., from residence to different amenities) for EMSF ₀ are multiplied by the modal share of strategies. Modal shares are collected from London Household Travel Survey 2016.	
Component -3	Average CO ₂ emission (kg/km)	For EMSF₀₋₃: Average CarbonEmission _{automobile} (kg/km) = $\{\sum(I_{\text{automobile-}i} \times \text{CarbonEmission}_{\text{rate-km-}i})\} \div (\sum N_{\text{automobile-}i})$ Where, CarbonEmission _{automobile} is mass of CO ₂ emission per kilometer by automobiles, N _{automobile-}i} is number of automobile sold of a Iertain type i and CarbonEmIssion _{rate-km-}i} is CO ₂ is emission per kilometer by a certain type of automobile [28].	STI – 1
Component -4	Average energy consumption by EV (KJ/km)	For EMSF₀₋₃: Average EnergyConsumption _{automobile} (KJ/km) = $\{\sum(N_{\text{automobile-}i} \times \text{EnergyConsumption}_{\text{rate-km-}i})\} \div (\sum N_{\text{automobile-}i})$ Where, EnergyConsumption _{automobile} is average energy consumption per kilometer by automobiles, N _{automobile-}i} is number of automobile sold of a certain type i and EnergyConsumption _{rate-km-}i} is energy consumption rate per kilometer by a certain type of automobile.	STI – 2
Component -5	Average speed (km/hr)	For EMSF₀₋₃: Walking = 1.2 m/s Cycling = 35 km/hr (Design speed) Public Transport = 45 km/hr (Design speed) Automobile = 50 km/hr (Max speed – Ontario regulations)	STI – 3
Component -6	Fuel consumption rate (Liter/km)	Fuel consumption rate is found from Fuel consumption ratings tool developed by Natural Resources Canada (NRCan).	STI – 4
Component -7	Cost of fuel (C\$/Liter)	Unit price of premium gasoline in context of London, Ontario is used for calculation.	STI – 4

At the final step of Sustainable Transportation Indicator (STI_{i=1-4}) are calculated for different EMSF_{i=0-3}, NS_{j=1-6} and DOAA_{k=1-6}. Annual Carbon emission (STI₁) and annual energy emission (STI₂) from walking and cycling are zero in EMSF₁, EMSF₂ and EMSF₃.

3.3.4. Analysis of Eco-Mobility Strategic Framework (EMSF)

The application of different degree of Eco-Mobility Strategic Framework ($EMSF_{i=0-3}$) is analyzed and its results are measured with respect to $STI_{l=1-4}$ where different $NS_{j=1-6}$ and $DOAA_{k=1-6}$ are generated and perused. Figure 18 depicts the combinations of analysis mentioned in this section,

Eco-Mobility Strategic Framework ($EMSF_i$) ($i = 0$ to 3) Iterations: 4	Neighborhood Scenario (NS_j) ($j = 1$ to 6) Iterations: 6	Degree of Amenity Availability ($DOAA_k$) ($k = 1$ to 6) Iterations: 7	Sustainable Transportation Indicator (STI_l) ($l = 1$ to 4) Iterations: 4
$i = 0$: No EMSF (base case) $i = 1$: 33% EMSF (walking strategies only) $i = 2$: No EMSF (walking and cycling strategies) $i = 3$: No EMSF (walking, cycling and public transportation strategies)	$j = 1$: Rectangular neighborhood unit (31.85 acre) $j = 2$: Rectangular neighborhood unit (70 acre) $j = 3$: Rectangular neighborhood cluster (700 acre) $j = 4$: Radial neighborhood unit (31.83 acre) $j = 5$: Radial neighborhood unit (70 acre) $j = 6$: Radial neighborhood cluster (700 acre)	$k = 2$: AR and AW amenities are available $k = 2$: AR and AS amenities are available $k = 2$: AR and AL amenities are available $k = 2$: AR and AC amenities are available $k = 2$: AR and AE amenities are available $k = 4$: AR, AW, AS and AL amenities are available $k = 6$: AR, AW, AS, AC, AL and AE amenities are available	$l = 1$: Annual Carbon Dioxide Emission (kg/year) $l = 2$: Annual Energy Consumption by EV (KJ/year) $l = 3$: Annual Travel Time (Hours/year) $l = 4$: Net Annual Cost (C\$/year)

Figure 18 Combination of settings for analyzing Eco-Mobility Strategies Framework (EMSF) with respect to Neighborhood Scenario (NS), Degree of Amenity Availability (DOAA) and Sustainable Transportation Indicator (STI)

This section described the procedure for analyzing the Eco-Mobility Strategic Framework (EMSF) with respect to Sustainable Transportation Indicator (STI) for different degrees of Eco-Mobility Strategies (EMS) application in different Neighborhood Scenarios (NS) where different Degree of Amenity Availability (DOAA) are implemented.

3.4. Methodology for development of Decision-Making Metric (DMM)

This part of the study depicts a procedure for interpreting the Sustainable Transportation Indicator (STI) calculated from previous section. Sustainable Transportation Indicators ($STI_{l=1-4}$) (Annual CO₂ emission (STI_1), Annual energy consumption (STI_2), Annual travel time (STI_3) and Annual net cost (STI_4)) measured for base case i.e., $EMSF_{i=0}$ describes the STI values when Eco-Mobility Strategies (EMS) are not implemented. The policy makers implement Eco-Mobility Strategic Framework ($EMSF_{1/2/3}$) when it proves beneficial for the community i.e., an EMSF is chosen for execution when the resultant STI values are lesser than base case STI. However, in order to take informed decision, the policy makers must be presented with report(s) that

summarizes the engineering calculations into simple numbers that can be comprehended by everyone and aids them to take decisions.

A Decision-Making Metric (DMM) is proposed at this stage that measure the effectiveness of implementing the Eco-Mobility Strategies Framework (EMSF) in a certain Neighborhood Scenario (NS). Effectiveness of each Eco-Mobility Strategic Framework ($EMSF_{i=1-3}$) is measured by introducing Framework Performance Coefficient (FPC) that determines the ratio of Sustainable Transportation Indicator ($STI_{i=1-4}$) for each $EMSF_{1-3}$ to base case i.e., $EMSF_0$ (see equation 6). Finally, Decision-Making Metric Value (DMMV) is proposed which gives the policy makers flexibility to set their priority, compare between different strategies and reach an informed conclusion from one single figure (equation 7). DMMV for a certain Neighborhood Scenario (NS) is determined by summing all the FPC calculated for all the Sustainable Transportation Indicators (STI) after applying appropriate Weighting Factor ($Weight_{Factor}$) on the FPC values. The Weighting Factor ($Weight_{Factor}$) is selected by the decision makers based on their priority of sustainable development factor i.e., environmental and/or social and/or economic. Values of $Weight_{Factor}$ are also selected by evaluating other factors such as Government policy, community preference etc. which are beyond the scope of this research. For the time being this research assume weights for all the sustainable development are equal i.e. $Weight_{Factor} = 0.25$.

Framework Performance Coefficient (FPC) = STI_{1-4} for $EMSF_{1-3}$ / STI_{1-4} for Base Case $EMSF_0$ (Equation 6)

DMMV for $EMSF_{i=1-4} = \Sigma(FPC_{STI-i} \times Weight_{Factor})$ (Equation 7)

Decision Making Metric (DMM) depicting the Framework Performance Coefficient (FPC) and Decision-Making Metric Value (DMMV) are described in table 9,

Table 9 Decision Making Metric containing Framework Performance Coefficient (FPC) for different Eco-Mobility Strategic Framework (EMSF)

Framework name	Sustainable Transportation Indicator (STI)	DMM condition for selecting $EMSF_i$	Framework Performance Coefficient (FPC)	Decision Making Metric Value (DMMV)
(i)	(ii)	(iii)	(iv)	(v)
Eco-Mobility Strategic Framework ($EMSF_i$)	Annual CO ₂ emission (STI_1)	STI_1 for $EMSF_{1-3} < STI_1$ for Base Case ($EMSF_0$)	STI_1 for $EMSF_{1-3}$ / STI_1 for $EMSF_0$	Select Minimum $\Sigma(FPC_{STI-i} \times Weight_{Factor})$
	Annual Energy Consumption (STI_2)	STI_2 for $EMSF_{1-3} < STI_2$ for Base Case ($EMSF_0$)	STI_2 for $EMSF_{1-3}$ / STI_2 for $EMSF_0$	
	Annual Travel Time (STI_3)	STI_3 for $EMSF_{1-3} < STI_3$ for Base Case ($EMSF_0$)	STI_3 for $EMSF_{1-3}$ / STI_3 for $EMSF_0$	

	STI ₃ for Base Case (EMSF ₀)	
Annual Net Cost (STI ₄)	STI ₄ for EMSF ₁₋₃ < STI ₄ for Base Case (EMSF ₀)	STI ₄ for EMSF ₁₋₃ / STI ₄ for EMSF ₀

For each Neighborhood Scenario (NS_j), the Decision-Making Metric Value (DMMV) are calculated using equation 7. For a certain NS_j, there are 4 DMMV values for 4 Eco-Mobility Strategic Framework (EMSF_{i=1to4}). Comparing among these 4 DMMV, the minimum value DMMV gives the policy makers least impactful framework. So, decision making process is made simpler by looking at only one number for each neighborhood containing one EMSF.

Figure 19 describes the summary of the methodology mentioned above. This study defines base case scenario where Eco-Mobility Strategies (EMS) are not implemented. Then 3 EMS i.e., walking, cycling and public transportation are implemented and consecutively 3 Eco-Mobility Strategic Framework (EMSF) are proposed. Application of EMSF is tested on 6 hypothetically developed Neighborhood Scenarios (NS) that have been converted to multi-functional neighborhood of different degrees i.e., 7 different Degree of Amenity Availability (DOAA). Impact of EMSF is measured using Sustainable Transportation Indicator (STI) (e.g., annual CO₂ emission, annual energy consumption, annual travel time and annual net cost) from environment, social and economic perspective by. Finally, a Decision-Making Metric (DMM) is proposed where tools such as Framework Performance Coefficient (FPC) and Decision Making Metric value (DMMV) is used to evaluate the effectiveness of a certain Eco-Mobility Strategic Framework (EMSF) on a certain Neighborhood Scenario (NS).

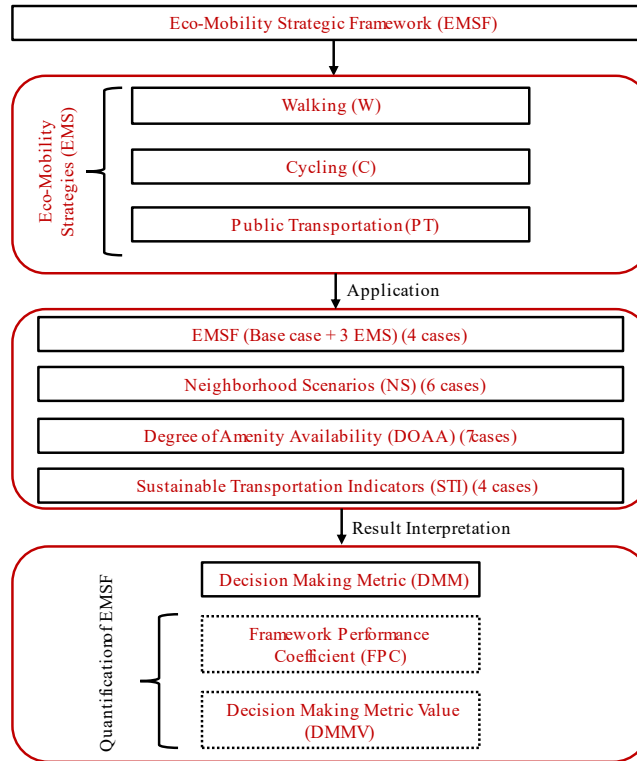


Figure 19 Methodology for development, analysis and interpretation of Eco-Mobility Strategic Framework (EMSF)

The chapter 4 delineates the application of strategies implemented in neighborhood scenarios mentioned earlier and corresponding results are generated from applying the methodology mentioned in this chapter. In line with the objectives and methodology of this chapter, chapter 4 presents the results obtained from application of Eco-Mobility Strategies.

4. Application of Eco-Mobility Strategic Framework (EMSF)

This chapter of the discourse delineates the results obtained from this application and interprets the findings. The principal goal of this research work is to reduce CO₂ emission from urban transportation system and make the system sustainable as well (see section 1.2). This study perused the base case scenario at West-5 in London, Ontario from two different fronts – West-5 as a no-amenity neighborhood with large trip lengths to amenities/destinations and the other front is introduction of Eco-Mobility Strategies of different degree at hypothesized neighborhoods where amenities are inclusive at different degree. The study proposes Eco-Mobility Strategic Framework (EMSF) that combines the strategies and different scenarios in one single framework and measures its impact with the aid of Sustainable Transportation Indicators (STI). Finally, the dilemma arises for policy makers as well as community members to select and/or implement one framework over other or to decide whether one framework is superior or inferior to another. This dilemma is rescinded by introduction of Decision-Making Metric (DMM) which employ tools such as Framework Performance Coefficient (FPC) and Decision-Making Metric Value (DMMV) which measures the effectivity of different frameworks and presents the decision makers with a single number based on which they can select a single or group of strategies. As a proof of concept of this framework and its measurement system, the application implements the model on West-5 as base case scenario and other hypothesized neighborhood scenarios.

The first sub-section describes computation of components for equation 1 to 4. Trip length for different Neighborhood Scenario (NS) are computed in article 3.1.1 followed by number of daily trips in 3.1.2. Average CO₂ emission and energy consumption are calculated from automobile purchasing behavior of Canadians in section 3.1.3 and 3.1.4. The average speed for Eco-Mobility modes and cost of fuel selected for determining the STIs are described in section 3.1.5.

Using the STI component values from article 3.1 for different case scenarios, Sustainable Transportation Indicator, $STI_{l=1to4}$ values are determined in article 3.2. Finally, Article 3.3 combines all the STI values from different case scenarios and generates the Decision-Making Metric (DMM).

4.1. Application of Eco-Mobility Strategic Framework (EMSF)

Base case scenario and implementation of the three Eco-Mobility Strategies (EMS) – walking, cycling and public transport in context of six Neighborhood Scenarios (NS) (3 rectangular and 3 radial, as mentioned in section 2.3.1 and figure 6 to 11) and seven Degrees of Amenity Availability (DOAA) (working, supplying, caring, learning, leisure/enjoying amenities individually and in combination) yields a range of values for the components mentioned in table 7. These components- namely, trip length, number of trips, average CO₂ emission, average energy consumption, average speed, fuel consumption rate, and cost of fuel) are presented in this section. Sustainable Transportation Indicator (STI) are then determined from these components in equations 1 to 4 concerning annual CO₂ emission, annual energy consumption, annual travel time and net cost.

4.1.1. Daily average trip length per person (variable-1) for EMSF₀₋₃

This section describes the result for trip length of EMSF₀ i.e., base case scenario constructed grounded on West-5 located at London, Ontario. From London Household travel survey 2016, the average trip length for London, Ontario for residence to work and school trips are 9.1 and 4.2 km respectively (regardless of mode of transportation) [70]. Average trip length for supply, care and leisure amenities from residences at West-5 have been measured using google map which are 10, 4.9 and 6.5 km (average distance to multiple outlets of amenities from West-5). The mean value of trip lengths for residence to working, learning, supplying, caring and leisure amenity trips have been calculated as 6.94 km. Trip length from residential unit to different amenities for Neighborhood Scenario (NS) 1 to 6 are measured from neighborhood scenarios (Figure 12 to 17) and presented in table 8. Neighborhood Scenarios – 1 to 6 are hypothesized on base case neighborhood West-5. Table 4 describes area of each of the neighborhood scenario where NS-1&4 have an area equal to 45% of West-5, NS-2&4 have equal area and NS-3&6 are 10 times larger than West-5. Considering the work amenity for example, NS-1 residential dwellers have to travel maximum 0.45 km (e.g., people who live at the furthest corner) or minimum 0 km (e.g., people who live right beside their work place) to work amenity, so average trip length here is $\{(0.45 + 0)/2\}$ or, 0.23km. Average trip lengths for all the neighborhood scenarios are described in table 10.

Table 10 Trip length from residence for EMSF_{1 to 3}

Neighborhood Scenario (NS)	Max dist. between two extreme corners (km)	Trip Length from residence (AR) to amenity (km)										Avg.
		Working (AW)		Supplying (AS)		Caring (AC)		Learning (AL)		Leisure (AE)		
		Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	
NS-1	0.83	0.45	0.23	0.77	0.39	0.62	0.31	0.49	0.25	0.55	0.28	0.29
NS-2	1.21	0.66	0.33	1.12	0.56	0.86	0.43	0.75	0.38	0.85	0.43	0.43
NS-3	0.76	0.62	0.31	0.63	0.32	0.61	0.31	0.61	0.31	0.63	0.31	0.31
NS-4	0.87	0.56	0.28	0.80	0.40	0.72	0.36	0.60	0.30	0.77	0.39	0.35
NS-5	1.26	0.8	0.4	1.1	0.55	0.94	0.47	0.78	0.39	0.98	0.49	0.46
NS-6	1.25	0.7	0.35	1.1	0.55	0.62	0.31	0.78	0.39	0.88	0.44	0.41
Average Trip Length = {(Maximum + Minimum) ÷ 2} where Minimum trip length is zero.												
Lengths are measured from extreme corner of the rectangular.												

From the Degree of Amenity Availability (DOAA) scenarios mentioned in table 6 and trip lengths for Neighborhood Scenarios (NS₁₋₆) from table 5, the following table depicts the trip lengths for the Degree of Amenity Availability (DOAA) scenarios analyzed in this study (Table 11).

Table 11 Trip Length for different Degree of Amenities Availability (DOAA_k)

Category of trip from living amenity (AR)	Trip Length (km) for EMSF ₀ (base case)	Trip Length for EMSF ₁₋₃					
		NS-1	NS-2	NS-3	NS-4	NS-5	NS-6
DOAA _{k=2} Scenario-1: AR & AW	9.1	0.23	0.33	0.31	0.28	0.4	0.35
DOAA _{k=2} Scenario-2: AR & AS	10	0.39	0.56	0.32	0.4	0.55	0.55
DOAA _{k=2} Scenario-3: AR & AL	4.2	0.25	0.38	0.31	0.3	0.39	0.39
DOAA _{k=2} Scenario-3: AR & AC	4.9	0.31	0.43	0.31	0.36	0.47	0.31
DOAA _{k=2} Scenario-3: AR & AE	6.5	0.28	0.43	0.31	0.39	0.49	0.44
DOAA _{k=4} Scenario-4: AR, AW, AS & AL (=Average of scenario-1, 2 & 3)	7.77	0.29	0.42	0.31	0.33	0.45	0.43
DOAA _{k=6} Scenario-5: AR, AW, AS, AC, AL & AE	6.94	0.29	0.43	0.31	0.35	0.46	0.41

4.1.2. Number of daily trips per person (variable-2) for EMSF₀₋₃

Household travel survey 2016 conducted at London, Ontario found that Londoners made 1.63 million trips every day and daily per capita number of trips is 3.4 for the city dwellers. 19% of these trips are residence to work trips, 8% are residence to school trips, 49% are residence to other reason trips and remaining 24% are not generated from residence [70]. Based on West-5 neighborhood, this study assumes that all trips are originated from residences to other amenities. therefore, the data from London household survey is converted to residence-based trips only. Since 24% trips are not residence based, the remaining 76% trips are residence-based trips. based on this (76% residence-based trips), the percentage of residence-based work, school and other purpose trips are recalibrated as 25%, 10.53% and 64.47% respectively. For example, out of 100 daily trips generated by Londoners, 76 are originated from residence and out of these 76 trips, the survey found that 19 are work trips, therefore work trips are $19/76 = 25\%$ of the home-based trips. Residence-based other trips (64.47%) are equally distributed among other three amenities (i.e., supplying, caring and leisure/enjoying). For example, out of 64.47 home to other amenity trips generated by Londoners, 1/3rd is assigned to supplying/caring/leisure (e.g., $64.47/3 = 21.49$ trips). Percentage of daily trips and number of daily trips from residences to the five other amenities is presented in table 12,

Table 12 Number of daily trips to amenities from residence per person

Type of trip from residence to amenity		Percentage of daily trips from residence to amenities	Total number of trips taken person in London, Ontario	Number of daily trips to amenities per person (trips/person/day)
(i)	(ii)	(iii)	(iv)	(v)=(iii) X (iv)
From Residence	To Work amenity (AW)	25%	3.4	0.85
	To Supply amenity (AS)	21.49%		0.73
	To Care amenity (AC)	21.49%		0.73
	To Learning amenity (AL)	10.53%		0.36
	To Leisure amenity (AE)	21.49%		0.73
		$\Sigma = 100\%$		$\Sigma = 3.4$
		Average = 20%		Average = 0.68

Pictorial presentation of percentage of daily trips taken by a dweller to different amenities is shown in Figure 20.

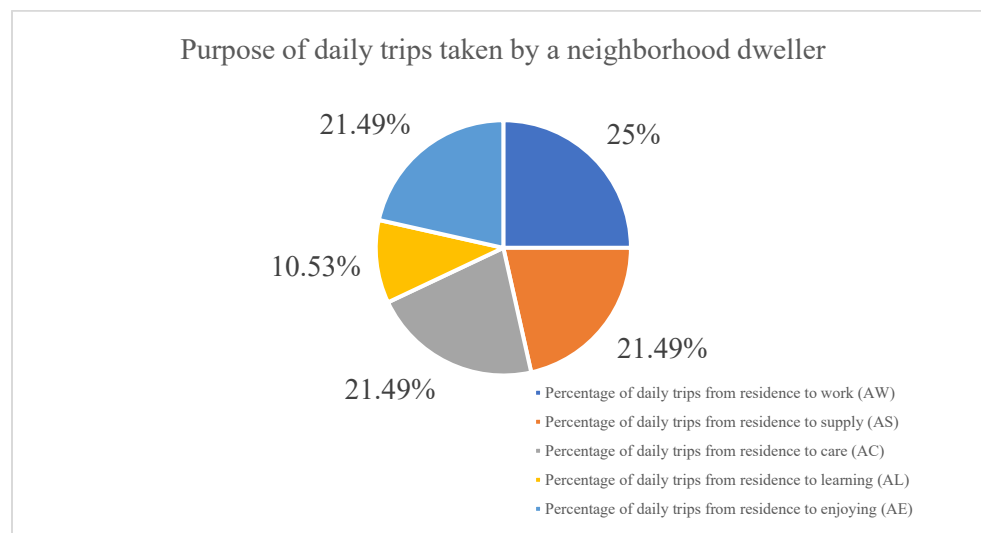


Figure 20 Purpose of daily trips (%) taken by a neighborhood dweller to different amenities

This study individually peruses scenarios where only one amenity is introduced in the neighborhood alongside the residential units. However, it is observed that number of trips from residence to 3 amenities - supply, care and leisure amenity is similar. Therefore, the inclusion of three amenities i.e., work, supply and learning amenities in the neighborhood is also perused in this study. Finally, a scenario is also examined where all amenities i.e., work, supply, learning, caring and enjoying/leisure are available in the neighborhood alongside the residential units.

For the modal share described in Figure 3, where automobile (driver), automobile (passenger), transit, walking, cycling and other mode percentages are 64.8%, 14.3%, 6.2%, 10%, 1.2% and 3.5% respectively, the number of daily trips for each type of mode is described in table 11. For example, Londoners make 0.85 trips every day to work when Eco-Mobility Strategies (EMS) have not been implemented i.e., EMSF₀ and 64.8% of these trips are taken by driving an automobile resulting into 0.55 trips to work by driving an automobile. Modal distribution for EMSF₀ is described in table 13.

Table 13 Number of trips to different amenities for different mode of transportation for Eco-Mobility Strategic Framework (EMSF₀)

Type of trips from residence (i)	Number of trips (trips/person/day)						
	All modes (ii)	Automobile (driver) mode (iii) = (ii) X modal share*	Automobile (passenger) mode (iv) = (ii) X modal share*	Transit mode (v) = (ii) X modal share*	Walking mode (vi) = (ii) X modal share*	Cycling mode (vii) = (ii) X modal share*	Other mode (viii) = (ii) X modal share*
To work (AW)	0.85	0.55	0.12	0.05	0.09	0.01	0.03
To supply (AS)	0.73	0.47	0.10	0.05	0.07	0.01	0.03
To care (AC)	0.73	0.47	0.10	0.05	0.07	0.01	0.03
To learning (AL)	0.36	0.23	0.05	0.02	0.04	0.004	0.01
To leisure (AE)	0.73	0.47	0.10	0.05	0.07	0.01	0.03
Total	3.40	2.20	0.49	0.21	0.34	0.04	0.12

**Modal share for base case scenario in London from figure 1: Automobile (driver) = 64.8%, Automobile (passenger) = 14.3%, Transit = 6.2%, Walking = 10%, Cycling = 1.2% and other mode = 3.5%*

2016 Household travel survey summary report states that 48% of automobile drivers would not consider changing their mode of transportation. This research uses the nomenclature “loyal users” for this class of mode users. It is assumed that upon implementation of Eco-Mobility

Strategic Frameworks (EMSF₁₋₃), remaining 52% of the trips are re-distributed to other mode(s) of transportation. For example, Londoners make 0.85 trips every day to work when Eco-Mobility Strategies (EMS) have not been implemented i.e., EMSF₀. Upon implementation of EMSF₁, 48% of these 0.85 trips are taken by automobile mode while the remaining 52% are taken by mode associated with EMSF₁ i.e., walking. Modal distribution for EMSF₁ is described in table 14.

Table 14 Number of trips to different amenities for different mode of transportation for Eco-Mobility Strategic Framework (EMSF₁)

Type of trips from residence	Number of trips (trips/person/day)		
	All modes	Automobile (driver) mode	Walking mode
(i)	(ii)	(iii) = (ii) X modal share % (automobile)* X Loyal users % (automobile)**	(iv)=(ii)-(iii)
To work (AW)	0.85	0.26	0.59
To supply (AS)	0.73	0.23	0.50
To care (AC)	0.73	0.23	0.50
To learning (AL)	0.36	0.11	0.25
To leisure (AE)	0.73	0.23	0.50
Total	3.40	1.06	2.34

*Modal share from figure 1: Automobile (driver) = 64.8%

**Loyal users (automobile) = 48%

Introduction of EMSF₂ introduces two modes – walking and cycling. From the example given above, upon implementation of EMSF₂, 48% keep using automobiles while ½ of remaining 52% i.e., 26% switch to walking and the remaining 26% cycle to their work. Modal distribution for EMSF₂ is depicted in table 15.

Table 15 Number of trips to different amenities for different mode of transportation for Eco-Mobility Strategic Framework (EMSF₂)

Type of trips from residence	Number of trips (trips/person/day)			
	All modes	Automobile (driver) mode	Walking mode	Cycling mode
(i)	(ii)	(iii) = (ii) X modal share % (automobile)* X Loyal users % (automobile)**	(iv)={ (ii)-(iii) } ÷ 2	(v) = { (ii)-(iii) } ÷ 2
To work (AW)	0.85	0.26	0.29	0.29
To supply (AS)	0.73	0.23	0.25	0.25
To care (AC)	0.73	0.23	0.25	0.25
To learning (AL)	0.36	0.11	0.12	0.12
To leisure (AE)	0.73	0.23	0.25	0.25
Total	3.40	1.06	1.17	1.17

*Modal share from figure 1: Automobile (driver) = 64.8%

**Loyal users (automobile) = 48%

Introduction of EMSF₃ introduces three modes – walking, cycling and public transit. From the example given above, upon implementation of EMSF₃ 48% keeps using automobiles while 1/3rd of remaining 52% i.e., 17.33% switch to walking, 17.33% switch to cycling and the remaining 17.33% use public transport mode to their work. Modal distribution for EMSF₃ is depicted in table 16.

Table 16 Number of trips to different amenities for different mode of transportation for Eco-Mobility Strategic Framework (EMSF₃)

Type of trips from residence	Number of trips (trips/person/day)				
	All mode	Automobile (driver) mode	Walking mode	Cycling mode	Public Transportation mode
(i)	(ii)	(iii) = (ii) X modal share % (automobile)* X Loyal users % (automobile)**	(iv)={ (ii)-(iii) } ÷ 3	(v)={ (ii)-(iii) } ÷ 3	(vi)={ (ii)-(iii) } ÷ 3
To work (AW)	0.85	0.26	0.20	0.20	0.20
To supply (AS)	0.73	0.23	0.17	0.17	0.17
To care (AC)	0.73	0.23	0.17	0.17	0.17
To learning (AL)	0.36	0.11	0.08	0.08	0.08
To leisure (AE)	0.73	0.23	0.17	0.17	0.17
Total	3.40	1.06	0.78	0.78	0.78

*Modal share from figure 1: Automobile (driver) = 64.8%

**Loyal users (automobile) = 48%

4.1.3. Average CO₂ emission (variable-3) and fuel consumption rate

This research work looks at trip length and number of trips that are originated from residential units. Popular automobile units purchased and used by Canadian people is investigated in this section. CO₂ emission and fuel consumption rate for top ten most sold automobiles for the year 2024 in Canada is collected from the fuel consumption ratings search tool developed by Natural Resources Canada [142]. A weighted average of CO₂ emission rate (gm/km) and fuel consumption rate (Liter/100km) with respect to the number of automobiles sold is calculated in table 17 [143].

Table 17 Average CO₂ emission from most sold automobiles in Canada for the year 2024

Ranking of most sold automobiles	Name	Units sold in 2024	CO₂ emission (gm/km)	Weighted average of carbon dioxide emission (gm/km) with respect to units sold (v) = {(iii) X (iv)} ÷ (Σ(iii))	Fuel consumption rate (Liter/100 km) (combined for city and rural) (vi)	Weighted average of fuel consumption (Liter/km) with respect to units sold (vii) = {(iii) X (vi)} ÷ (Σ(iii))
(i)	(ii)	(iii)	(iv)			
1	Ford F-series	133,857.00	280.33	235.23	12.03	0.0998
2	Toyota RAV4	77,556.00	199		8.5	
3	GMC Sierra	59,912.00	281		11.77	
4	Ram 1500/Heavy Duty	56,992.00	269		11.5	
5	Honda CR-V	55,363.00	181		7.8	
6	Chevrolet Silverado	52,078.00	279		11.67	
7	Nissan Rogue	32,737.00	169		7.2	
8	Honda Civic	31,774.00	180		7.0	
9	Ford Escape	31,037.00	185		8.0	
10	Hyundai Kona	30,020.00	179		7.6	

CO₂ emission for transit buses is considered 0.95 pounds per passenger-mile which is equivalent to 267.843 gm per passenger-km [144].

4.1.4. Average energy consumption by EV (variable-4)

This research work peruses residence-based trips only therefore popular Electric Vehicles (EV) purchased by Canadian people is taken into account for determining their power consumption. Energy consumption from top five most sold electric vehicles for the year 2024 in Canada is collected from the fuel consumption ratings search tool developed by Natural Resources Canada [142]. A weighted average of energy consumption (kW-Hr/100 km) with respect to the number of automobiles sold is calculated in table 18 [145]. It is found from table 18 that average energy consumption for popular EVs in Canada is 0.1991 kW-Hr/km.

Table 18 Average energy consumption from most sold electric vehicles in Canada for the year 2024

Ranking of most sold automobiles	Name	Units sold in 2024	Energy consumption (kW-Hr/100 km)	Weighted average of energy consumption (kW-Hr/100 km) with respect to units sold
(i)	(ii)	(iii)	(iv)	(v) = {(iii) X (iv)} ÷ (Σ(iii))
1	Tesla Model Y	19,188	20.1	0.1991
2	Tesla Model 3	9,490	19.2	
3	Volkswagen ID.4	7,259	19.6	
4	Ford Mustang Mach-E	7,083	20.1	
5	Hyundai Kona Electric	6,683.00	20.5	

Average energy consumption by electric buses is 2.6 ± 0.3 kW-Hr/mile (60 ft) or 3.6 ± 0.5 kW-Hr/mile (60 ft) [146]. This study will consider 60 ft electric buses for which the average energy consumption rate is 2.24 kW-Hr/km.

4.1.5. Average speed for transportation modes (variable-5) and Cost of fossil fuel (variable-7)

Average speed for Eco-Mobility Strategies (EMS) i.e., walking, cycling and public transport is 4.32 km/hr, 35 km/hr and 45km/hr respectively. Average speed for automobiles in Ontario province is considered 50 km/hr [147]. Cost of diesel and premium gasoline per liter in Ontario is C\$1.316 and C\$1.644 respectively (Date: 12-May-2025) [148].

4.2. Results for application of Eco-Mobility Strategic Framework (EMSF)

This section shows the results of implementing Eco-Mobility Strategic Framework (EMSF_{i=0to3}) on Sustainable Transportation Indicator (STI) in context of different Neighborhood Scenario (NS_{j=1to6}) and Degree of Amenity Availability (DOAA_{k=1to6}). It has four sub-sections that describe STI results for each Eco-Mobility Strategic Framework (EMSF_{0 to 3}) i.e., STIs at base case scenario is described in first sub-section, second sub-section describes the STIs at EMSF₁ where walking related strategies have been implemented, third sub-section describes the STIs at EMSF₂ where walking and cycling related strategies have been implemented and finally the third sub-section depicts STIs at the EMSF₃ where walking, cycling and public transportation related strategies have been fully implemented.

STI values are determined from equation 1 to 4 mentioned in section 3.3.3. Data required to calculate the STIs such as trip length, number of trips and other components are collected from section 4.1. In figure 12 to 17, the graphs have 7 DOAA scenarios in horizontal axis where the first 5 DOAA describes residence-based (AR) trips to one other amenity (e.g., work (AW), supply (AS), learning (AL), caring (AC), leisure/enjoying (AE)). DOAA₄ scenario depicts a scenario where a combination of amenities is available such as residence (AR), work (AW), supply (AS) and learning (AL). The final DOAA₆ scenario describes a scenario where all the

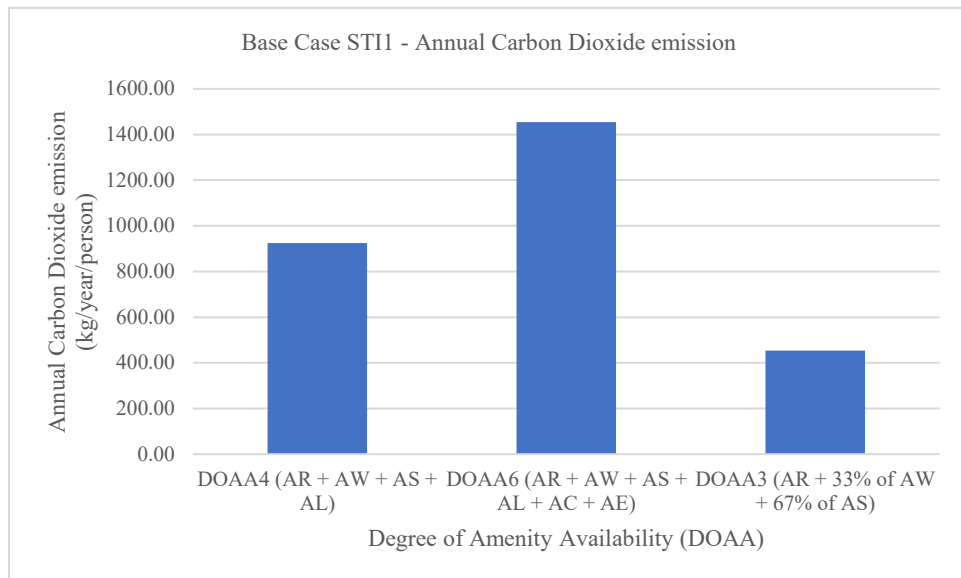
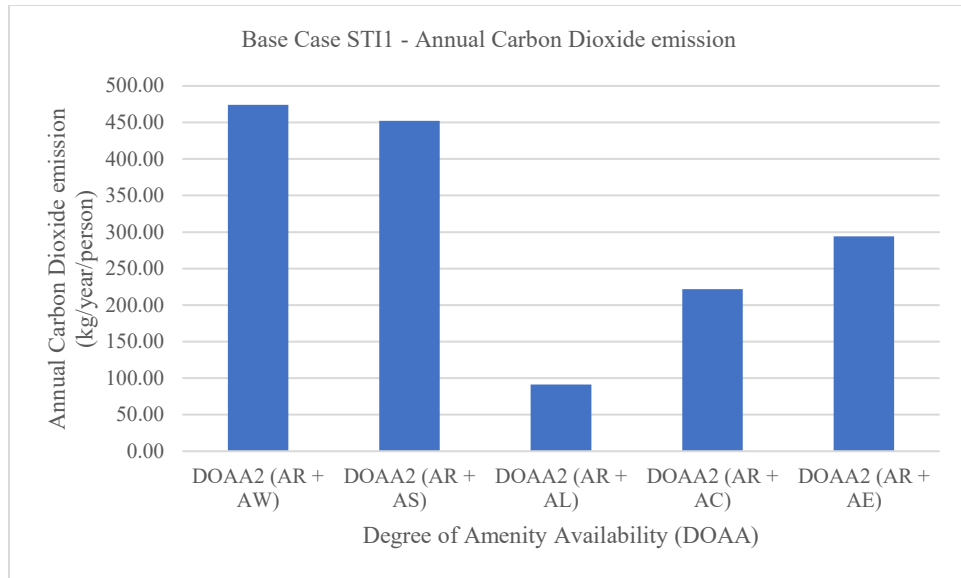
amenities (e.g., residence (AR), work (AW), supply (AS), learning (AL), caring (AC) and leisure/enjoying (AE)) are available and an urban dweller travels to all of these amenities (see table 6 of section 3.3.2).

4.2.1. Sustainable Transportation Indicator (STI) results for base case at Eco-Mobility Strategic Framework-0 (EMSF₀)

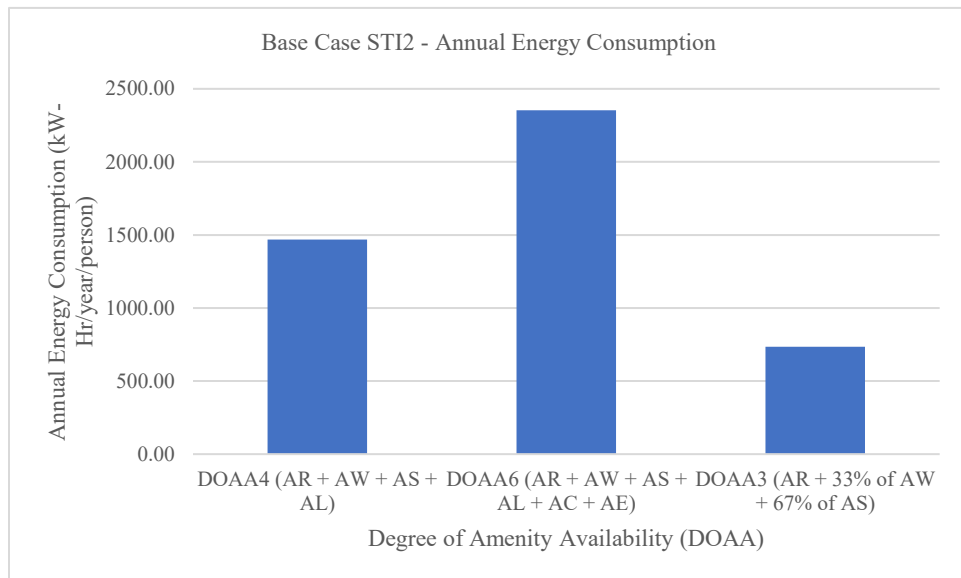
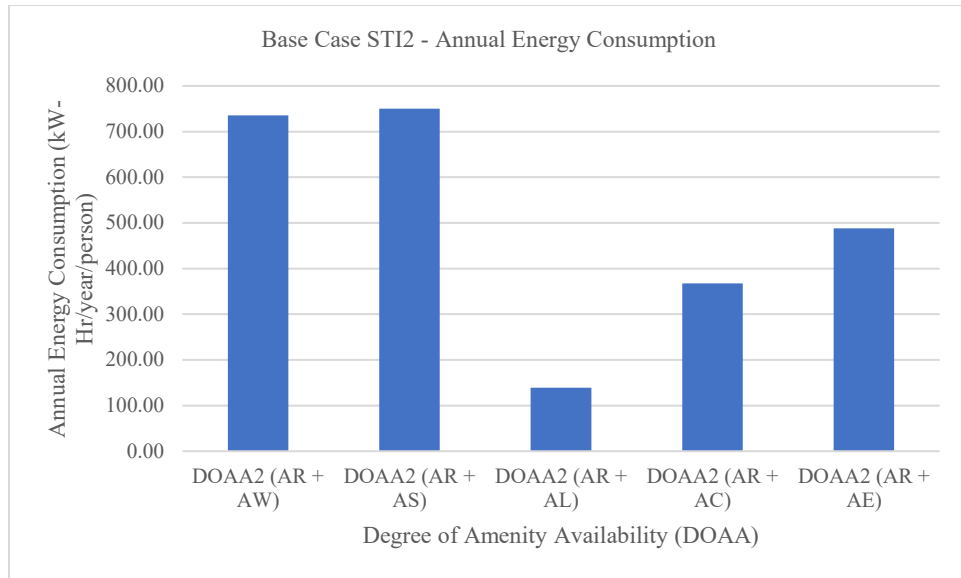
Sustainable Transport Indicators (STI) (i.e., annual CO₂ emission, annual energy consumption, annual travel time and annual net cost) for base case scenario (i.e., Eco-Mobility Strategic Framework (EMSF₀)) where Eco-Mobility Strategies (EMS) have not been implemented, are presented in appendix-1 and delineated in Figure 15 (a to d). Four graphs (i.e., Figure 15.a to d) describes the relationship between four Sustainable Transportation Indicators (STI₁₋₄) vs Degree of Amenity Availability (DOAA₁₋₆) where all the four graphs show similar pattern. Figure 15 (a to d) describes current amenity availability scenario of West-5 where none of the Eco-Mobility Strategies (EMS) have been implemented. Observations from the pattern seen in the figure 21 (a to d) is explained below,

(i) Work amenity (AW) due to its higher trip length (e.g., 9.1 km) and number of trips (e.g., 0.55 trips) in the base case scenario i.e., EMSF₀ results into maximum STI values (e.g., 474 kg CO₂/year/person, 736 kW-Hr/year/person, 110 Hr/year/person and C\$327/year/person). Learning amenity (AL) has least value for all four STIs (e.g., 91 kg CO₂/year/person, 139 kW-Hr/year/person, 22 Hr/year/person and C\$63/year/person) indicating that spatial distribution of AL is denser (e.g., trip length is 4.2 km) thus making it the most available amenity under current conditions. However, STI values for working (AW) & supplying (AS) amenities are roughly 5 times and caring (AC) & leisure/enjoying (AE) amenities are roughly 2.5 to 3 times more than that of AL. This scenario indicates that AW is the least and AL is the most available amenity in base case scenario from which it is concurred that introduction of work and/or supply amenities should be prioritized over caring and/or leisure amenities in West-5.

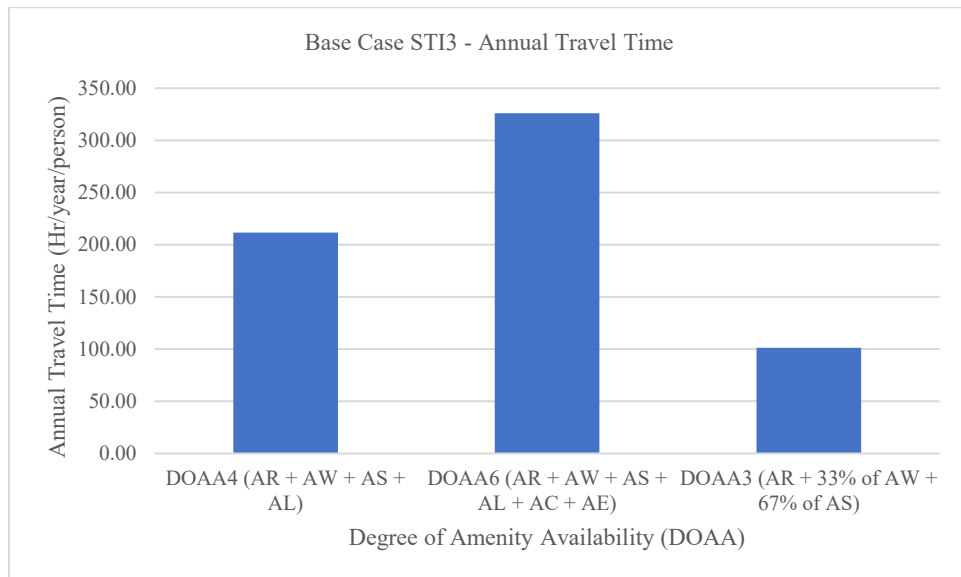
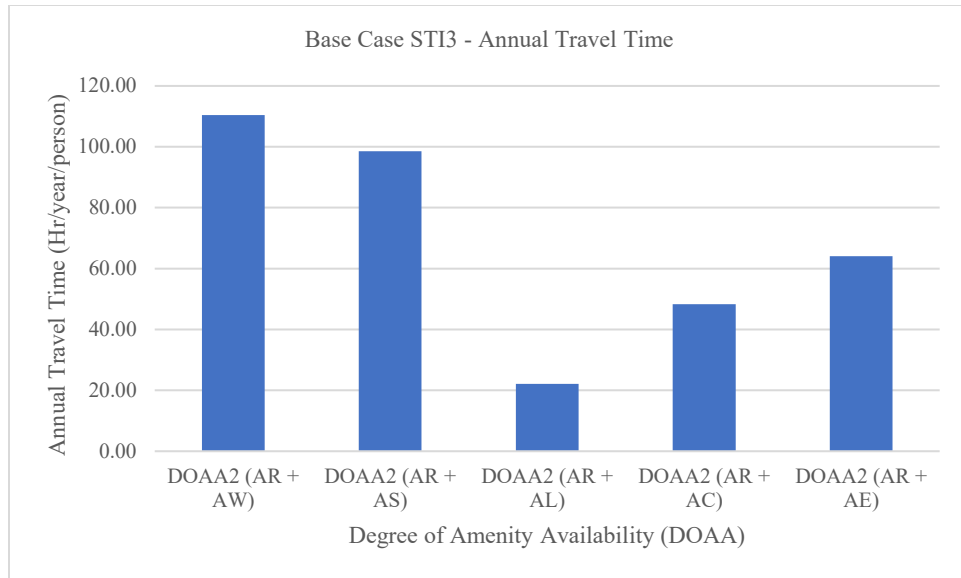
(ii) Degree of Amenity Availability - 4 (DOAA₄) is a combination of four amenities and has STI values of 925 kg CO₂/year/person, 1,468 kW-Hr/year/person, 212 Hr/year/person and C\$637/year/person. Notable here that average trip length has been used to calculate the STI values of combined AW, AS and AL effect instead of algebraic summation. DOAA₄ reflects the scenario found in a typical Canadian family of 4 where parents travel to work and buy groceries while the children travel to school has this impact from transportation perspective. In other words, a family of two parents and two children emit 3,700 kg CO₂/year (=925 X 4), consume 5,872kW-Hr/year energy (=1468 X 4), spend 848Hr/year on road (=212 X 4) and spend \$2,548/year (=637 X 4) on fuel from home to work, supply and learning amenity related trips.



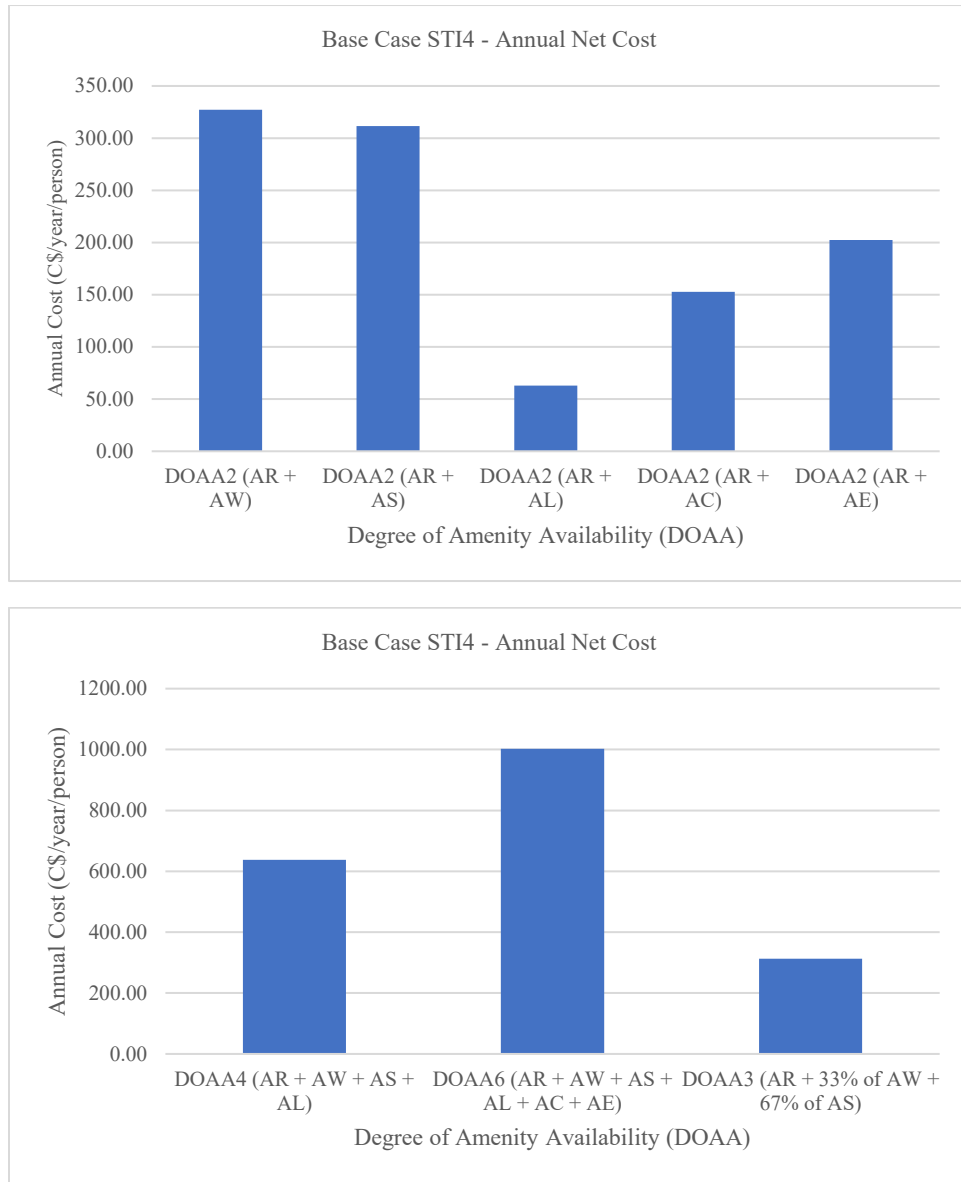
(21.a) Annual Carbon Dioxide emission (STI_1) for different Degree of Amenity Availability ($DOAA_k$) for base case scenario (EMS_{f0})



(21.b) Annual energy consumption (STI_2) for different Degree of Amenity Availability ($DOAA_k$) for base case scenario ($EMS F_0$)



(21.c) Annual travel time (STI_3) for different Degree of Amenity Availability ($DOAA_k$) for base case scenario ($EMSF_0$)



(21.d) Annual cost (STI_4) for different Degree of Amenity Availability ($DOAA_k$) for base case scenario ($EMSF_0$)

Figure 21 Sustainable Transportation Indicators (STI) for different Degree of Amenity Availability ($DOAA_k$) for base case scenario ($EMSF_0$)

(iii) Degree of Amenity Availability - 6 ($DOAA_6$) is a combination of all amenities such as residence (AR), working (AW), supplying (AS), learning (AL), caring (AC) and leisure/enjoying (AE). It has STI values of 1,454 kg CO_2 /year/person, 2,353 kW-Hr/year/person, 326 Hr/year/person and C\$1,002/year/person. Similar to $DOAA_4$, average trip length has been used to calculate the STI values of combined AW, AS, AL, AC and AE effect instead of simple algebraic summation.

(iv) Combination of amenities in DOAA₄ (AR, AW, AS & AL) and DOAA₆ (AR, AW, AS, AL, AC & AE) have higher trip length and number of trips that resulted in even higher value for STI. For example, STI₁ results from combined scenarios i.e., DOAA₄ and DOAA₆ indicates that if a dweller multi-tasks to 3 or 5 amenities every day, which is probably the case for most urban dwellers and families, then 925 kg CO₂/year/person to 1,454 kg CO₂/year/person is emitted. In such scenario a family of 4 is going to emit 3,700 (=925 X 4) to 5,816 (=1454 X 4) kg CO₂/year.

It is inferred from base case scenario that EMSF₀ has higher trip lengths and has higher number of automobile-based trips that resulted in higher value of Sustainable Transportation Indicator (STI).

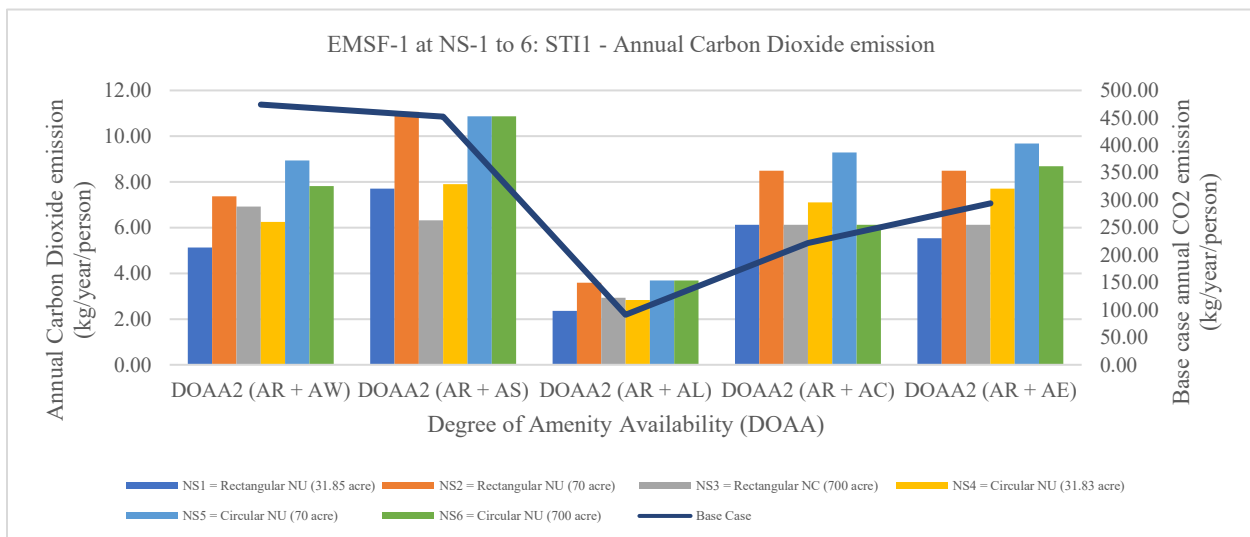
4.2.2. Sustainable Transportation Indicator (STI) results for application of Eco-Mobility Strategic Framework-1 (EMSF₁)

Sustainable Transport Indicators (STI) (i.e., annual CO₂ emission, annual energy consumption, annual travel time and annual net cost) for Eco-Mobility Strategic Framework-1 (EMSF₁) where walking related strategies have been implemented, are described in appendix-1 and delineated in figure 16 (a to d). Four graphs (i.e., Figure 16.a to d) describes the relationship between four Sustainable Transportation Indicators (STI₁₋₄) vs Degree of Amenity Availability (DOAA₁₋₆) for EMSF₁ where all the four graphs show similar pattern. Figure 16 (a to d) describes amenity availability scenario at multi-functional Neighborhood Scenario 1-6 (NS₁₋₆) where walking related Eco-Mobility Strategies (EMS) have been fully implemented and consecutively dwellers are also enjoying these walking related strategies/features. Number of trips for EMSF₃ is collected from table 14 where trips have been distributed as per modal ratio. Observations from the pattern seen in the figure 22 (a to d) is explained below,

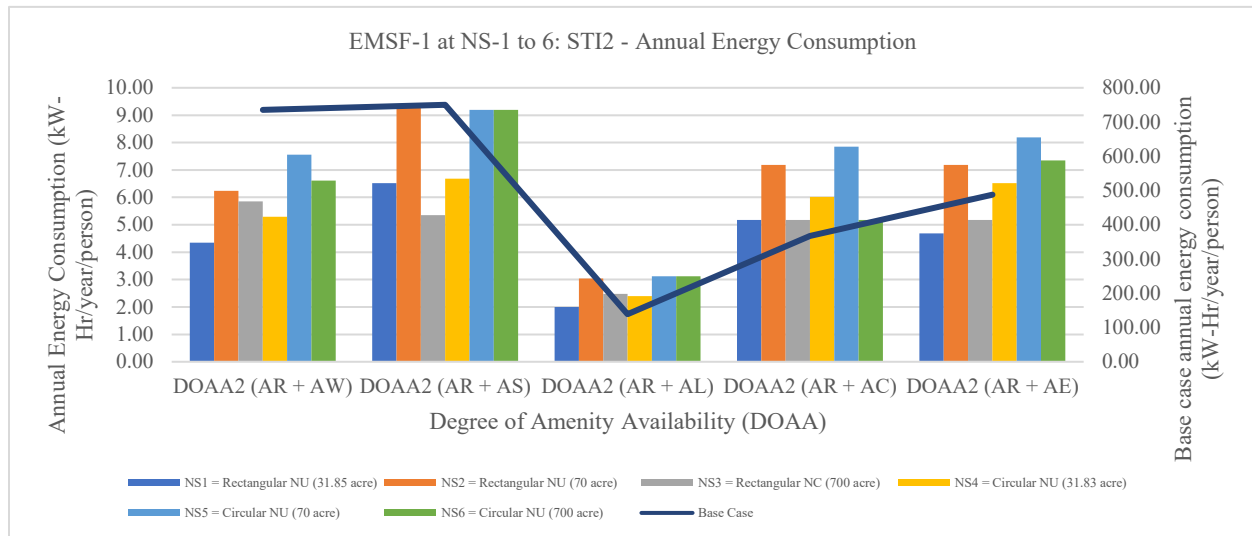
- (i) Bar chart in figure 16 (a to d) shows the STI values for EMSF₁ at different NS and DOAA scenarios. The line diagram in the same figures show the corresponding STI value at EMSF₀, values of which are read on the vertical axis at right hand side graph.
- (ii) Upon implementation of multi-functional neighborhood measures i.e., features and dimensions of 15-minute city where amenities are available at different degree inside the neighborhood, all the Sustainable Transportation Indicator (STI) values for Eco-Mobility Strategic Framework (EMSF) is significantly less than the base case. For example, base case neighborhood West-5 and Neighborhood Scenario-2 (NS₂) both has an area of 0.2833km². In the base case scenario, if a person completes the task of traveling to all the amenities i.e., DOAA₆ then 1,454 kg CO₂/year/person is emitted. However, if all the amenities are available in the multifunctional neighborhood of NS₂, then conducting similar task throughout the year emits 39 kg CO₂/person/year which is a reduction of 97% of annual CO₂ emission per person.
- (iii) Introduction of amenities at different degrees in different neighborhood scenarios alongside implementation of Eco-Mobility Strategic Framework (EMSF₁) have resulted in higher annual CO₂ emission (STI₁), annual energy consumption (STI₂) and annual travel time (STI₃) values for supply amenity than any other amenities (when only two

amenities are considered i.e., residential and any other amenity). It is observed from table 9 that trip length from residence to supply (AS) is higher than work (AW) amenity i.e., 0.39 km and 0.23 km respectively. For example, NS₁ (Area = 0.1289km²) resident-based supply amenity trips yield STI values 8 kg CO₂/year/person, 7 kW-Hr/year/person and 17 Hr/year/person which are higher than any other residence-based amenity trips (when DOAA₂). However, annual net cost for work amenity is 138 which is higher than any other residence-based amenity. Number of trips to different amenities are determined from London Household Travel Survey 2016 and showed in table 12 where it is observed that number of Carbon emitting automobile-based trips from residence to work (AW) is higher than supply (AS) amenity i.e., 0.26 and 0.23 respectively. It is concurred that instead of both trip length and number of trips for non-multi-functional neighborhood, inside a multi-functional neighborhood i.e., 15-minute city where trip lengths to amenities are almost similar, number of trips is the governing reason that effects the Sustainable Transportation Indicator (STI).

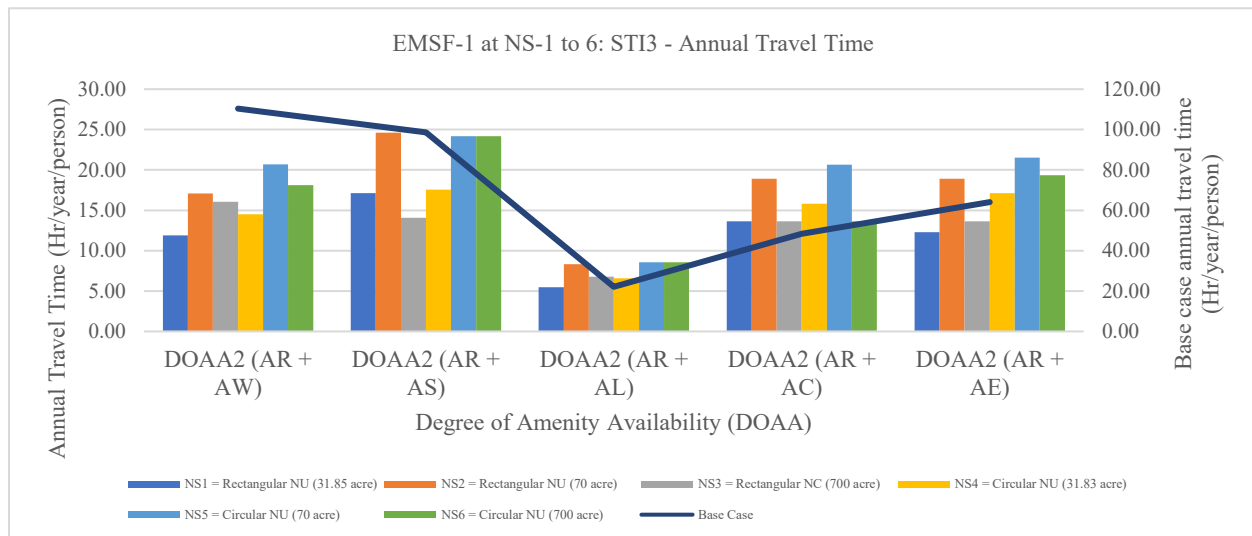
(iv) Degree of Amenity Availability - 4 (DOAA₄) is a combination of three amenities such as working (AW), supplying (AS) and learning (AL). From appendix-1, NS₂ (Area = 0.2833 km²) has STI values of 22 kg CO₂/year/person, 18 kW-Hr/year/person, 49 Hr/year/person and C\$264/year/person. Notable here that average trip length has been used to calculate the STI values of combined AW, AS and AL effect instead of simple algebraic summation. A typical Canadian family where parents travel to work and buy groceries while the children travel to school has significantly less impact from transportation perspective. In other words, a family of two parents and two children emit 88 kg CO₂/year (=22 X 4), consume 72 kW-Hr/year energy, spend 196 Hr/year on road and save C\$1,056 on fuel from home-based work, supply and learning amenity related trips. This is significantly decreased STI values than the same scenario for base case scenario at EMSF₀.



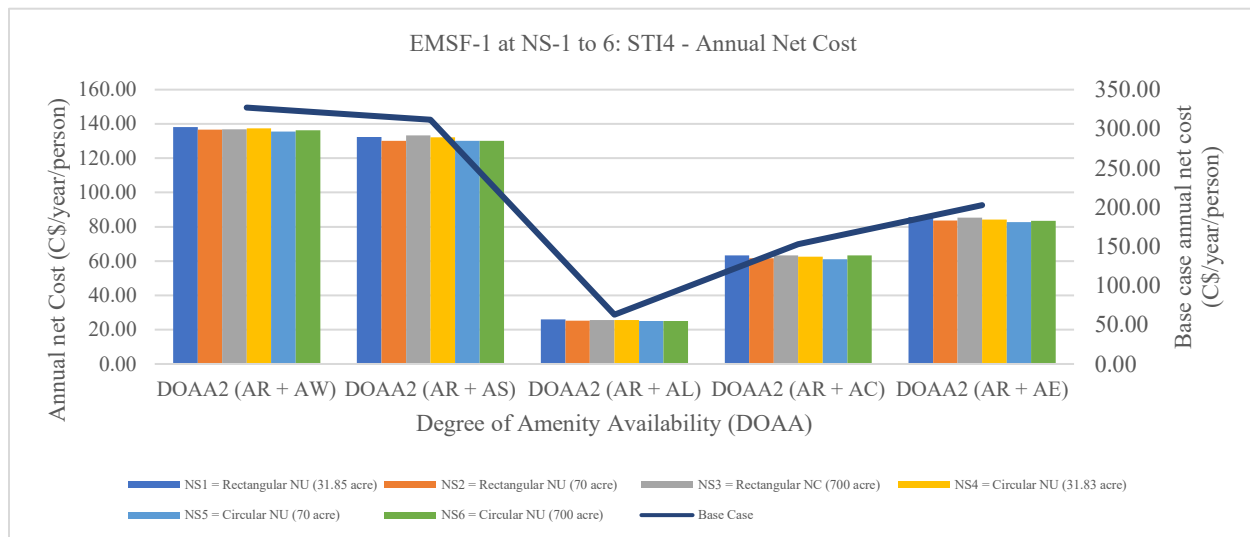
(22.a) Annual Carbon Dioxide emission (STI_1) for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-1 ($EMS F_1$)



(22.b) Annual energy consumption (STI_2) for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-1 ($EMS F_1$)



(22.c) Annual travel time (STI_3) for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-1 ($EMS F_1$)



(22.d) Annual cost (STI₄) for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework-1 (EMSFi)

Figure 22 Sustainable Transportation Indicators (STI) for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework (EMSFi)

(v) Degree of Amenity Availability - 6 (DOAA₆) is a combination of all amenities such as working (AW), supplying (AS), learning (AL), caring (AC) and leisure/enjoying (AE). For example, NS₂ (Area = 0.2833 km²) has STI values have STI values of 39 kg CO₂/year/person, 33 kW-Hr/year/person, 88 Hr/year/person and C\$413/year/person. Similar to DOAA₄, average trip length has been used to calculate the STI values of combined AW, AS, AL, AC and AE effect instead of simple algebraic summation.

(vi) Combination of amenities in DOAA₄ (AR, AW, AS & AL) and DOAA₆ (AR, AW, AS, AL, AC & AE) have higher trip length and number of trips that resulted in even higher value for STI. For example, STI₁ results from combined scenarios i.e., DOAA₄ and DOAA₆ indicates that if a dweller of a 15-minute neighborhood multi-tasks to 3 or 5 amenities every day (which is probably the case for most urban dwellers and families) then 22 kg CO₂/year/person to 39 kg CO₂/year/person is emitted. For such scenario, a family of 4 is going to emit 88 to 156 kg CO₂/year.

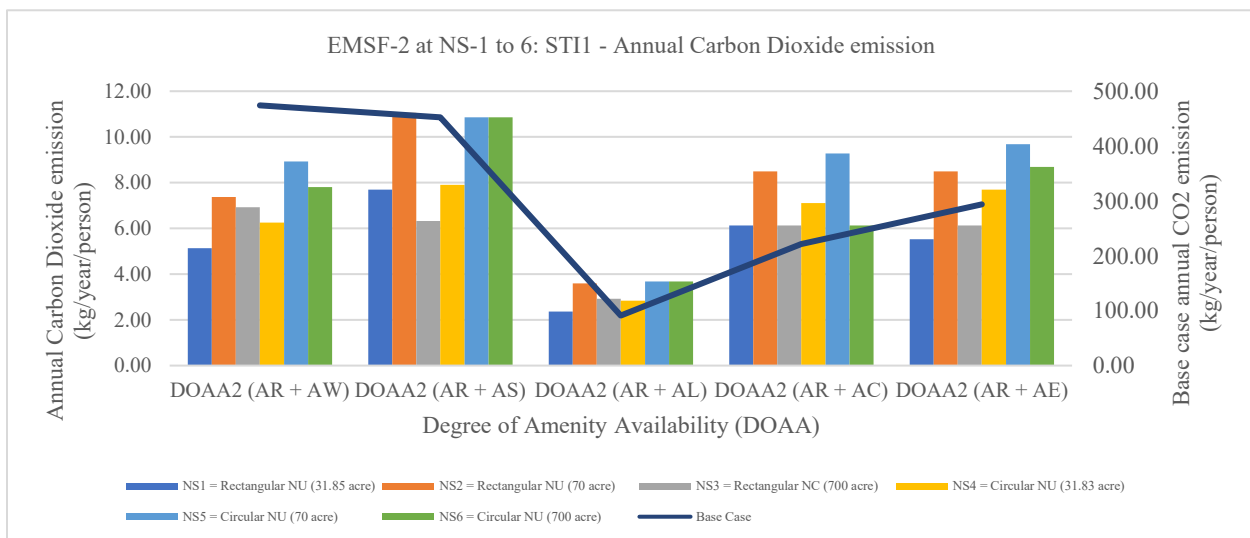
Even upon full implementation of Eco-Mobility Strategic Framework (EMSFi) covering all the walking related strategies in multi-functional neighborhoods, still 48% loyal users keep using automobiles as loyal users (Source: London Household Travel Survey 2016) which results in continuous emission of CO₂ and energy consumption. As 48% dwellers are still prone to using automobiles which obviously has a higher travel speed than walking, annual travel time of 48% dwellers is significantly reduced due to availability of amenity at a very short trip length of less

than 1 km. However, one advantage of 15-minute city is the reduction of trip lengths contributed in significant decrease of annual fuel cost for 48% loyal automobile users.

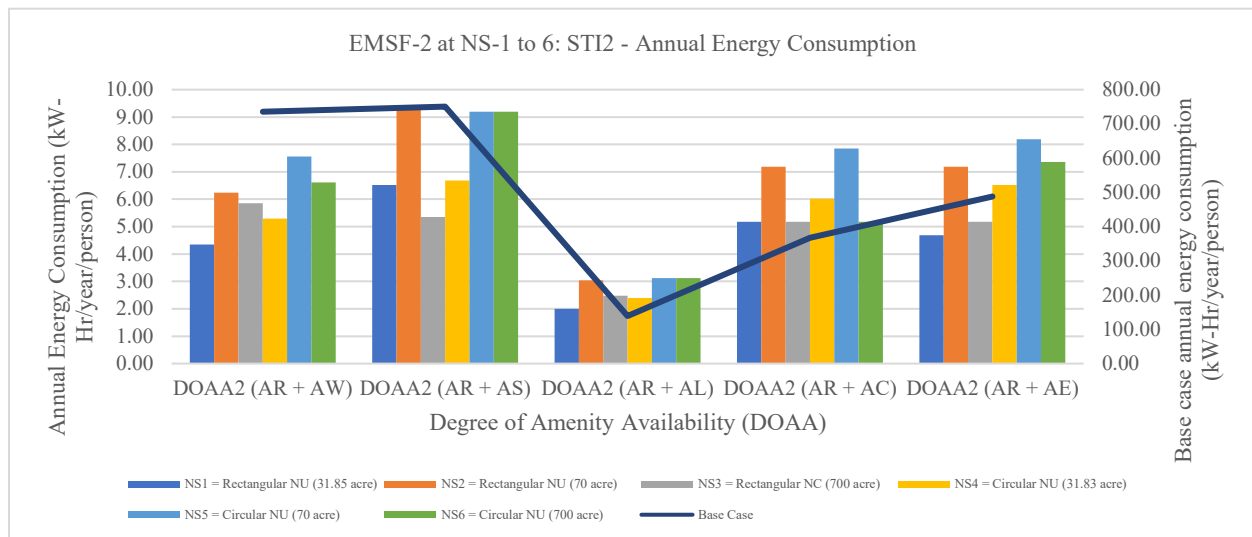
4.2.3. Sustainable Transportation Indicator (STI) results for application of Eco-Mobility Strategic Framework-2 (EMSF₂)

Sustainable Transport Indicators (STI) (i.e., annual CO₂ emission, annual energy consumption, annual travel time and annual net cost) for Eco-Mobility Strategic Framework-2 (EMSF₂) where walking & cycling related strategies have been implemented, are described in appendix-1 and delineated in figure 17 (a to d). Four graphs (i.e., Figure 17.a to d) describes the relationship between four Sustainable Transportation Indicators (STI₁₋₄) vs Degree of Amenity Availability (DOAA₁₋₆) where all the four graphs show similar pattern. Figure 17 (a to d) describes amenity availability scenario at Neighborhood Scenario-1 to 6 (NS₁₋₆) where walking & cycling related Eco-Mobility Strategies (EMS) have been implemented. Number of trips for EMSF₃ is collected from table 14 where trips have been distributed as per modal ratio. Observations from the pattern seen in the figure 23 (a to d) are explained below,

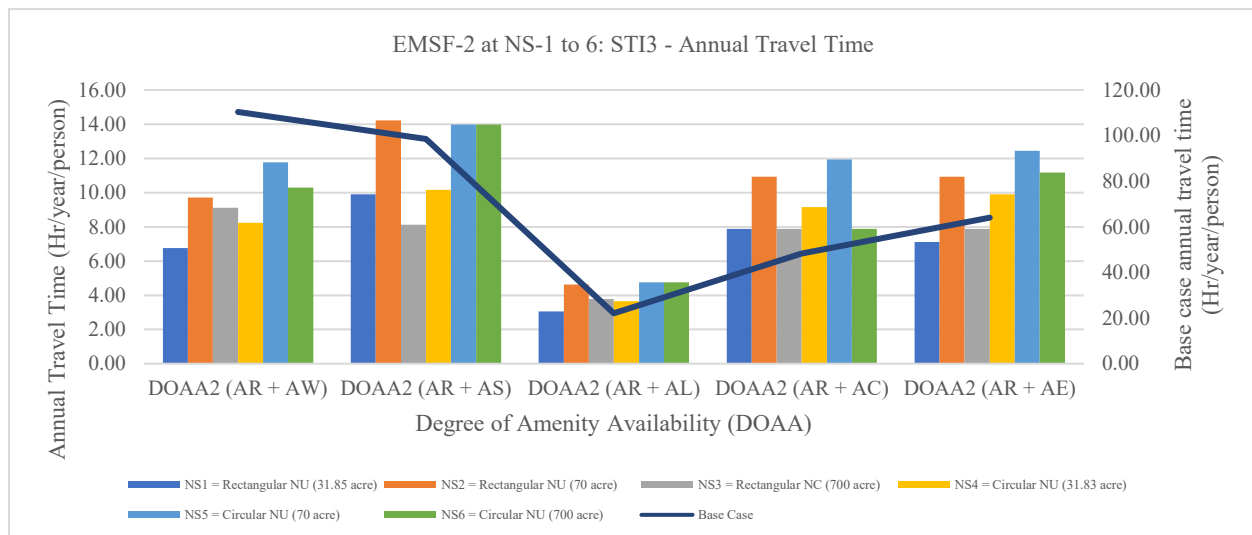
- (i) Bar chart in figure 23 (a to d) shows the STI values for EMSF₂ at different NS and DOAA scenarios. The line diagram in the same figures show the corresponding STI value at EMSF₀, values of which are read on the vertical axis at right hand side graph.
- (ii) Figure 23 (a to c) shows similar patterns where supply amenity (AS) generates more annual CO₂ emission, annual energy consumption annual travel time than any other amenity. However, work amenity has most annual net cost value than other amenities.



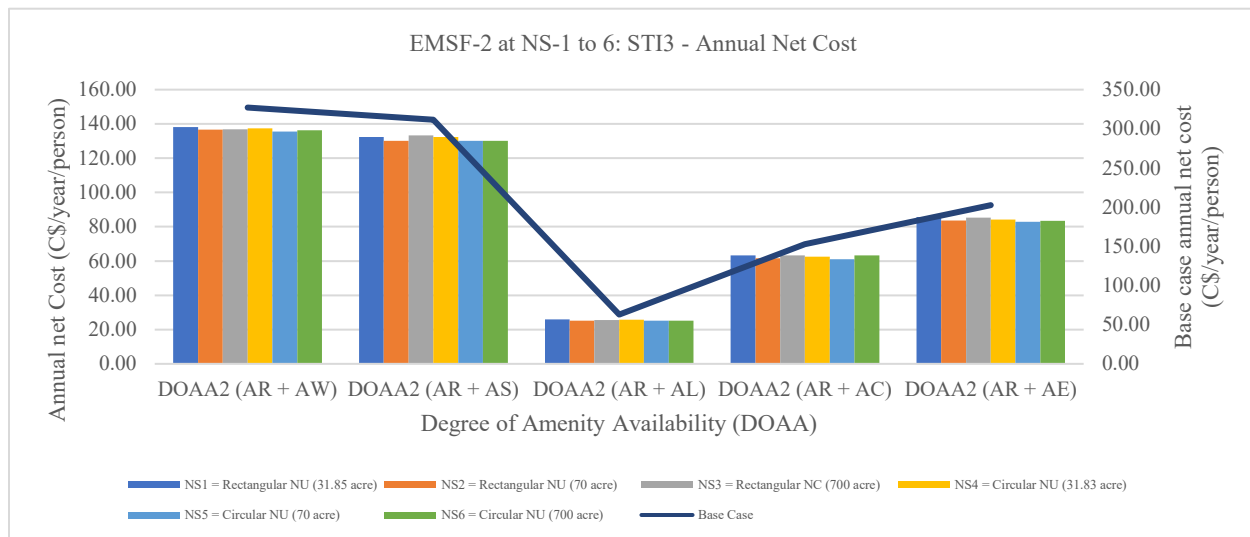
(23.a) Annual Carbon Dioxide emission (STI₁) for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework-2 (EMSF₂)



(23.b) Annual energy consumption (STI_2) for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-2 (EMS_2)



(23.c) Annual travel time (STI_3) for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-2 (EMS_2)



(23.d) Annual cost (STI_4) for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-2 ($EMSF_2$)

Figure 23 Sustainable Transportation Indicators (STI) for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework ($EMSF_2$)

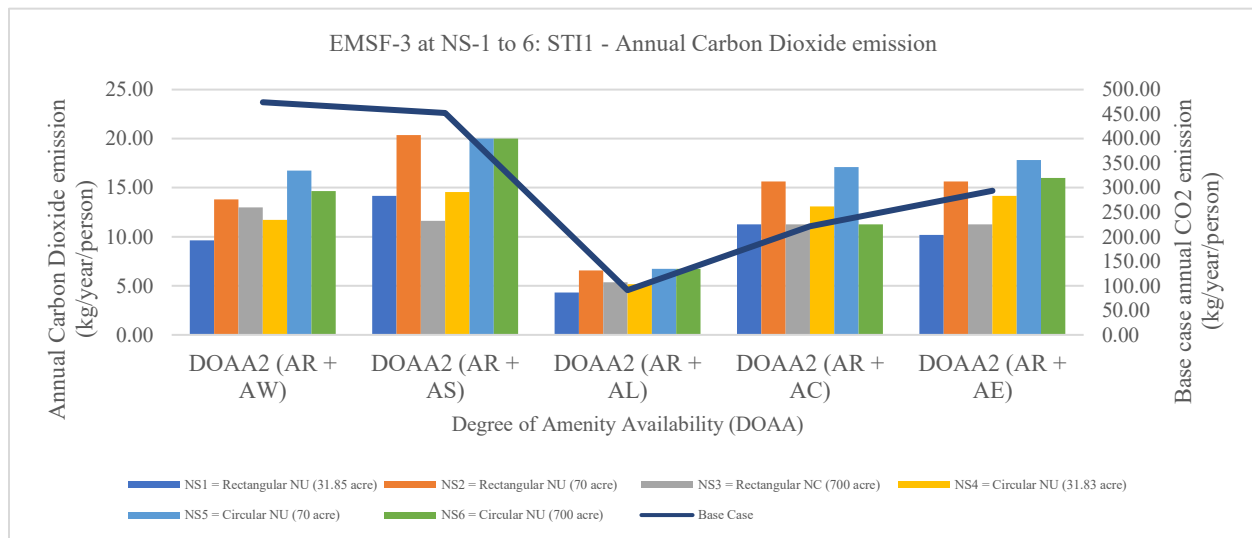
- (iii) A comparison between two neighborhood scenarios having same degree of amenity at $EMSF_1$ and $EMSF_2$ shows that annual CO_2 emission (STI_1), annual energy consumption (STI_2) and annual net cost (STI_4) for both $EMSF_1$ & 2 are same due to the fact that $EMSF_2$ introduces cycling related strategies in addition to walking related strategies of $EMSF_1$, both of which are active mode of transportation that emits zero Carbon. However, annual travel time (STI_3) for $EMSF_2$ is much lesser than that of $EMSF_1$. For example, Neighborhood Scenario-3 (NS_3) (area = $2.833 km^2$) at $EMSF_2$ for Degree of Amenity Availability ($DOAA_2$) for residence-based work tours has an annual travel time (STI_3) of 9.12 hours/year/person. The same STI_3 value for $EMSF_1$ is 16.04 hours/year/person i.e., 43% annual travel time reduces due to switching from $EMSF_1$ to $EMSF_2$. Though the trip length is same in both the scenarios, the change in speed coupled with number of trips for both walking and cycling modes is the key reason behind this reduction in annual travel time.
- (iv) Under the base case scenario conditions (Area of West-5 = $0.28 km^2$) when an individual is traveling to work from their home, annual CO_2 emission (STI_1) is 474.2 kg of CO_2 /year/person and annual energy consumption (STI_2) is 735.73 kW-Hr/year/person. $STI_{1\&2}$ values indicate that if neighborhood dwellers switch to electric vehicles from fossil fuel-based automobiles, CO_2 emission will reduce by roughly 474 kg/year/person but instead 736 kW-Hr/year/person of power is now required to travel to work which translates into $3.64 m^2$ of PV per person for work amenity related trips only if we consider a horizontal PV system consisting $0.6m \times 0.6m$ PVs with 15% efficiency and mean daily solar irradiation of $3.69 kW-Hr/m^2$ [149]. Introduction of multi-functional

neighborhood (Area of NS₂ = 0.28 km²) features and eco-mobility reduces the annual energy consumption (STI₂) for work amenity to 6.24 kW-Hr/year/person which requires only 0.03 m²/person of PV demonstrating a substantial reduction (e.g., 99%) in required area of PV, corresponding resources and cost as well.

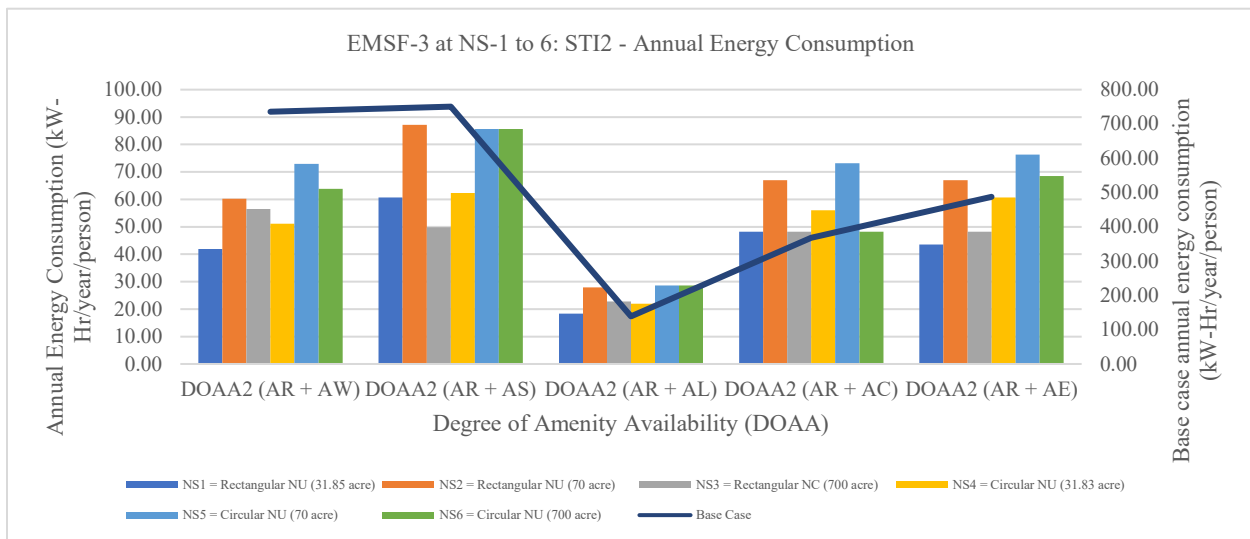
4.2.4. Sustainable Transportation Indicator (STI) results for application of Eco-Mobility Strategic Framework-3 (EMSF₃)

Sustainable Transport Indicators (STI) (i.e., annual CO₂ emission, annual energy consumption, annual travel time and annual net cost) for Eco-Mobility Strategic Framework-3 (EMSF₃) where walking, cycling & public transportation related strategies have been implemented, are described in appendix-1 and delineated in figure 18 (a to d). Four graphs (i.e., Figure 18.a to d) describes the relationship between four Sustainable Transportation Indicators (STI₁₋₄) vs Degree of Amenity Availability (DOAA₁₋₆) where all the four graphs show similar pattern. Figure 18 (a to d) describes amenity availability scenario at Neighborhood Scenario 1-6 (NS₁₋₆) where walking, cycling & public transportation related Eco-Mobility Strategies (EMS) have been implemented. Number of trips for EMSF₃ is collected from table 14 where trips have been distributed as per modal ratio. Observations from the pattern seen in the figure 24 (a to d) is explained below,

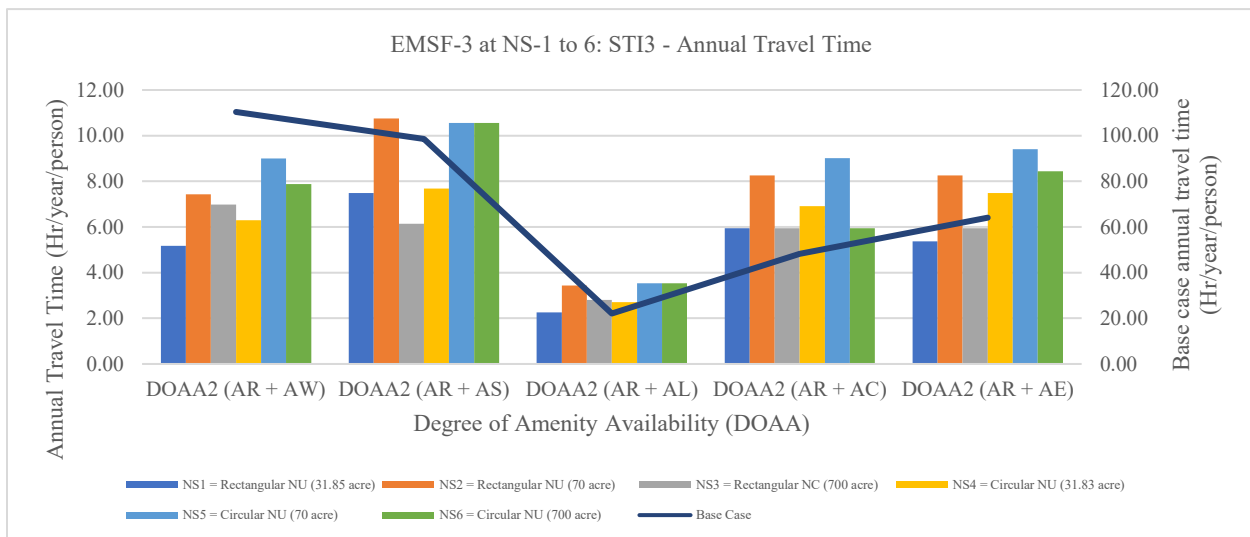
- Bar chart in figure 24 (a to d) shows the STI values for EMSF₁ at different NS and DOAA scenarios. The line diagram in the same figures show the corresponding STI value at EMSF₀, values of which are read on the vertical axis at right hand side graph.
- Figure 24 (a to c) shows similar patterns where supply amenity (AS) generates more annual CO₂ emission, annual energy consumption, annual travel time than any other amenity. However, work amenity has most annual net cost value than other amenities.



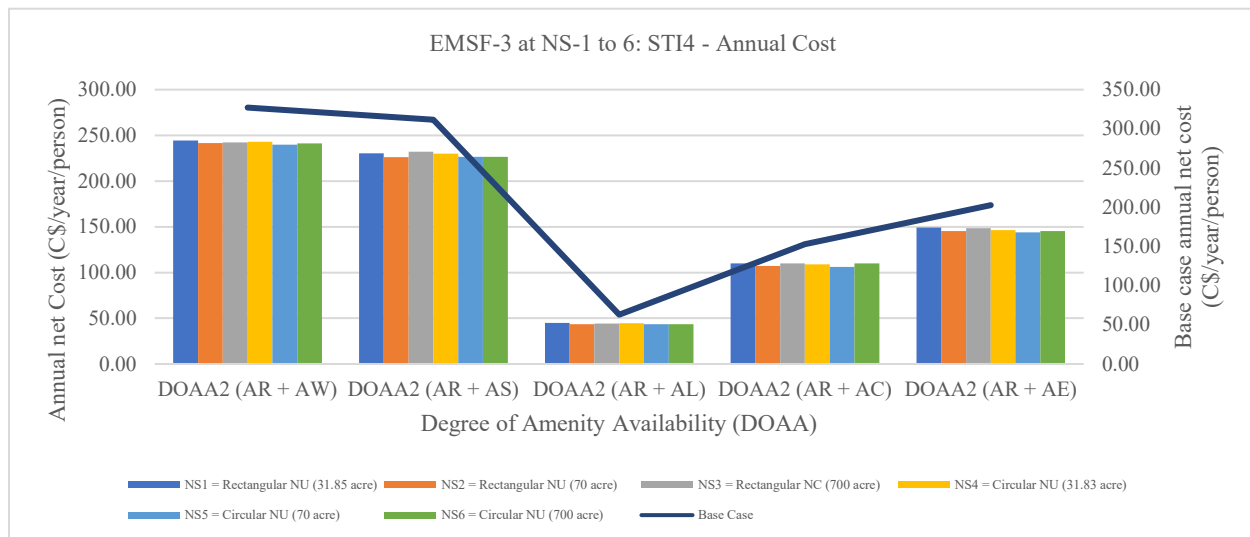
(24.a) Annual Carbon Dioxide emission (STI₁) for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework-3 (EMSF₃)



(24.b) Annual energy consumption (STI₂) for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework-3 (EMS_F₃)



(24.c) Annual travel time (STI₃) for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework-3 (EMS_F₃)



(24.d) Annual cost (STI_4) for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-3 ($EMSF_3$)

Figure 24 Sustainable Transportation Indicators (STI) for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework ($EMSF_3$)

- (iii) A comparison between two same neighborhood scenarios having same degree of amenity at $EMSF_1$, $EMSF_2$ and $EMSF_3$ shows that annual CO_2 emission (STI_1), annual energy consumption (STI_2) and annual net cost (STI_4) for both $EMSF_1$ & 2 are same but higher for $EMSF_3$. For example, Neighborhood Scenario-3 (NS_3) (area = $2.833km^2$) at $EMSF_3$ for Degree of Amenity Availability ($DOAA_2$) for residence to work trips has an annual CO_2 emission (STI_1) and annual energy consumption (STI_2) of 12.98 kg/year/person and 56.55 kW-Hr/year/person respectively. The corresponding STI_1 and STI_2 value is 6.92 kg/year/person and 5.86 kW-Hr/year/person respectively for both $EMSF_1$ (walking only) and $EMSF_2$ (walking and cycling only). This signifies that absence of Carbon emitting or energy consuming eco-mobility strategies in $EMSF_1$ (walking only) and $EMSF_2$ (walking and cycling) resulted in unchanged STI_1 and STI_2 where the only source of Carbon emission and energy consumption are the loyal users of automobiles i.e., 48% dwellers. Upon introduction of public transportation in $EMSF_3$ in increases the CO_2 emission by 88% and energy consumption by 865% with respect to $EMSF_{1\&2}$. This is caused due to the fact that CO_2 emission rate between automobiles vs bus (both fossil fuel-based) is 0.24 kg/km and 0.27 kg/passenger-km respectively i.e., almost similar. However, energy consumption between automobiles vs bus (both electric vehicle) is 0.2 and 2.24 kW-Hr/km respectively i.e., busses consume almost 11 times more energy than electric automobiles. $EMSF_1$ & 2 introduces non-Carbon emitting strategies such as walking and cycling i.e., active mode of transportation while $EMSF_3$ also includes public transportation that causes the increase in STI_1 and STI_2 values.

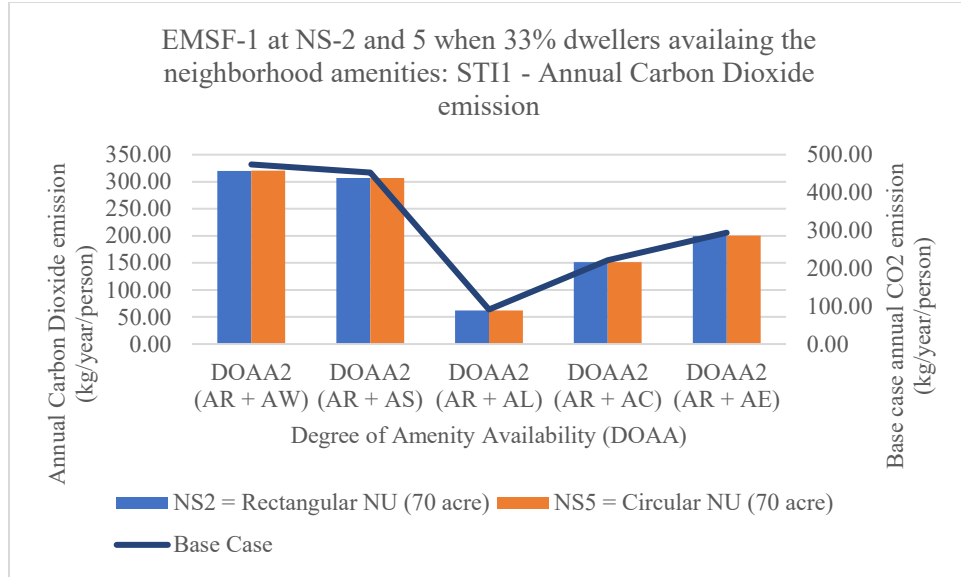
- (iv) However, annual travel time (STI_3) for $EMSF_3$ is much lesser than that of $EMSF_1$ & 2. For example, Neighborhood Scenario-3 (NS_3) (area = 2.833km^2) at $EMSF_3$ for Degree of Amenity Availability ($DOAA_2$) for residence-based work trips has an annual travel time (STI_3) of 6.98 hours/year/person. The same STI_3 value for both $EMSF_1$ and $EMSF_2$ is 16.04 and 9.12 hours/year/person respectively i.e., 56% and 23% annual travel time reduces due to switching from $EMSF_1$ and $EMSF_2$ to $EMSF_3$. Though the trip length is same in all the scenarios in the example mentioned above, the change in speed coupled with number of trips for walking, cycling and public transportation mode is the key reason behind this reduction in annual travel time.
- Upon implementation of Eco-mobility strategic Framework ($EMSF_{1-3}$), the annual travel time at NS_2 is 24.6 ($EMSF_1$), 14.23 ($EMSF_2$) and 10.75 ($EMSF_3$) Hr/year/person – a reduction of about 75 to 89%. It is also observed that the annual travel time decreases with introduction of new Eco-Mobility Strategies (EMS). From $EMSF_1$ i.e., walking only to $EMSF_3$ i.e., walking, cycling and public transportation, the annual travel time reduced by 56.3%.

4.3. Results for partial application of amenity

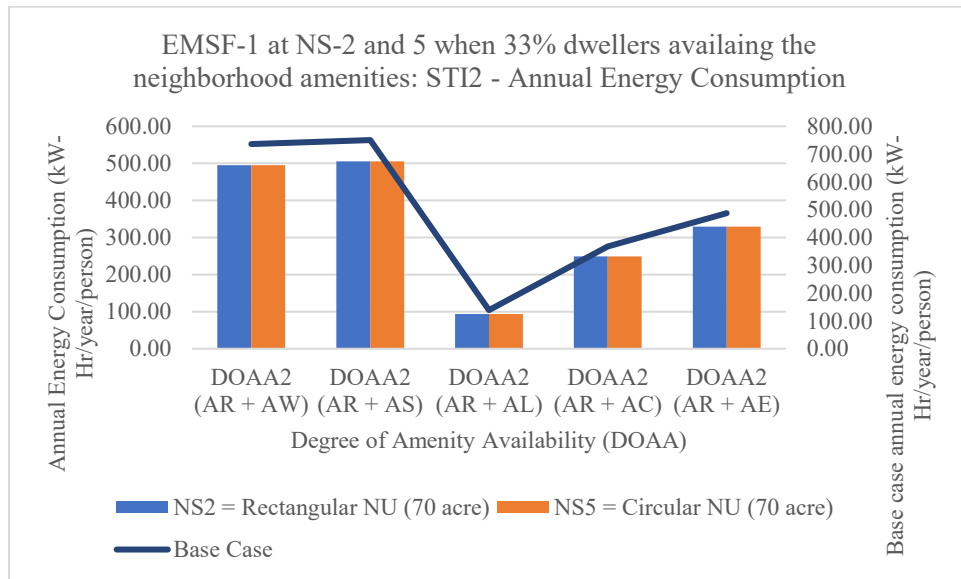
Following section peruses the effect of partial application of amenity inside the neighborhood scenarios. This study considers four scenarios – 0%, 33%, 66% and 100% indicating that dwellers are availing the amenities are the aforementioned ratio. All the $DOAA$ scenarios are examined for two neighborhood scenarios only i.e., NS_2 and NS_5 .

Following figures (figure-25) delineate the effect of 33% and 66% dwellers availing the amenities available inside two neighborhood scenarios. Observations from the pattern seen in the figure 25 (a to l) is explained below,

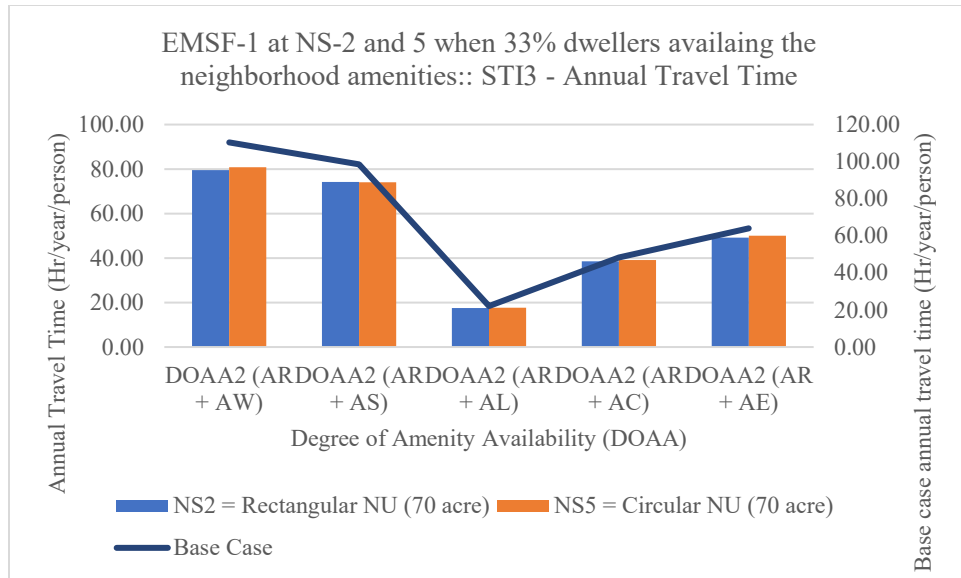
- Bar chart in figure 25 (a to l) shows the STI values for $EMSF_1$ to $EMSF_3$ at different NS and $DOAA$ scenarios. The line diagram in the same figures show the corresponding STI value at $EMSF_0$, values of which are read on the vertical axis at right hand side graph.
- Figure 25 (a to l) shows similar patterns where work amenity (AW) generates more annual CO_2 emission, annual travel time and annual net cost than any other amenity. However, supply amenity has most annual energy consumption value than other amenities.



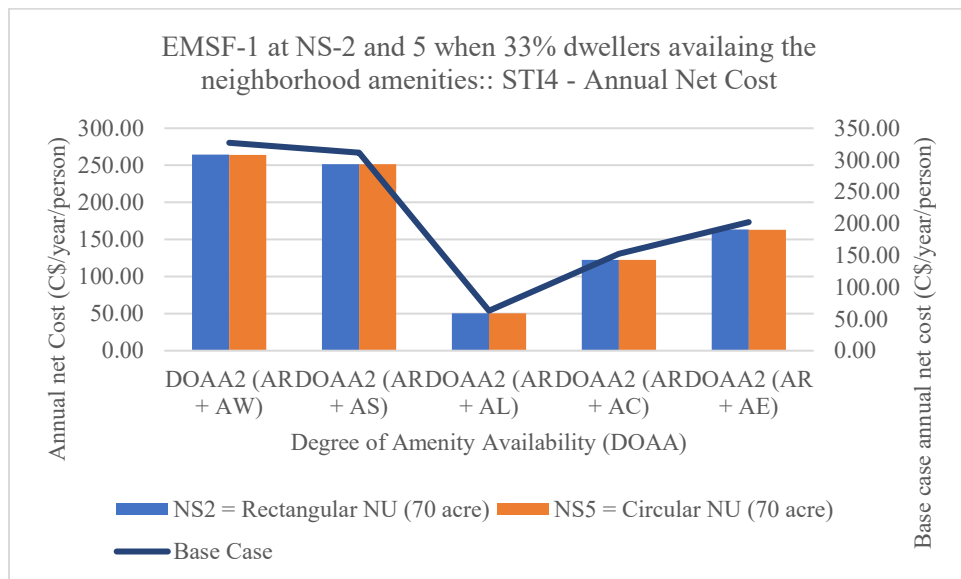
(25.a) Annual Carbon Dioxide emission (STI₁) at dweller utilization ratio of 33% for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework-1 (EMS_F₁)



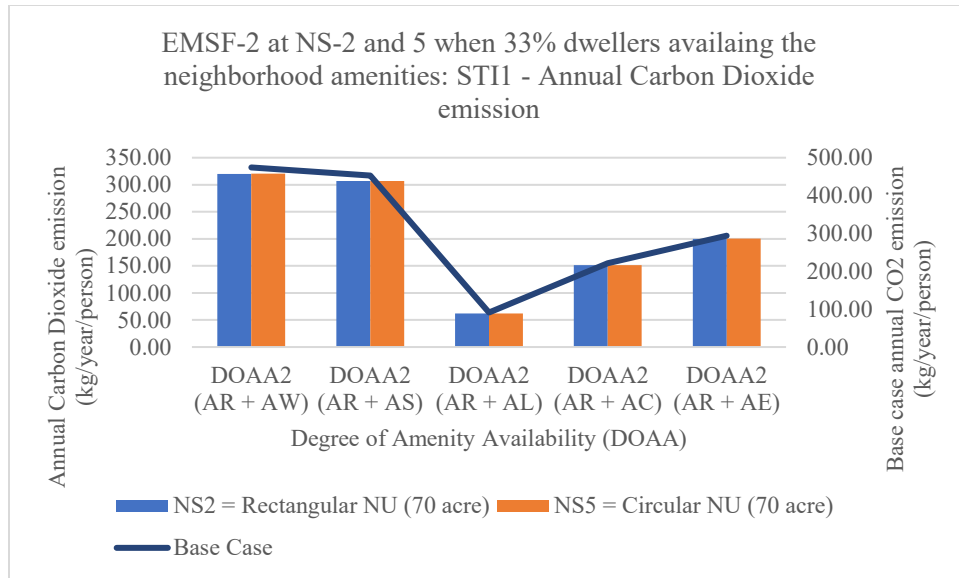
(25.b) Annual energy consumption (STI₂) at dweller utilization ratio of 33% for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework-1 (EMS_F₁)



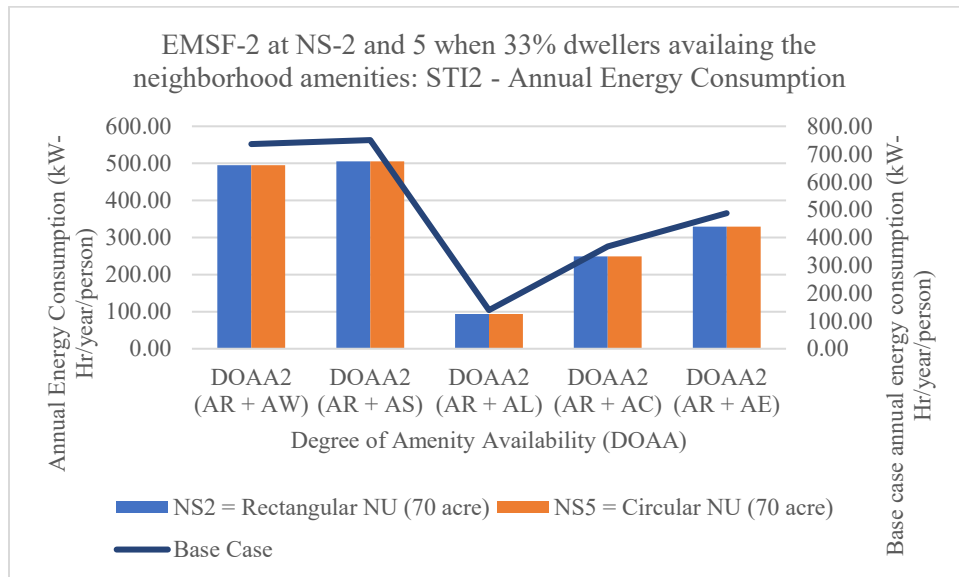
(25.c) Annual travel time (STI₃) at dweller utilization ratio of 33% for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework-1 (EMS_F₁)



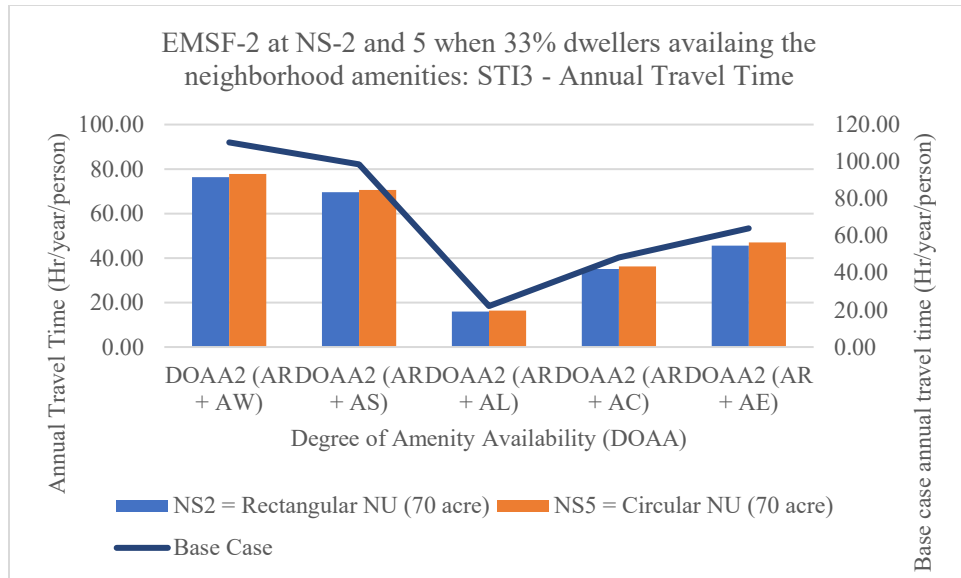
(25.d) Annual net cost (STI₄) at dweller utilization ratio of 33% for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework-1 (EMS_F₁)



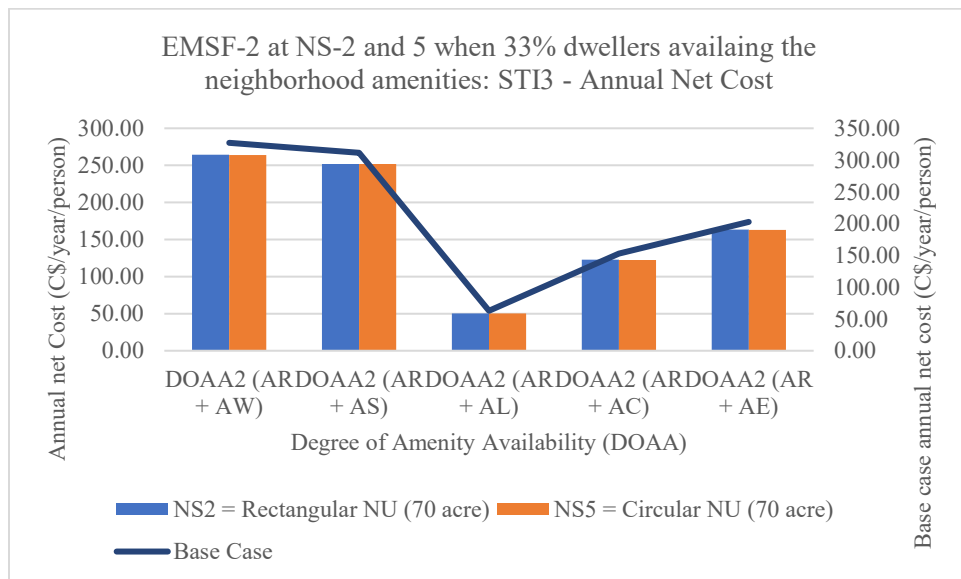
(25.e) Annual Carbon Dioxide emission (STI_1) at dweller utilization ratio of 33% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-2 (EMSF₂)



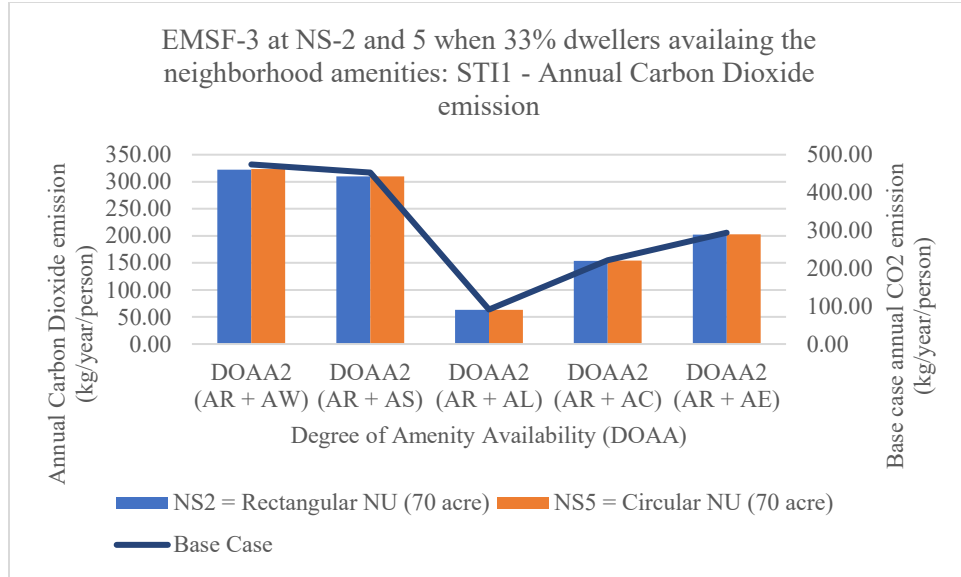
(25.f) Annual energy consumption (STI_2) at dweller utilization ratio of 33% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-2 (EMSF₂)



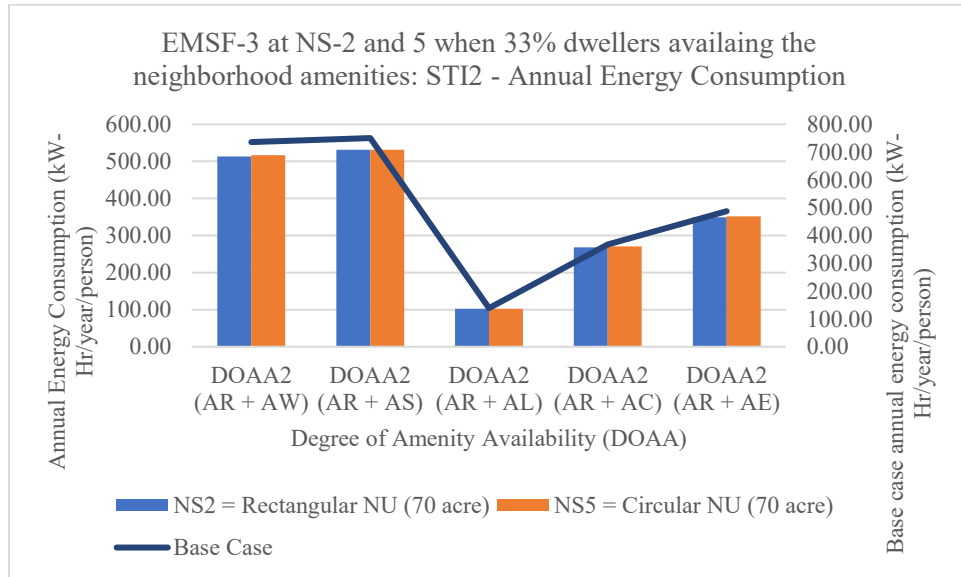
(25.g) Annual travel time (STI_3) at dweller utilization ratio of 33% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-2 ($EMS F_2$)



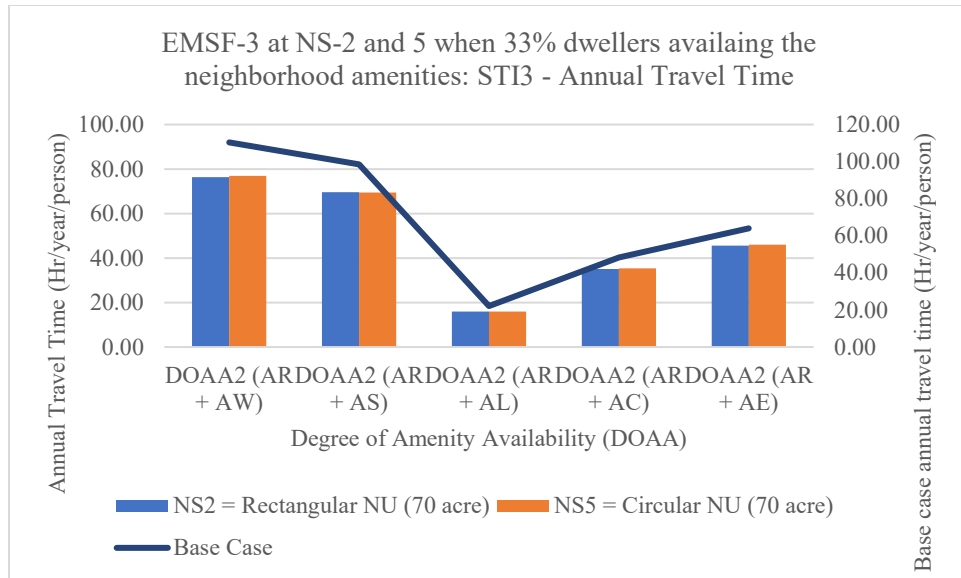
(25.h) Annual net cost (STI_4) at dweller utilization ratio of 33% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-2 ($EMSF_2$)



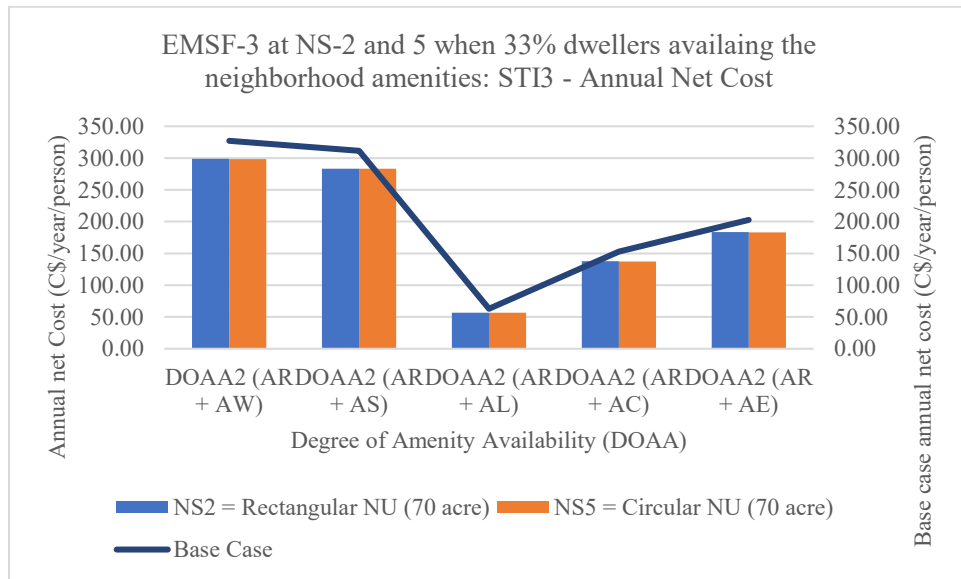
(25.i) Annual Carbon Dioxide emission (STI₁) at dweller utilization ratio of 33% for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework-3 (EMS_F₃)



(25.j) Annual energy consumption (STI₂) at dweller utilization ratio of 33% for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework-3 (EMS_F₃)



(25.k) Annual travel time (STI_3) at dweller utilization ratio of 33% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-3 ($EMSF_3$)



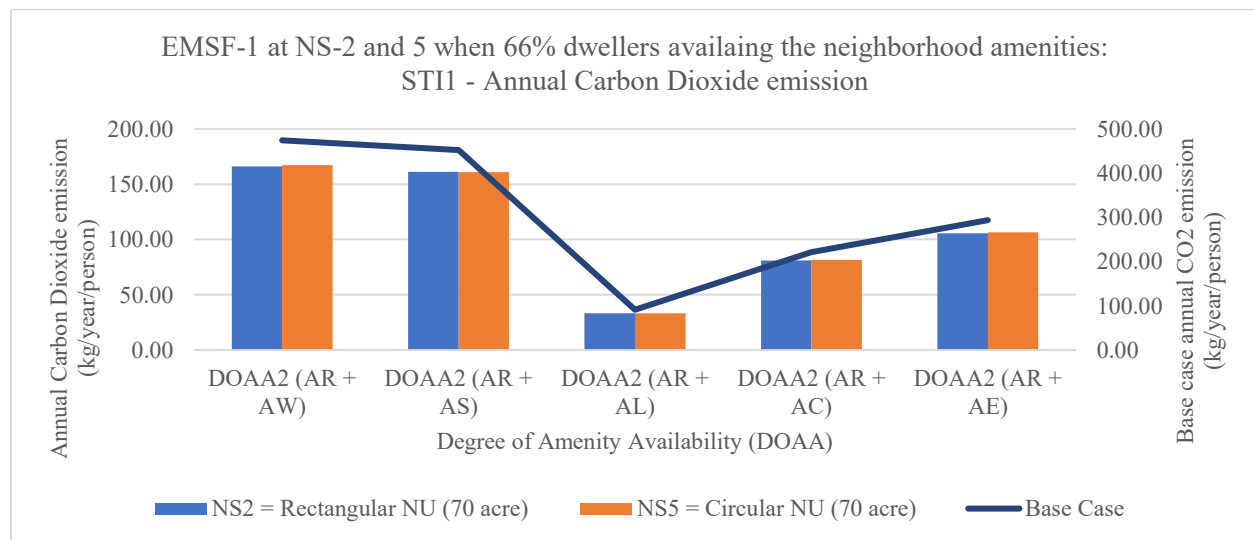
(25.1) Annual net cost (STI_4) at dweller utilization ratio of 33% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-3 ($EMSF_3$)

Figure 25 Sustainable Transportation Indicators (STI) for different Degree of Amenity Availability (DOAAk) at 33% of amenity utilization ratio by dwellers for Eco-Mobility Strategic Framework 1 to 3

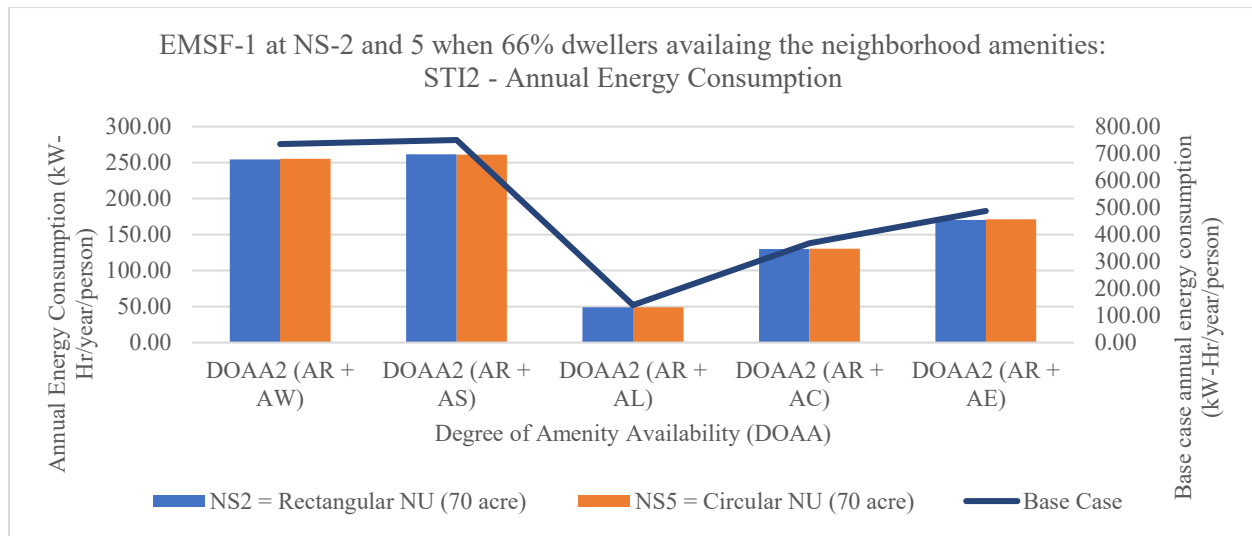
- (iii) When 33% dwellers are availing the amenities situated inside the neighborhood while the remaining dwellers keep using the amenities located outside the neighborhood, the average framework performance coefficient is found to be 0.74. This indicates that 33% utilization results in 24% reduction in environmental, social and economic impact on the neighborhood. It signifies that 1 unit increase in dwellers who avail the amenity results in 0.72 unit reduction of combined environmental, social and economic effect on the neighborhood.
- (iv) Both NS-2 and NS-5 neighborhoods has an area of 70 acres with different road patterns – rectangular and radial. STI values for both neighborhood types are almost identical indicating that road pattern has insignificant effect.

Following figures (figure-26) delineate the effect of 66% dwellers availing the amenities available inside two neighborhood scenarios. Observations from the pattern seen in the figure 26 (a to l) is explained below,

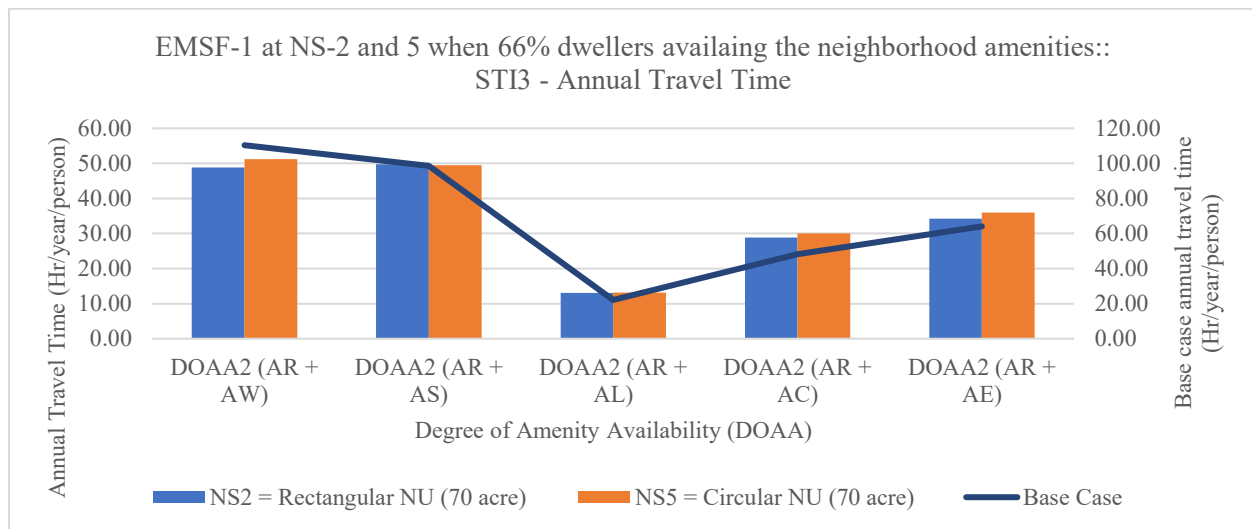
- (i) Bar chart in figure 26 (a to l) shows the STI values for EMSF₁ to EMSF₃ at different NS and DOAA scenarios. The line diagram in the same figures show the corresponding STI value at EMSF₀, values of which are read on the vertical axis at right hand side graph.
- (ii) Figure 26 (a to l) shows similar patterns where work amenity (AW) generates more annual CO₂ emission, annual travel time and annual net cost than any other amenity. However, supply amenity has most annual energy consumption value than other amenities.



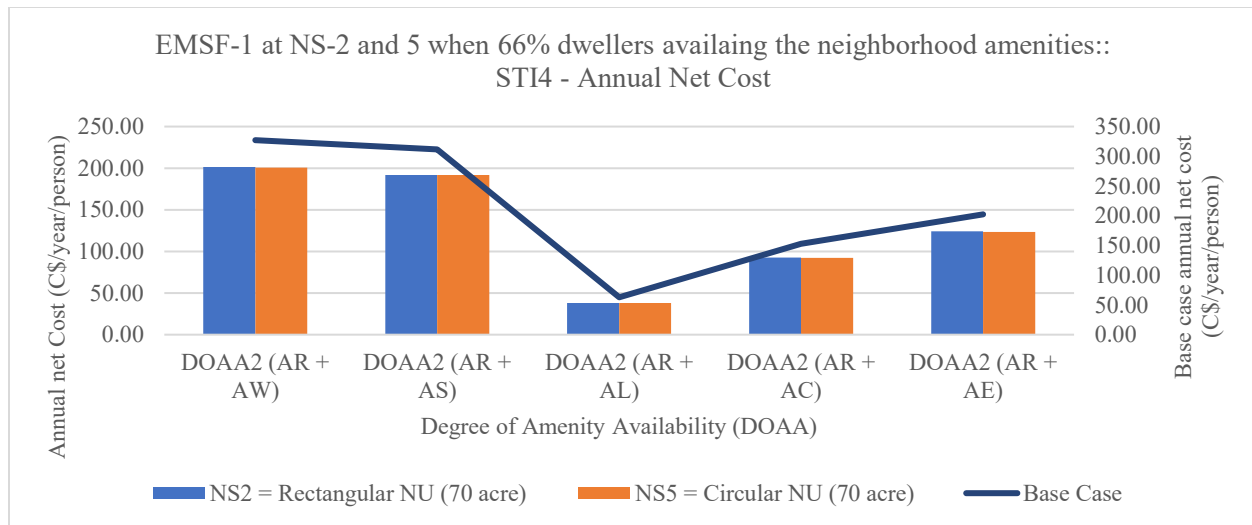
(26.a) Annual Carbon Dioxide emission (STI₁) at dweller utilization ratio of 66% for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework-1 (EMSF₁)



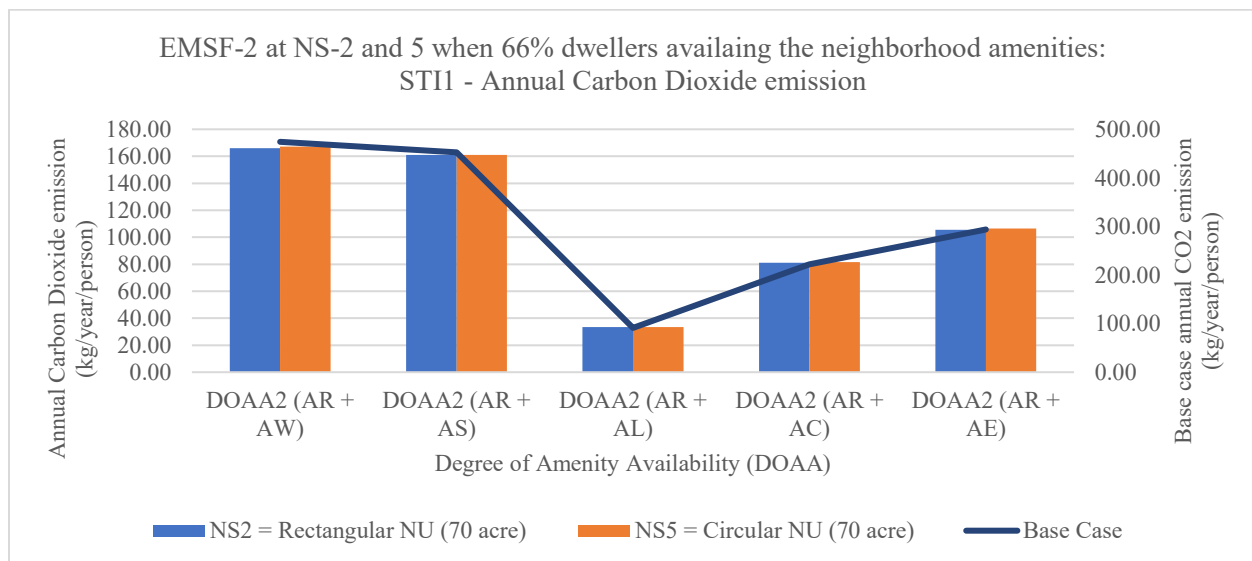
(26.b) Annual energy consumption (STI_2) at dweller utilization ratio of 66% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-1 (EMS_{F1})



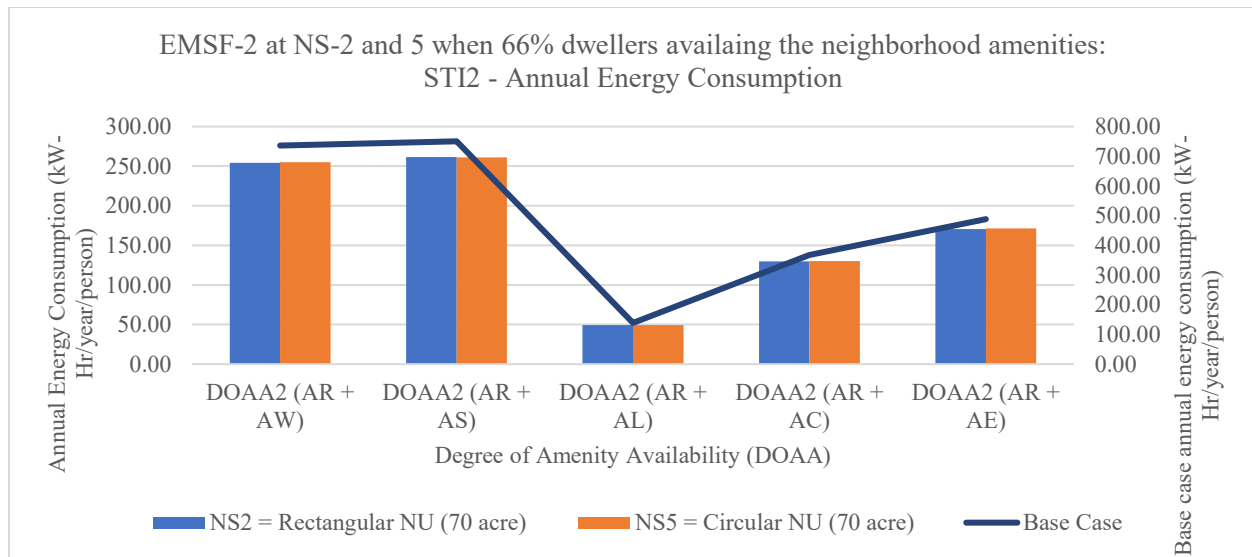
(26.c) Annual travel time (STI_3) at dweller utilization ratio of 66% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-1 (EMS_{F1})



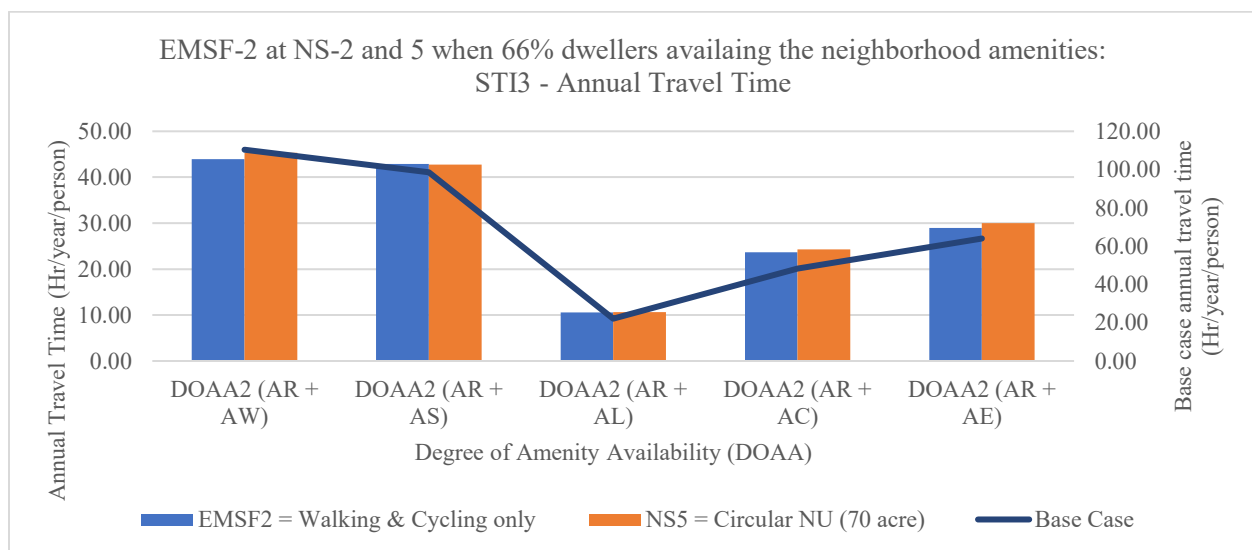
(26.d) Annual net cost (STI_4) at dweller utilization ratio of 66% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-3 ($EMSF_3$)



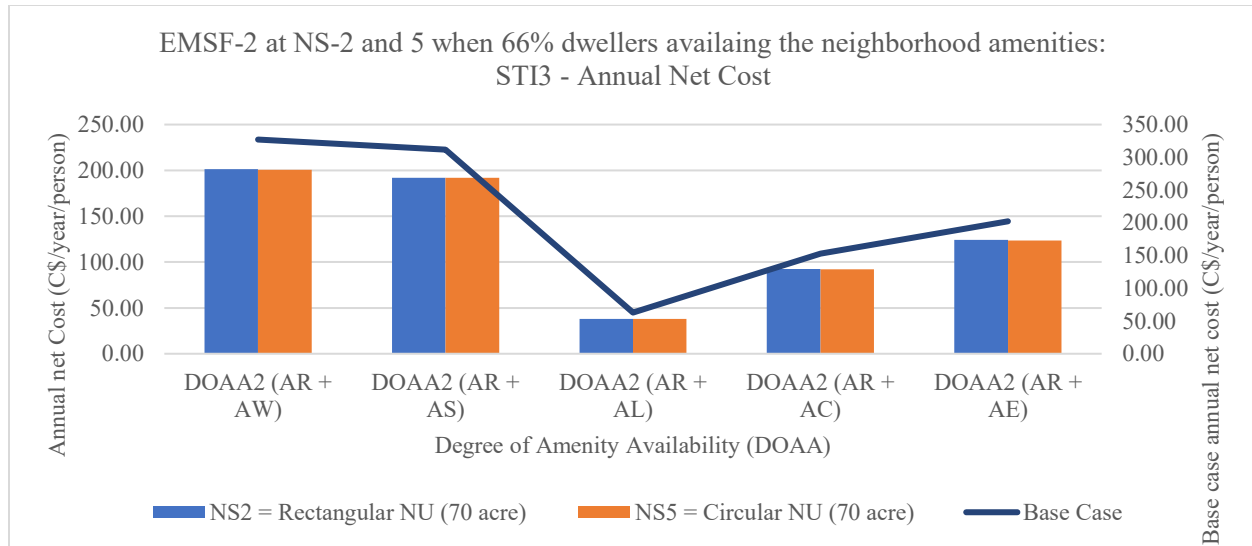
(26.e) Annual Carbon Dioxide emission (STI_1) at dweller utilization ratio of 66% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-2 ($EMSF_2$)



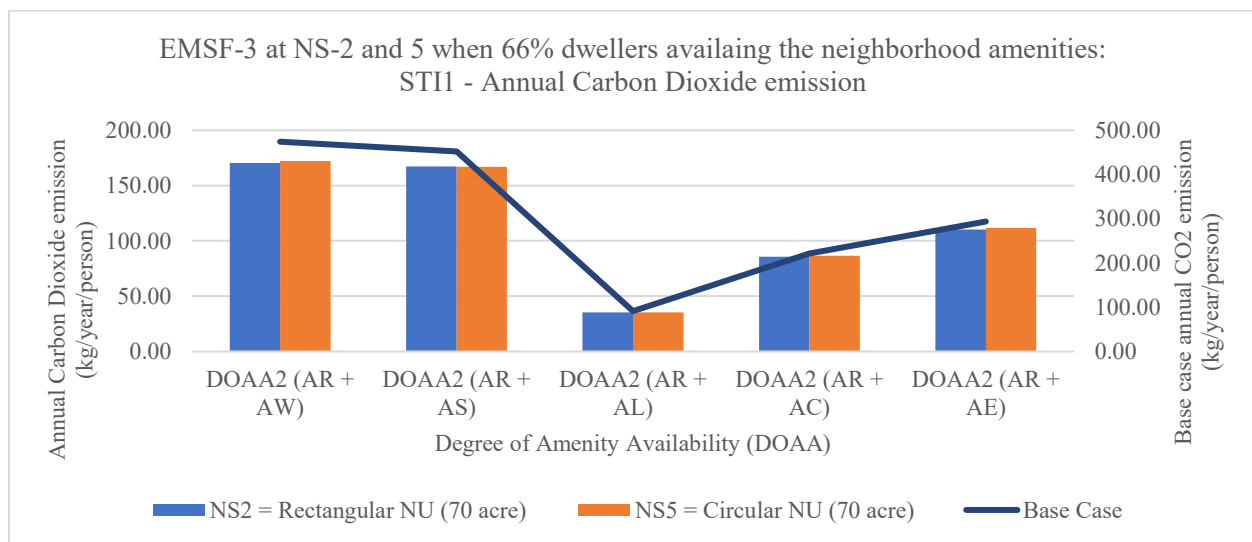
(26.f) Annual energy consumption (STI_1) at dweller utilization ratio of 66% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-2 ($EMSF_2$)



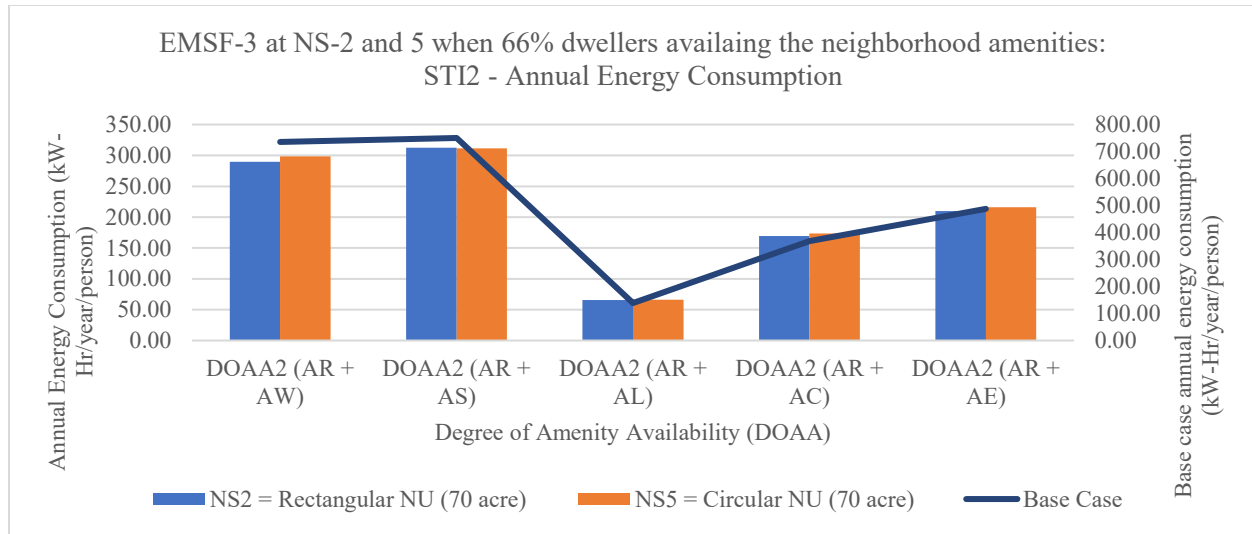
(26.g) Annual travel time (STI_3) at dweller utilization ratio of 66% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-2 ($EMSF_2$)



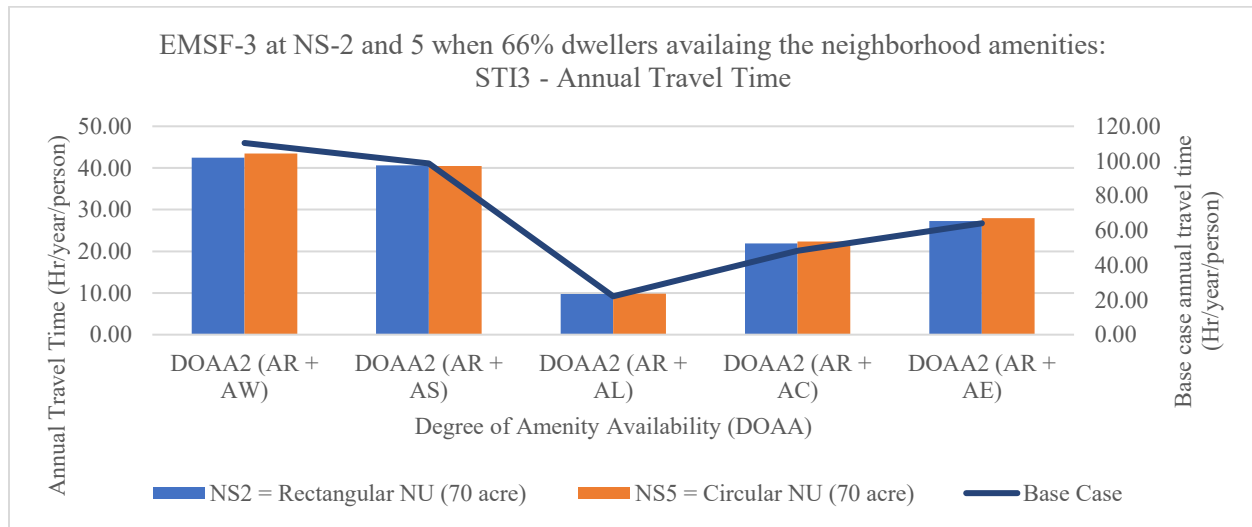
(26.h) Annual net cost (STI_4) at dweller utilization ratio of 66% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-2 ($EMSF_2$)



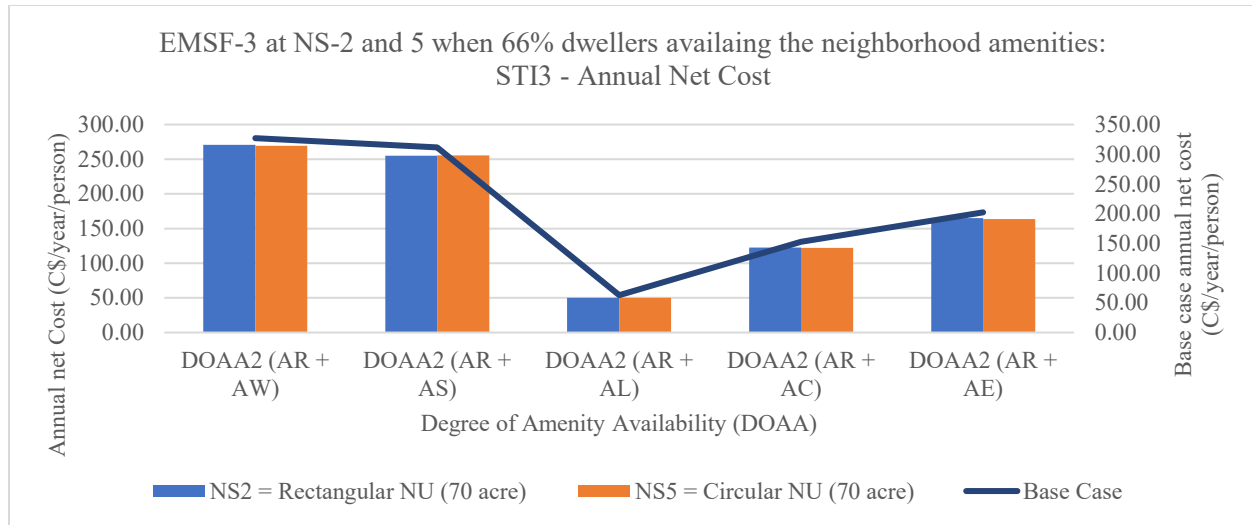
(26.i) Annual Carbon Dioxide emission (STI_1) at dweller utilization ratio of 66% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-3 ($EMSF_3$)



(26.j) Annual energy consumption (STI_2) at dweller utilization ratio of 66% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-3 (EMS3)



(26.k) Annual travel time (STI_3) at dweller utilization ratio of 66% for different Degree of Amenity Availability ($DOAA_k$) for Eco-Mobility Strategic Framework-3 (EMS3)



(26.1) Annual net cost (STI₄) at dweller utilization ratio of 66% for different Degree of Amenity Availability (DOAA_k) for Eco-Mobility Strategic Framework-3 (EMS₃)

Figure 26 Sustainable Transportation Indicators (STI) for different Degree of Amenity Availability (DOAA_k) at 66% of amenity utilization ratio by dwellers for Eco-Mobility Strategic Framework 1 to 3

- (iii) When 66% dwellers are availing the amenities situated inside the neighborhood while the remaining dwellers keep using the amenities located outside the neighborhood, the average framework performance coefficient is found to be 0.47. This indicates that 66% utilization results in 53% reduction in environmental, social and economic impact on the neighborhood. It signifies that 1 unit increase in dwellers who avail the amenity results in 0.80 unit reduction of combined environmental, social and economic effect on the neighborhood.
- (iv) Both NS-2 and NS-5 neighborhoods has an area of 70 acres with different road patterns – rectangular and radial. STI values for both neighborhood types are almost identical indicating that road pattern has insignificant effect.

4.4. Results for Decision Making Metric (DMM)

Decision Making Metric (DMM) comprises of two parts - a Framework Performance Coefficient (FPC) that measures the effectiveness of Eco-Mobility Strategic Framework (EMS₃) in a certain Neighborhood Scenario (NS) and a Decision-Making Metric Value (DMMV) that sums of all the FPC values for a certain NS and comes up with one single answer showing combined effect of environmental, social and economic impact of Eco-Mobility Strategic Framework (EMS₃).

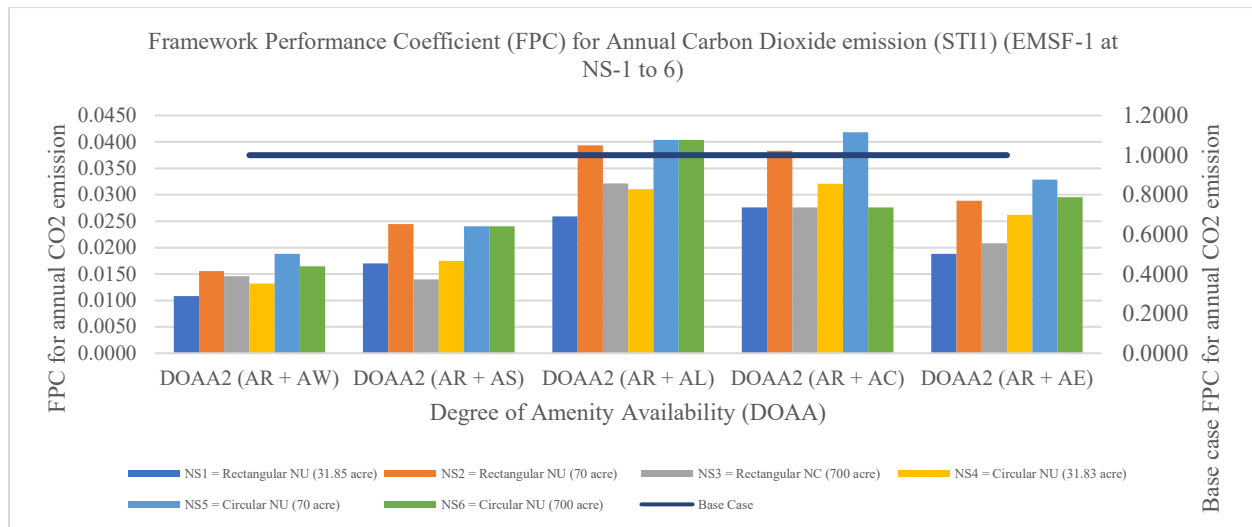
Framework Performance Coefficient (FPC) and Decision-Making Metric Value (DMMV) for each EMS₃ and each NS are determined from equation 6 and 7. Sustainable Transportation Indicator (STI) values for different Eco-Mobility Strategic Framework (EMS₃) in different Neighborhood Scenario (NS) containing different Degree of Amenity Availability (DOAA) have been determined from equation 1 to 4 and have been delineated in figure 15 to 18 & explained in

section 3.2. FPC values for each framework is determined by comparing STI values of EMS_{1to3} to that of base case scenario i.e., EMS_0 . Once the FPC values are known, then $Weight_{Factor} = 0.25$ is used to calculate the DMMV value for each framework and neighborhood. Same weight factor for all STIs (e.g., environmental, social and economic indicators) imply this study considers these indicators equally important. FPC values for EMS_1 (walking only strategy), EMS_2 (walking & cycling only) and EMS_3 (walking, cycling and public transportation) at 6 Neighborhood Scenario (NS) and at 7 different Degree of Amenity Availability (DOAA) are delineated in figure 27 (a to l). FPC values and DMMV are presented in appendix 2 and 3 respectively. Following part of the study describes the findings from the graphs in figure 27 (a to l),

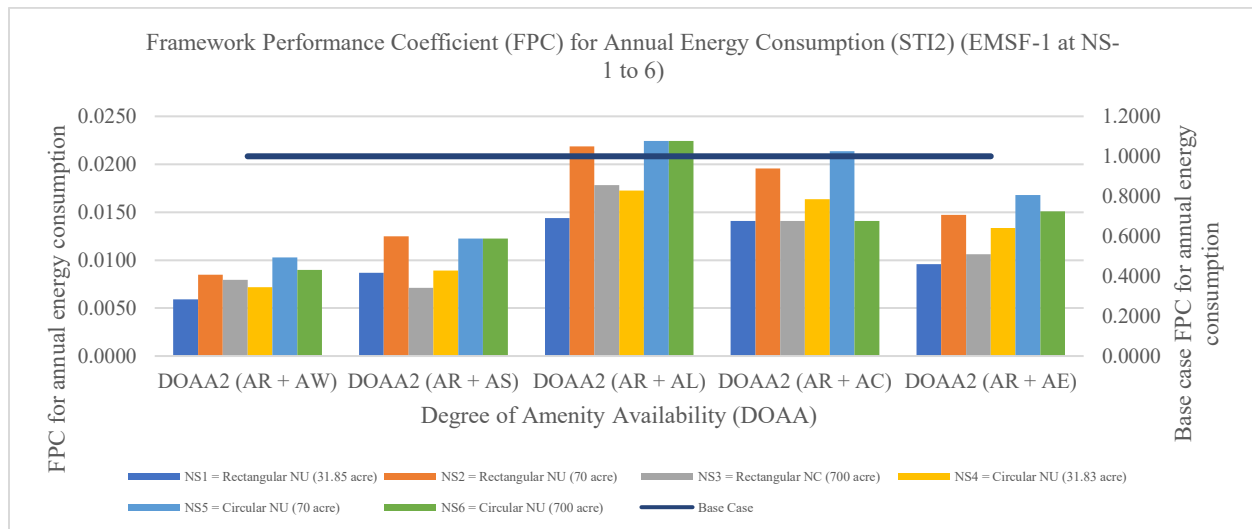
(i) FPC values for base case scenario i.e., Eco-Mobility Strategic Framework (EMS_0) are unity which is seen in figure 27 (a to l) as a horizontal line depicting unity value for all DOAA scenario. This indicates that 1 is the upper limit for FPC values and application of an engineering strategy to reduce environmental, social and economic aspect of sustainability must result into a FPC value less than 1, otherwise the said strategy is not feasible.

(ii) FPC for other EMS_{1to3} are determined with respect to the Sustainable Transportation Indicator (STI) values at EMS_0 . All FPC values EMS_{1to3} are less than 1 which indicates that implementation of Eco-Mobility Strategic Framework (EMS) has resulted into reduction of environmental, social and economic indicators. For example, FPC values for EMS_0 (base case) scenario at $DOAA_2$ (AR+AW) i.e., work amenity is 1 for all the STIs. However, FPC values for EMS_1 scenario at same $DOAA_2$ (AR+AW) is 0.01 for STI_1 , 0.01 for STI_2 , 0.11 for STI_3 and 0.42 STI_4 . This indicates that annual CO_2 emission for EMS_1 is only 0.01 times of EMS_0 i.e., 99% reduction in CO_2 emission have been achieved upon implementation of walking related strategies at EMS_1 . Similarly, the annual energy consumption, annual travel time and annual net cost has been reduced by 99%, 89% and 58% respectively at EMS_1 .

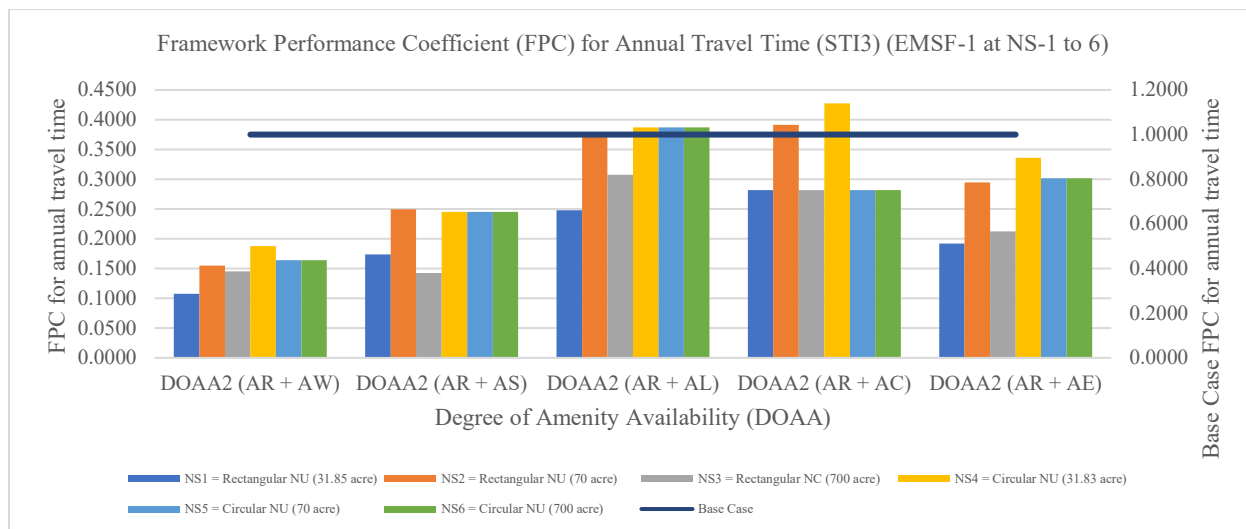
(iii) For Neighborhood Scenario -2 (NS_2), FPC values at EMS_1 (walking only) and $DOAA_2$ (AR+AS) are 0.02 (=FPC (STI_1)), 0.01 (=FPC (STI_2)), 0.25 (=FPC (STI_3)) and 0.42 (=FPC (STI_4)) respectively. Similarly, FPC values at EMS_2 (walking & cycling) and $DOAA_2$ (AR+AS) are 0.02 (=FPC (STI_1)), 0.01 (=FPC (STI_2)), 0.14 (=FPC (STI_3)) and 0.42 (=FPC (STI_4)) for same STIs. Then again, FPC values at EMS_3 (walking, cycling and public transportation) and $DOAA_2$ (AR+AS) are 0.05 (=FPC (STI_1)), 0.12 (=FPC (STI_2)), 0.11 (=FPC (STI_3)) and 0.73 (=FPC (STI_4)) for same STIs. It is observed here that FPC pertaining to the annual CO_2 emission (STI_1) and energy consumption (STI_2) are same for $EMS_{1\&2}$ but increased at EMS_3 due to the inclusion of public transportation related emissions. However, annual travel time has gradually decreased from EMS_1 to EMS_2 (e.g., 44% reduction) and continued to decrease in EMS_3 (e.g., 21% reduction). Annual net cost remained same for $EMS_{1\&2}$ due to absence of Carbon emitting or energy consuming mode of transportation but increased by 74% at EMS_3 due to introduction of public transportation.



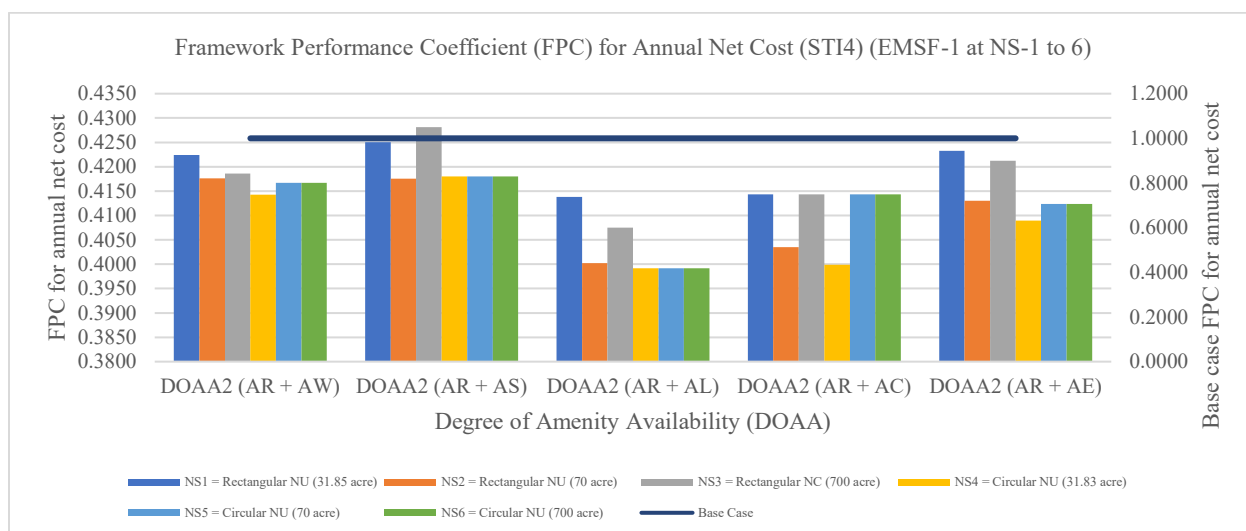
27.a. Framework Performance Coefficient (FPC) for Annual CO₂ emission vs Degree of Amenity Availability (DOAA) graph at Eco-Mobility Strategic Framework-1 (EMSF₁) for 6 Neighborhood Scenario (NS_{1to6})



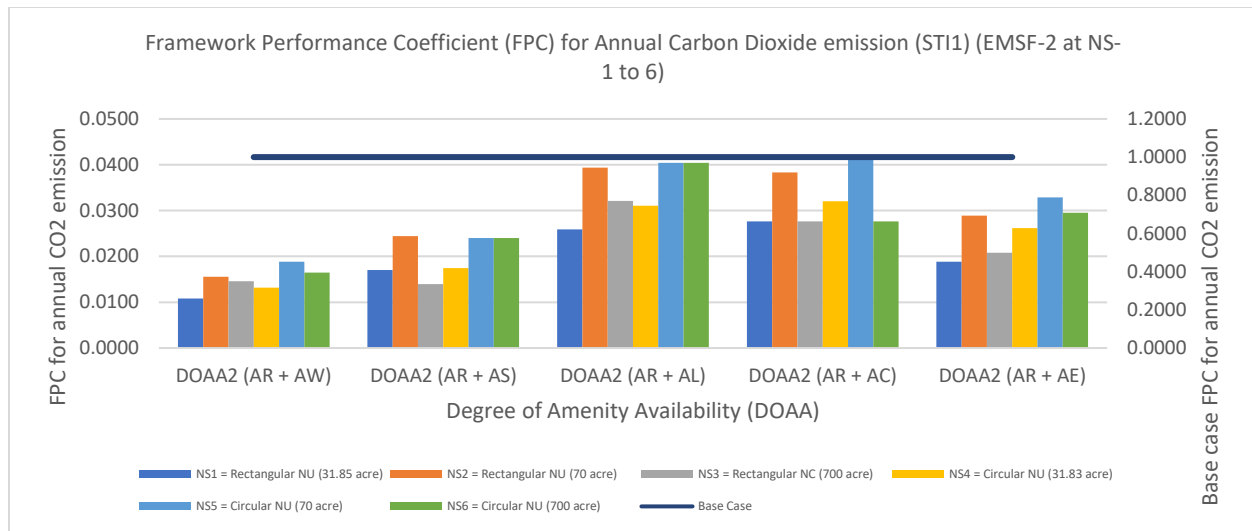
27.b. Framework Performance Coefficient (FPC) for Annual energy consumption vs Degree of Amenity Availability (DOAA) graph at Eco-Mobility Strategic Framework-1 (EMSF₁) for 6 Neighborhood Scenario (NS_{1to6})



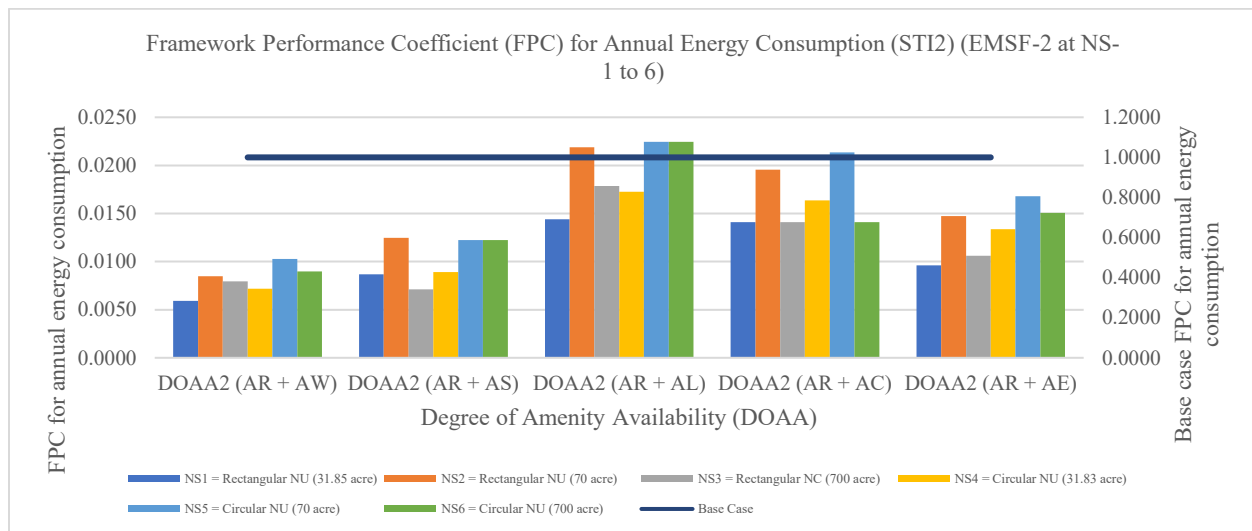
27.c. Framework Performance Coefficient (FPC) for Annual travel time vs Degree of Amenity Availability (DOAA) graph at Eco-Mobility Strategic Framework-1 (EMSF₁) for 6 Neighborhood Scenario (NS_{1to6})



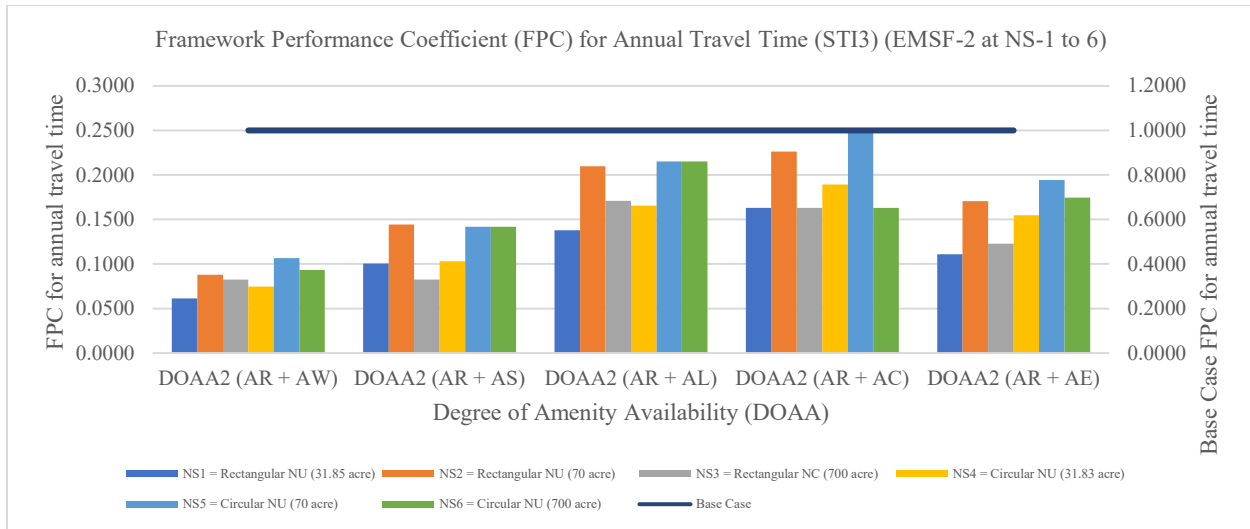
27.d. Framework Performance Coefficient (FPC) for Annual net cost vs Degree of Amenity Availability (DOAA) graph at Eco-Mobility Strategic Framework-1 (EMSF₁) for 6 Neighborhood Scenario (NS_{1to6})



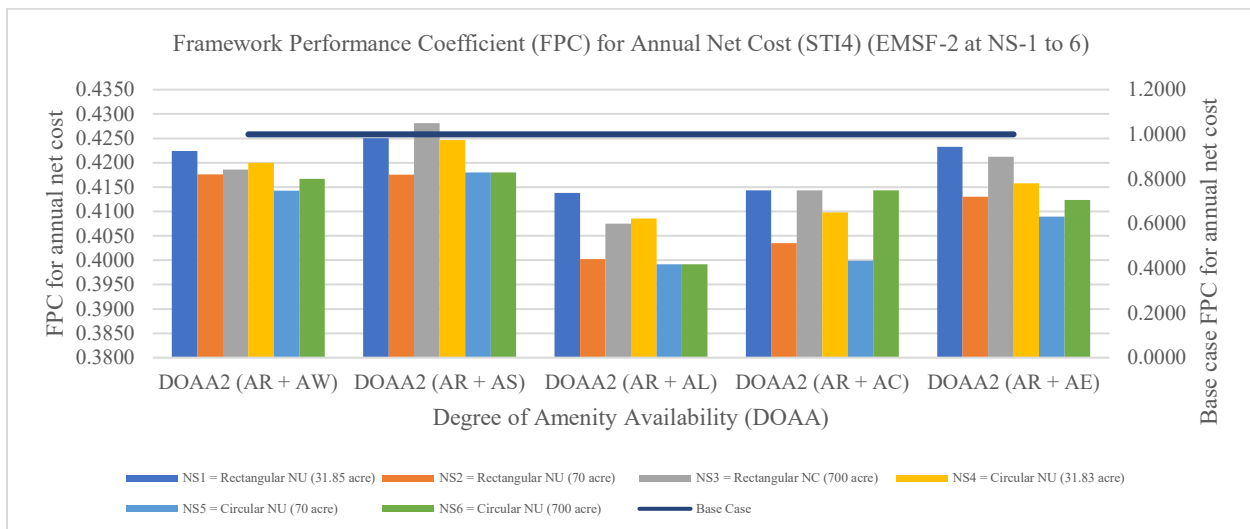
27.e. Framework Performance Coefficient (FPC) for Annual CO₂ emission vs Degree of Amenity Availability (DOAA) graph at Eco-Mobility Strategic Framework-2 (EMSF₂) for 6 Neighborhood Scenario (NS_{1to6})



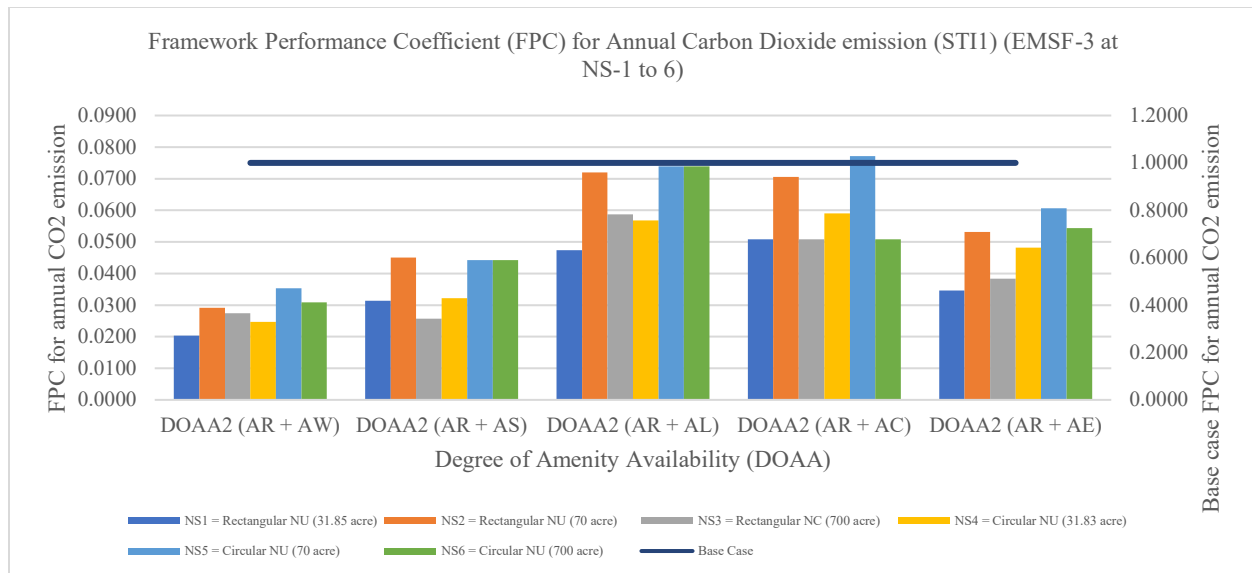
27.f. Framework Performance Coefficient (FPC) for Annual energy consumption vs Degree of Amenity Availability (DOAA) graph at Eco-Mobility Strategic Framework-2 (EMSF₂) for 6 Neighborhood Scenario (NS_{1to6})



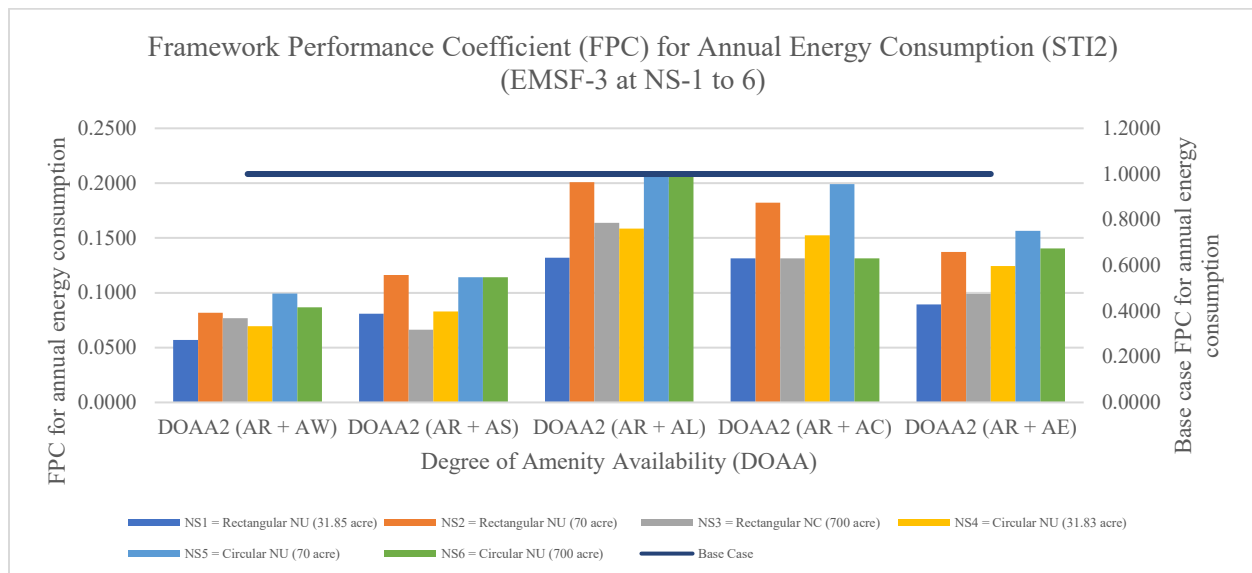
27.g. Framework Performance Coefficient (FPC) for Annual travel time vs Degree of Amenity Availability (DOAA) graph at Eco-Mobility Strategic Framework-2 (EMSF₂) for 6 Neighborhood Scenario (NS_{1to6})



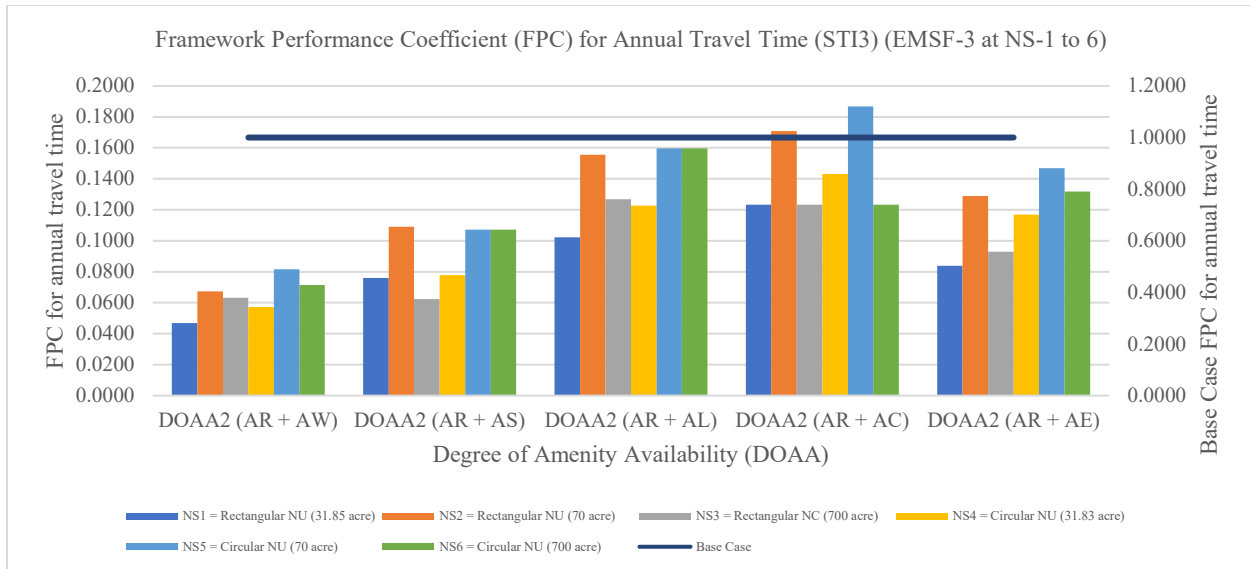
27.h. Framework Performance Coefficient (FPC) for Annual net cost vs Degree of Amenity Availability (DOAA) graph at Eco-Mobility Strategic Framework-2 (EMSF₂) for 6 Neighborhood Scenario (NS_{1to6})



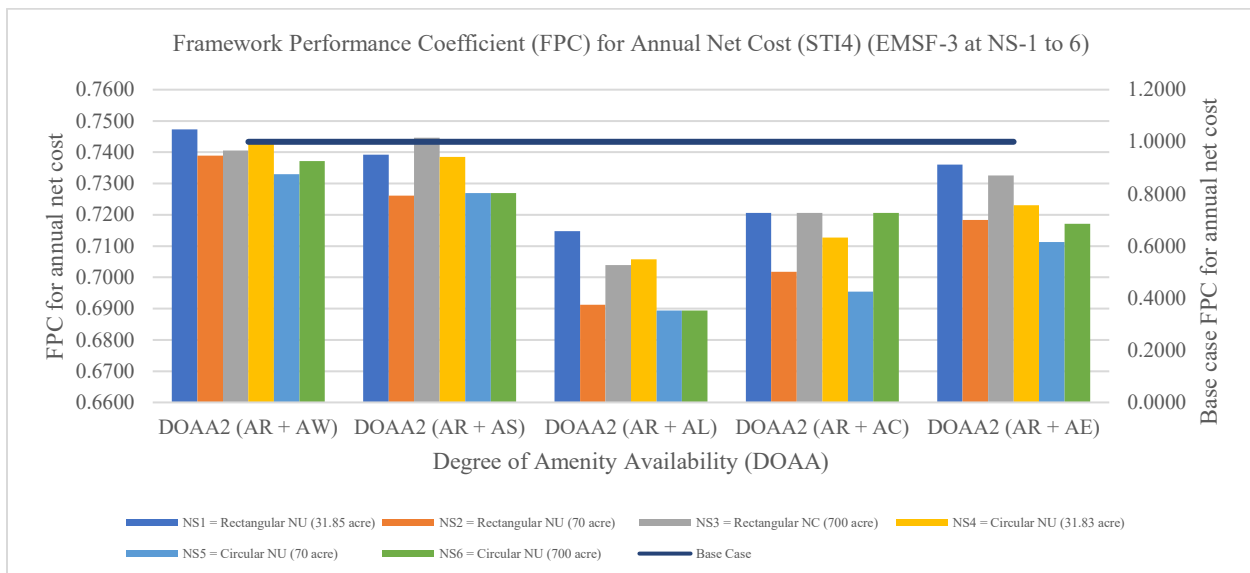
27.i. Framework Performance Coefficient (FPC) for Annual CO₂ emission vs Degree of Amenity Availability (DOAA) graph at Eco-Mobility Strategic Framework-3 (EMSF₃) for 6 Neighborhood Scenario (NS_{1to6})



27.j. Framework Performance Coefficient (FPC) for Annual energy consumption vs Degree of Amenity Availability (DOAA) graph at Eco-Mobility Strategic Framework-3 (EMSF₃) for 6 Neighborhood Scenario (NS_{1to6})



27.k. Framework Performance Coefficient (FPC) for Annual travel time vs Degree of Amenity Availability (DOAA) graph at Eco-Mobility Strategic Framework-3 (EMS_{F3}) for 6 Neighborhood Scenario (NS_{1to6})



27.l. Framework Performance Coefficient (FPC) for Annual net cost vs Degree of Amenity Availability (DOAA) graph at Eco-Mobility Strategic Framework-3 (EMS_{F3}) for 6 Neighborhood Scenario (NS_{1to6})

Figure 27 Framework Performance Coefficient (FPC) for different Sustainable Transportation Indicator (STI) vs Degree of Amenity Availability (DOAA) graph at Eco-Mobility Strategic Framework-3 (EMS_{F1 to 3}) for 6 Neighborhood Scenario (NS_{1 to 6})

- (iv) Decision Making Metric Value (DMMV) for base case scenario (EMS_{F_0}) is 1 for all Degrees of Amenity Availability (DOAA). However, DMMV for $EMS_{F_{1to3}}$ are less than unity which indicates that implementation of Eco-Mobility Strategies has cumulatively decreased the sustainable transportation indicators.
- (v) At base case scenario (EMS_{F_0}) for $DOAA_2$ (AR+AL), DMMV is 1. For Neighborhood Scenario-5 (NS_5) and same $DOAA_2$ (AR+AL), DMMV for $EMS_{F_{1to3}}$ are 0.21 ($=EMS_{F_1}$), 0.17 ($=EMS_{F_2}$) and 0.28 ($=EMS_{F_3}$). In addition to walking in EMS_{F_1} , introduction of cycling in EMS_{F_2} has resulted in reduced DMMV due to reduction in travel time (i.e., STI_3). EMS_{F_3} has public transportation which adds to the STI_1 (CO_2 emission) and STI_2 (energy consumption) which in turn has resulted in increased DMMV.
- (vi) DMMV is an easy-to-use tool developed particularly for policy-makers. Instead of dealing with large number of numbers and results, DMMV aids the decision makers with only one number that is used for informed decision making. For example, policy-makers are considering a multi-functional ($DOAA_6$) neighborhood such as NS_5 where EMS_{F_1} , EMS_{F_2} and EMS_{F_3} have DMMV of 0.19, 0.16 and 0.26 respectively. Based on this data the policy-makers may opt to implement EMS_{F_2} i.e., walking and cycling related strategies due to lowest DMMV. This study multiplies all the FPCs by equal weight factor of 0.25. Policy makers may change this weight factor based on their priority on sustainable transportation indicators i.e., environmental, social and economic factors.

This section of the study presented the application of 4 Eco-Mobility Strategic Framework ($EMS_{F_{i=1-4}}$) in 6 Neighborhood Scenario ($NS_{j=1-6}$) at 7 different Degree of Amenity Availability ($DOAA_{k=1-6}$), assessed the effectivity of Eco-Mobility Strategies (EMS) numerically with respect to Sustainable Transportation Indicators (STI) and finally measured the Decision-Making Metric Value (DMMV) to compare among different sustainability indicators. Chapter 4 showcases the discussion on the study where results obtained in chapter 3 are explained while scalability & general application is depicted.

5. Discussion

This research develops a framework that brings together eco-mobility and multifunctional neighborhoods, guided by the principles of the 15-minute city. By applying the framework to the Canadian context, the study highlights its potential to reduce greenhouse gas emissions while also enhancing community sustainability and livability.

Evolving from the traditional viewpoints on neighborhood and transportation system, this study explores 3 Eco-Mobility Strategies (EMS) – walking, cycling & public transportation in context of multi-functional neighborhood scenario(s) i.e., 15-minute city. Inclusion of electric vehicles (EV) in the neighborhood increases electricity demand from the national or local grid electricity and in turn has the potential to actually increase the carbon footprint depending on the carbon intensity in the electricity generation process.

Considering the neighborhood of West-5 located in London, Ontario as base case scenario where aforementioned EMS are not implemented, the base case scenario is studied as Eco-Mobility Strategic Framework (EMS_{F0}) while 3 more Eco-Mobility Strategic Frameworks (EMS_{F1to3}) are perused - EMS_{F1} implements walking related strategies, EMS_{F2} implements walking & cycling related strategies and EMS_{F3} implements walking, cycling and public transportation related strategies. Alongside a base case scenario at West-5, six other Neighborhood Scenarios (NS) are scrutinized in this study where NS has areas less than (e.g., NS₁ & NS₄) or area equal to (e.g., NS₂ & NS₅) or area greater than (e.g., NS₃ & NS₆) the base case scenario and they are further sub-divided based on their road pattern and geometrical shape (e.g., rectangular or radial road pattern). Multi-functional neighborhoods such 15-minutes city is investigated at 7 different degrees of amenity availability (e.g., living, working, supplying, learning, caring, leisure/enjoying). Upon implementation of Eco-Mobility Strategic Framework (EMS_F), the 3 pillars of sustainable development – environmental, social and economic perspective of the newly implemented Eco-Mobility Strategic Framework (EMS_F) are examined using 4 Sustainable Transportation Indicators (STI) – annual CO₂ emission, annual energy consumption, annual travel time and annual net cost. Finally, this study aids the policy-makers by proposing a Decision-Making Metric (DMM) where effectivity of Eco-Mobility Strategic Framework (EMS_F) at multifunctional Neighborhood Scenarios (NS) under different Degree of Amenity Availability (DOAA) are measured and quantified using two metric –Framework Performance Coefficient (FPC) computed with respect to base case STI and a Decision-Making Metric Value (DMMV) that combines the FPCs altogether with respect to their importance weight to the policy makers.

5.1. Overview of key findings

This study perused multi-functional Neighborhood Scenarios (NS) i.e., 15-minute neighborhoods and found out that all the STIs reduced significantly upon combination and implementation of two strategies - Eco-Mobility Strategic Framework (EMS_F) and spatial redistribution of amenities, in the neighborhood. Introduction of EMS_F influences the modal choice of neighborhood dwellers and also the number of trips using CO₂ emitting modes fall which leads towards reduction of STIs. Implementation of 15-minute neighborhood features and

establishing amenities in the neighborhood, reduces trip lengths to amenities which in turn decreases the Sustainable Transportation Indicators (STI).

5.1.1. Objective achievement

In accordance with the first objective stated at section 1.2, this research work postulates 3 Eco-Mobility Strategic Framework (EMSF_{1to3}) in section 2.2 where walking, cycling and public transportation related Eco-Mobility Strategies (EMS) have been implemented. EMSF₁ fully implements walking strategies, EMSF₂ fully implements walking and cycling related strategies and EMSF₃ fully implements walking, cycling and public transportation related strategies.

Second objective involved application of the EMSF in context of different Neighborhood Scenario (NS) and Degree of Amenity Availability (DOAA) where it is expected that Sustainable Transportation Indicators (STIs) set to measure the impact of EMSF will significantly decrease from base case scenario. Two types of environmental impacts are studied – annual CO₂ emission (STI₁) and annual energy consumption (STI₂), that accounts for both fossil fuel-based automobiles and electric vehicles. Introduction of EMSF_{1to3} in multi-functional neighborhoods have greatly decreased trip lengths and impacted number of trips at different modal share which resulted in significant reduction of STI values. For example, average reduction in annual CO₂ (STI₁), annual energy consumption (STI₂), annual travel time (STI₃) and annual net cost (STI₄) is 97%, 95%, 83%, 48%. These values are averaged across a wide range of EMSFs and neighborhood scenarios, however they do delineate the fact that implementation of Eco-Mobility Strategic Framework (EMSF) in multi-functional neighborhoods (e.g., 15-minute city) have the potential to decrease the environmental, social and economic impact, making these duo – EMSF & 15-minute city a sustainable development pair.

Third objective comprised of a Decision-Making Metric (DMM) which measured and quantified the effectivity of the EMSF in multi-functional neighborhood. Framework Performance Coefficient (FPC) values in this research work delineate significant reduction of environmental, social and economic impacts upon introduction of mobility-amenity duo (i.e., Eco-Mobility Strategic Framework (EMSF) in multi-functional neighborhood). FPC shows least value for EMSF₁ i.e., walking only and highest value for EMSF₃ i.e., walking, cycling & public transportation indicating that active mode of travel such as walking has least impact. Finally, the Decision-Making Metric Value (DMMV) in this study with an equal weight factor has an average value of 0.19 indicating 81% overall reduction of in environmental, social and economic impacts.

Automobile centric transportation system in North American urban neighborhood scenario where amenities are located far away resulting in high trip length and consequently high Carbon emission needs major change at rudimentary level. The concept of multifunctional neighborhood such as 15-minute neighborhood is gaining pace in cities such as Paris, Barcelona, London and few other European cities but this is still a relatively young urban planning tool. This study develops a framework that amalgamates eco-mobility with multi-functional neighborhood system and proves the application of framework on different Neighborhood Scenario (NS) through reduction of environmental, social and economic impact on the world. Considerable reduction in Carbon reduction as well as energy consumption makes the multi-

functional neighborhood more resilient from both environmental and energy perspective. Finally, this study also aids the policy makers and community members by simplifying the policy selection process by developing a Decision-Making Metric (DMM). Scalability of this framework is guaranteed through using simple procedure of interpreting the Eco-Mobility Strategic Framework (EMSF) and multi-functional neighborhood scenarios into a simple trip length, number of trips, modal ratio components which are easily measured. Both existing and proposed neighborhoods can benefit from this application which determines future sustainable strategies regarding amenities selection. For example, West-5 is an existing neighborhood in this study, home to work (AW) and supply (AS) amenity trips cumulatively generated 64% of STIs indicating the fact that establishing these two amenities inside the West-5 reduces 64% of the environmental, social and economic impact which is a significant contribution towards achieving sustainability.

5.2. Impact analysis by Strategy and Framework

Impacts of three Eco-Mobility Strategic Framework ($EMSF_{i=1to3}$) perused in this study are measured using four Sustainable Transportation Indicators ($STI_{l=1to4}$) that stemmed from environmental, social and economic pillars of sustainable development pertaining to multi-functional neighborhood and eco-mobility. This study looks into these STIs individually and also in combination. Furthermore, this study proposes a Decision-Making Metric (DMM) that measures the STIs into more comprehensible manner for policy-makers. Following portion of this section individually looks into the impacts of each of the EMSFs on the STIs.

5.2.1. Environmental impacts

Three Eco-Mobility Strategic Framework (EMSF) are studied in this research where the first two strategies – waking and cycling, also known as active mode of transportation, are zero emission (STI_1) & energy consumption (STI_2) strategies. Introduction of an all-electric-vehicle approach replacing the fossil fuel-based automobiles in base case scenario i.e., $EMSF_0$ only trades off high volume of CO_2 emission (e.g., 474 kg/year/person) by high level of energy consumption (e.g., 736 kW-Hr/year/person) which still requires a high quantity of PV i.e., $3.64m^2$ /person for fulfilling the demand of energy pertaining to work related trips only. However multi-functional neighborhoods studied in this research work have amenities at short distance from residential units which decreases trip length significantly from base case neighborhood that results into substantial reduction in STI_1 and STI_2 . In case of Eco-Mobility Strategic Framework ($EMSF_3$), STI_1 and STI_2 decrease by 95% and 87% respectively from the base case scenario. However, STI_1 and STI_2 of $EMSF_3$ increase from the $EMSF_1$ and $EMSF_2$. Public transportation system operated by Carbon emitting vehicles causes 88% increase CO_2 emission but causes a staggering 865% increase in energy consumption in comparison to the $EMSF_1$ and $EMSF_2$. However, reduction of STI_1 is 95% and STI_2 is 87% is observed for $EMSF_3$ in comparison to that of $EMSF_0$ which shows significant reduction.

Inference from this finding is that active transportation oriented eco-mobility strategies i.e., $EMSF_1$ featuring walking only and $EMSF_2$ featuring walking & cycling are more environment friendly from both CO_2 emission and energy consumption perspective. Shift from fossil fuel-based automobiles to electric vehicles coupled with multi-functional neighborhood

boosted with lower degrees of eco-mobility (i.e., active modes only) decreases energy demand for the 15-minute neighborhood which contributes towards achieving energy resilience for the urban neighborhood. However, introduction of electric buses as public transportation system increases the energy demand by 865%. Considering the material and monetary investments required to generate this amount of power, the focus should be on identifying solutions that align with long-term sustainability objectives. Rather than defaulting to fossil fuel-based transportation units, more realistic and future-oriented approaches include the use of electric buses equipped with integrated PV systems, as well as renewable energy generation on site to support their operation. While a detailed comparison between fossil fuel-based and renewable-powered systems is beyond the scope of this research, future studies should examine these alternatives to ensure that multifunctional neighborhoods contribute to emission reduction and sustainable development goals.

5.2.2. Social and behavioral implications

Annual travel time for walking and cycling are higher than automobile, however multifunctional neighborhoods have amenities at short distance from home which requires significantly reduced travel time in comparison to the base case neighborhood. Annual travel time for walking and cycling are higher than automobile for the base case scenario which makes active mode of transportation unpopular modal choice i.e., only 10% and 1% people in London walk or cycle respectively (see figure 1). Moreover, use of public transportation in London city at base case scenario is 6% only. Introduction of public transportation at multi-functional neighborhoods (e.g., neighborhood cluster at NS₃ with an area of 2.833 km²) in Eco-Mobility Strategic Framework (EMSF₃) decreases the annual travel time (STI₃) by roughly 94%, 56% and 23% in comparison to the EMSF₀ (base case scenario), EMSF₁ (walking only) and EMSF₂ (walking and cycling only) respectively. Multi-functional neighborhoods have reduced trip length and eco-mobility strategies decrease automobile dependency i.e., modal share of Carbon emitting modes shrinks down to the loyal users i.e., 48%.

Almost 80% Londoners are automobile users and 48% of them are loyal users who are not willing to change their mode of transportation upon introduction of eco-mobility strategies [70]. Here almost half the population are pro-automobile and yet 23% to 94% reduction in travel time is achieved vide introduction of different degree of eco-mobility. This also indicates to the policy makers that implementation of lower level of eco-mobility (e.g., walking only) does not reduce travel time significantly due to dependency of neighborhood dwellers on slower mode of transportation i.e., walking. Then again other variables such as weather (e.g., temperature, precipitation), age of dwellers etc. are not explored in this study that may affect the modal distribution of people choosing to walk over automobiles. However, introduction of higher degree of eco-mobility strategies in EMSF₃ reduces the travel time in the neighborhood scenarios up to 94% from the base case scenario.

It is inferred from the discussion that introduction of 15-minute city features alone by spatially redistributing the amenities alongside implementation of lower degree of eco-mobility features such as EMSF₁ or EMSF₂ are not enough to substantially reduce the travel time. However, introduction of higher degree of eco-mobility features such as public transport units in

EMSF₃ reduce the travel time by substantial amount which increases its acceptability to the dwellers while also protecting them from weathering effects as well.

5.2.3. Economic and technical feasibility

Annual net cost (STI₄) for base case scenario at EMSF₀ featuring West-5 neighborhood represent the fuel cost generated from long trip lengths to amenities from residential units by the use of fossil fuel-based automobiles. EMSF₁ and EMSF₂ generate identical results for STI₄ due to absence of fossil-fuel based mode of transportation i.e., walking & cycling is introduced while presence of 48% loyal automobile users who are the only clients of fossil fuel under EMSF₁ and EMSF₂. STI₄ values of EMSF₃ is roughly 74% higher in comparison to that of EMSF₁ & EMSF₂.

It is observed that higher degree of eco-mobility features causes higher amount of net cost i.e., savings in comparison to the base case scenario. Spatial redistribution of amenities resulting in lower trip length coupled with higher modal option (e.g., walking or cycling or public transportation) and distribution of number of trips among different modes of transportation is the key reason for higher opportunity for cost savings in EMSF₃.

The methodology described in this research work employs the Sustainable Transportation Indicators (STIs) to measure the result of implementing eco-mobility features in multi functional neighborhoods. STIs are described in section 2.3.3. where equations 1 to 4 are employed to compute STI values for different Eco-Mobility Strategic Framework (EMSF_i) and Neighborhood Scenarios (NS_j). The equations utilized in this research work have 7 component that are described in table 7. Trip length depends on neighborhood scenario while number of trips to different amenities and modal ratio of transportation utilized by the dwellers are collected from survey data. CO₂ emission, energy consumption, fuel consumption rate is collected from vehicle manufacturer. Speed of mode is collected from design standards and cost of fuel from historical data. All these information is replicable in context of any other neighborhood making the methodology stated in this study scalable. However, different neighborhood scenario poses different challenges regarding spatial redistribution of amenities. Availability of proper infrastructure at 15-minute distance is the key challenge here.

In summary, analysis of environmental, social and economic aspects of the multi-functional neighborhood equipped with different degree of eco-mobility delineate that environmental indicator such as annual CO₂ emission (STI₁) & annual energy consumption (STI₂) is minimum at Eco-Mobility Strategic Framework – 1 and 2 (EMSF_{1&2}). However, higher degree of eco-mobility strategic framework yields better results for annual travel time and net annual cost. This contrast is addressed in this research work through the introduction of Decision-Making Metric (DMM) where Decision Making Metric Value (DMMV) contains weight factors for each of the Framework Performance Coefficients that corresponds to each of the STIs. Depending on federal policies or community demand or other issues that are beyond the scope of this study, the policy makers can choose to assign higher or lower weight factor to put more or less emphasize on environmental (STI_{1&2}) or social (STI₃) or economic indicators (STI₄).

5.2.4. Interactions and Missed Synergies

Eco-Mobility Strategies (EMS) studied in this research work are walking, cycling and public transportation and the Eco-Mobility Strategic Frameworks (EMSF) studies 4 cases where EMS is not implemented in base case scenario, only walking related strategies are fully implemented in EMSF₁ while EMSF₂ has full implementation of walking and cycling related strategies, and finally EMSF₃ describes full implementation of walking, cycling and public transport related strategies. However, this research work did not study the EMSF scenario where public transportation is implemented alongside walking or cycling only. Moreover, partial implementation of EMS individually or in combination is also not explored in this research work. In real life situations, due to policies, budget constraints and other reasons partial implementation of all the strategies at the same time is possible. In such scenario, traffic related data i.e., number of trips and modal ratio of neighborhood dwellers are likely to be changed. It can be assumed that partial implementation of EMS is likely to thwart the dwellers and push them towards automobiles. Future studies ought to peruse partial implementation of Eco-Mobility Strategies (EMS) in Eco-Mobility Strategic Framework (EMSF). Also, studying the traffic response from implementation of partial EMS and analyzing the corresponding Sustainable Transportation Indicators (STI) is another stem of this scholarship that warrants perusal.

5.3. Method of transferability and generalization

This study peruses amenity-mobility nexus and proposes a scalable methodology that involves a certain set of steps which requires data. Source of data could be primary from household survey or secondary from citywide surveys or design standards or codes. STI (Annual CO₂ emission, annual energy consumption, annual travel time and annual net cost) values are calculated from equation 1 to 4 and components mentioned in table 7 of section 2.3.3. It is observed in table 7 that data required for calculating STIs depend on selection and degree of application of eco-mobility strategy (e.g., EMSF₁ or EMSF₃), geometric (e.g., trip length) and demographic data of the neighborhood, traffic data of the neighborhood dwellers (e.g., modal ratio, number of trips, trip length), amenity related data (e.g., type and number of amenity) and other information (e.g., vehicle speed, emission rate, fuel consumption related information). One baseline scenario i.e., West-5 and three EMSF_{1 to 3} that involves walking, cycling and public transportation are perused for 7 DOAAs in 6 NS and the results indicate significant reduction in environmental, social and economic indicators or STIs. Finally, DMM takes the STIs into account and calculates FPC and DMMV.

EMSF, DOAA and NS described in this study are analyzed using STIs while their effectivity is measured and summarised by DMM using the FPC and DMMV. Methodology described at section 2 follows a certain set of steps to reach a single solution (e.g., one DMMV) for a fixed set of condition. For example, when a certain degree of eco-mobility strategy is implemented in a certain neighborhood (e.g., EMSF₂ that includes walking and cycling only), geometric shape of neighborhood (e.g., trip length) and degree of amenity availability (e.g., DOAA₄ that includes residence, work, supply and learning amenity) in the neighborhood (e.g., trip lengths and type of trips). DMMV is computed from FPCs which in turn depends on individual STIs of EMSF.

Traffic data for the target neighborhood is collected from the city traffic survey data or a specific household traffic survey conducted in the neighborhood.

Data required to calculate STIs and analyze the DMM employed in this study are quantifiable in any scenario, globally. Next sub-section describes application and results found from another neighborhood located in London (ON) as a proof of concept of this study.

5.3.1. Applicability in other settings

Amenity-Mobility duo applied in this study peruses one base case North American neighborhood i.e., West-5 and implements the methodology on 6 more neighborhood scenarios that are generated with similar design pattern to West-5.

To examine the Scalability of the framework, it is applied to another neighborhood (Byron) located at London, Ontario. Byron is located in London city, at 3.6 km south-east from West-5 and has a lot area of 0.7 hectare or 0.007 km² and a population of 15,525.

Application of EMSF and DMM for West-5 and Byron are presented in the table-18 which shows the components required for calculating STIs (Annual CO₂ emission, annual energy consumption, annual travel time and annual net cost), FPCs and DMMV. Following inferences are drawn from table 19,

- Daily average trip length depends on the amenities chosen to incorporate in a neighborhood. More multifunctional the neighborhood becomes, lower the STI values and also the DMMV in turn.
- Number of daily trips and modal ratio of the trips depends on the traffic behavior of the neighborhood dwellers which in turn depends on multiple variables such as climate condition, available mode of transportation, user behaviour.
- Studying two neighborhoods (e.g., West-5 and Byron) located in the same city i.e., London city where traffic data (e.g., number of daily trips, modal ratio) and other information being same, trip length to amenities is the only variable between two neighborhoods. Lower the trip length to amenities, lower the STI values for a neighborhood.
- EMSF involves two active modes of transportation (e.g., walking and cycling) where the modal ratio is weather and time sensitive. First and last mile walking involved with the public transportation system also effects the dwellers choice for mode.

Table 19 Type of data required for application of Amenity-Mobility Integration

Serial		Type of information (Context-specific or general)		
		Neighborhood: West-5	Neighborhood: Byron	Comment(s)
1	Daily average trip length	Depends on amenity selection and it's degree		Context-specific
2	Number of daily trips	Depends on neighborhood dwellers traffic behaviour		Context-specific

Serial	Type of information (Context-specific or general)		
	Neighborhood: West-5	Neighborhood: Byron	Comment(s)
3	Average CO ₂ emission (kg/km)	Depends on number of car ownership and type of car	Context-specific
4	Average energy consumption (KJ/km)	Depends on number of car ownership and type of car	Context-specific
5	Average speed (km/km)	Depends on local regulatory authorities	Context-specific
6	Fuel consumption (Litre/km)	Depends on type of car ownership	Context-specific
7	Cost of fuel (C\$/liter)	Depends on local regulatory authorities	Context-specific

- Average CO₂ emission, fuel consumption rate and energy consumption are dependent on the type of automobiles or electric vehicles driven by the neighborhood dwellers. Choice and selection of dwellers is influenced by other factors such as price, availability, refuelling/recharging options, price of fuel which are not in the scope of this research work.
- Speed and cost of fuel is regulated by the local regulatory authorities and this study assumes that neighborhood dwellers abide by the law and follow the rules.
- Table 18 clearly depicts that application of EMSF alone is not enough to yield favorable environmental, social and economic results. This emphasizes the importance of multi-functional neighborhood planning i.e., 15-minute city inclusive of amenities alongside implementation of eco-mobility strategies.

This study takes the number of trips for a certain type of mode constant throughout the year. However, the modal ratio as well number of trips varies due to climate condition. Also, different neighborhoods in the city have different car ownership ratio which in turn will result in different STIs for different neighborhood. This shows that importance of conducting household surveys for the neighborhood instead of using city wide traffic data for every neighborhood.

5.3.2. Data and process requirement

Global application of amenity-mobility nexus at an existing or a proposed neighborhood require data involving the neighborhood that pertains to the framework mentioned in section 2. The required data includes neighborhood, its transportation system, traffic behaviour of neighborhood dwellers and amenity related data. As mentioned in section 2.3.3 and the equations 1 to 4, the data collected from these sources are utilized to compute the STIs that delineates the sustainability of a neighborhood at base case scenario. Upon implementation of one strategy or combination of eco-mobility strategies, same set of information are computed for modified scenario to calculate the STIs. STI values computed from both base case scenario and modified scenario are used in the DMM to calculate the FPC and DMMV that gives the total picture regarding the effectivity of the chosen strategy under the current circumstances (e.g., FPC for chosen strategy must be less than 1 otherwise the application of strategy is not feasible).

The neighborhood related data required involves geometric shape of the neighborhood (e.g., road pattern), demographic data of dwellers (e.g., population), transportation system of the neighborhood and traffic data of dwellers (trip length to amenities, number of car ownership, modal ratio, number of daily trips to amenities), amenities (availability, number of amenities, location of amenities). Data required pertaining to the selected eco-mobility strategy are speed of the chosen mode of transportation, carbon emission rate, energy consumption rate, fuel consumption rate.

Data required for execution of EMSF and DMM are collected from primary source i.e., household survey conducted at chosen neighborhood or secondary source i.e., survey data of the city. In case of data scarcity, reasonable assumptions considering the extreme case scenario can be used in the calculation process. For example the car ownership rate in Canada is 90% where 89% are gasoline or diesel fueled vehicles which can be used when car ownership related specific data for a neighborhood is not available [150].

5.3.3. Flowchart of the methodology

Integration of Eco-Mobility Strategies with amenity rich neighborhoods decreases trip length and changes the balance of modal ratio towards less-Carbon-emitting modes which in turn benefits the neighborhood dwellers from environmental, social and economic pillars of sustainable development involving amenity-mobility duo. This study postulates an Eco-Mobility Strategic Framework (EMSF) and applies it in Neighborhood Scenarios (NS) where different degrees of amenities are available and results are measured using Sustainable Transportation Indicators (STIs). Finally, the STIs are interpreted to policy makers through a Decision-Making Metric (DMM) that includes a Framework Performance Coefficient (FPC) and Decision-Making Metric Value (EMMV). This section describes the procedure for implementing and measuring the amenity-mobility duo via a flowchart (figure -28) that is easily comprehensible and reciprocated globally by urban planners and policy makers.

Amenity-Mobility Integration (AMI) flowchart is developed following the methodology described in section 2. This flowchart takes two principal pillars of this study – Eco-Mobility Strategic Framework (EMSF) and Neighborhood Scenarios (NS) with different Degree of Amenity Availability (DOAA) and describes the outputs from two principal pillars i.e., amenity-mobility duo acts as input for Sustainable Transportation Indicators (STIs). Equation 1 to 4 described in section 2.3.3 and the corresponding components of these equations described in table 7 of section 2.3.3 are measured from the combined effect of EMSF and DOAA on Neighborhood Scenarios (NS).

Outputs from Eco-Mobility Strategic Framework (EMSF), Neighborhood Scenarios (NS) and Degree of Amenity Availability (DOAA) are described below,

- **Eco-Mobility Strategic Framework (EMSF)**
 - **Eco-Mobility Strategies (EMS) – selection and degree of application.** the inputs for selecting and implementing Eco-Mobility Strategies and the degree of their application include: Community choice, policy makers

decision, budget and financial limitations, federal government policy, international environmental goals and standards.

- **Modal Ratio.** Number of selected EMS and the degree of their application (e.g., fully or partially developed and implemented) determines the modal ratio of neighborhood dwellers.
- **Neighborhood Scenarios (NS)**
 - **Daily Average Trip Length.** Neighborhood Scenarios are perused where the geometric shape and road pattern governs the trip length of neighborhood dwellers. This study peruses three types of neighborhoods with area less than, equal and greater than baseline neighborhood i.e., West-5. Three neighborhood types are further sub-divided based on their road/geometrical pattern – radial and rectangular. Distance from furthest residential unit located from amenities are computed which in turn is used to determine the average trip length of neighborhood dwellers to amenities.
 - **Purpose of trips/Type of Amenities.** Data pertaining to amenities in or out of a neighborhood are collected from household surveys.
 - **Number of daily trips to amenities.** Data collected from household surveys.
 - **Demographic Information.** Data collected from household surveys.
- **Degree of Amenity Availability:**
 - **Type and number of available amenities.** In context of FMC, the amenities are sub-divided into 6 categories – living, working, supplying, caring, learning, leisure/enjoying. Incorporation of all or few of these amenities in existing or multi-functional neighborhood scenarios, depend on the community choice, policy makers, budget and financial factors and so on.
 - **Number of daily trips to amenities.**
 - Type of amenity and number of amenities to be introduced in a neighborhood effects the number of trips to the amenities by the neighborhood dwellers.
- Other information (e.g., CO₂ emission rate by automobiles, energy consumption rate by automobiles, cost of fuel, fuel consumption rate, speed of different mode of transportation) required for calculating the STIs are collected from NRCan.

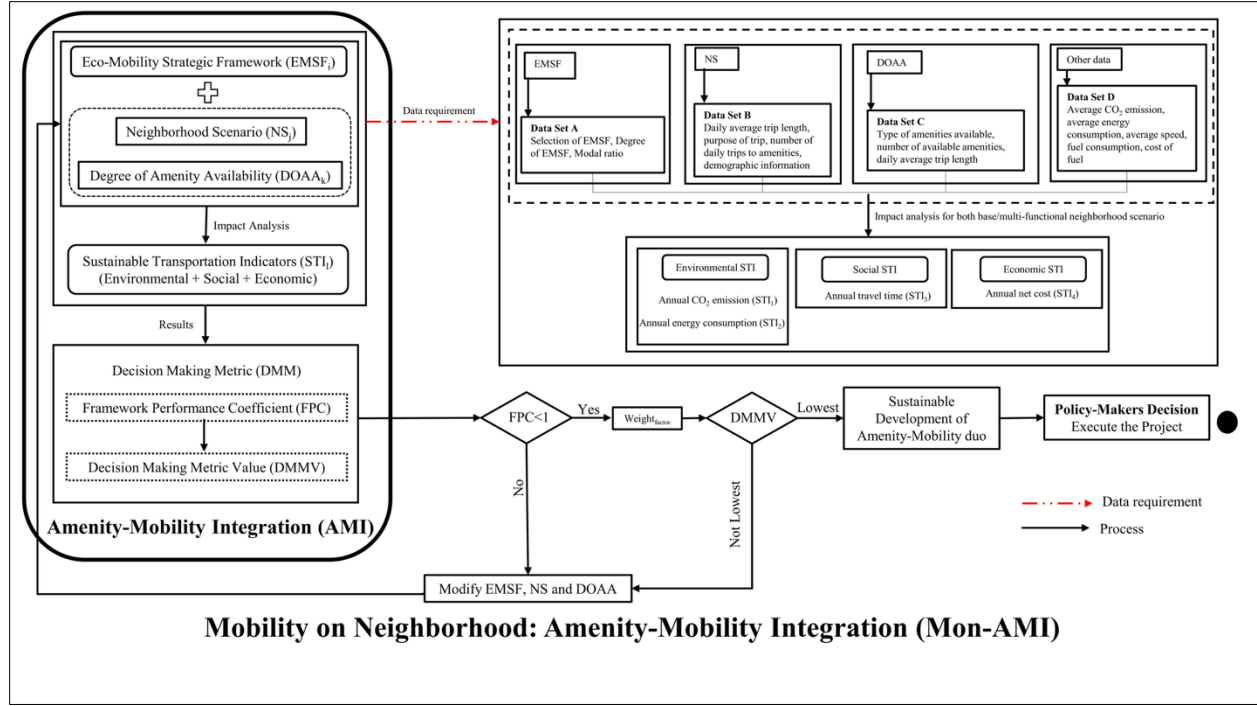


Figure 28 Flowchart for Amenity-Mobility Integration (AMI)

○ Expected outputs and interpretation methods

Methodology described in this research work computes the Sustainable Transportation Indicators (STIs) using the seven components described in table 8 of section 3.3.3. Figure 20 describes the method of calculating the components from different mobility-amenity duo. The components are determined from different Neighborhood Scenarios (NS) with different degree of amenities, making the Amenity-Mobility Integration (AMI) flowchart applicable and usable by urban planners and policy makers around the globe. This chart will serve as a practical guide for practitioners and researchers aiming to replicate or build such amenity-mobility based model.

5.4. Limitations and directions for future research

This study focuses on framework building between amenity-mobility where components required for calculating the STIs and DMM are described in section 2 of this study. Absence of traffic data required for calculation was offset by making reasonable assumptions that puts a limitation in this study. Future works pertaining to this topic may collect traffic data from primary sources making the research work more precise.

5.4.1. Key Limitations

Key limitations in this study involving the EMSF, NS, DOAA and STI are described below,

- **EMSF related limitation.**

Application of different degree of EMSF is perused in this study where EMSF₁ involves walking only, EMSF₂ includes walking and cycling only and EMSF₃ describes full application of walking, cycling and public transportation related

strategies have been fully applied. Scope of this study does not examine the other combinations of eco-mobility strategies and also does not scrutinise the partial application of strategies (e.g., partial implementation of walking, cycling and public transportation combination).

- **NS related limitations.**

Neighborhood scenarios hypothesised and developed in this study are based on West-5 and examines the rectangular and radial road pattern only. Combination of road patterns or cul-de-sac for residential neighborhoods are not explored in this study.

- **DOAA related limitations.**

Degree of amenities explored in this study looks into each of the amenities individually and also in combination. This study only examines two combinations (e.g., DOAA₄ with living, walking, supplying and learning and DOAA₆ with six amenities altogether). Other combinations of amenities are not explored in this study. Also, the density of the amenities in the neighborhood scenario is not examined here. Land use and spatial reallocation of amenities are not explored in this study.

- **STI related limitations.**

This study looked into sustainable development of urban neighborhood by calculating 2 environmental (e.g., CO₂ and energy), 1 social (travel time) and 1 economic indicator (e.g., net annual cost). Other environmental (e.g., air quality, social (e.g., accessibility to essential services, traffic safety) and economic (e.g., transportation affordability, infrastructure and maintenance cost) are not studied in this research work. STIs described in this study are calculated from the traffic data of the base case neighborhood (i.e., London city) and hypothesized neighborhood scenarios. Absence of updated and West-5 specific traffic data was thwarted by application of traffic data from “2016 Household Travel Survey Summary Report” that summarises the traffic data for the census metropolitan area (CMA). Specific traffic behaviour (e.g., modal ratio and number of trips to different amenities) of the West-5 dwellers could yield better result for this research work. For example, this study assumed that all trips are originated from residence and also assumed that number of trips from residence to supplying, caring and leisure are distributed in same ratio. 2016 based London city survey mentioned that 48% loyal automobile users never shift to eco-mobility modes and this study assumes that the modal ratio of remaining 52% are equally distributed on walking, cycling and public transportation. However, traffic data in case of spatial redistribution of amenities is not available. Such data could’ve been collected from neighborhood specific household surveys. This study assumed that traffic behavior of neighborhood dwellers are not climate sensitive which puts a major limitation on this study.

In summary, this research considers modal ratio and number of trips to amenities static and also considers the dwellers choice of transportation mode fixed and homogenous with

respect to time and climate. These limitations are covered in this research work by assuming that they are static. However, the methodology mentioned in this research work is applicable and remains the same when these limitations are met.

5.4.2. Future research needs

Future research work based on the flowchart mentioned in figure 20 and table 18 should proceed with updated and neighborhood specific traffic data. Also, more degrees and combinations of EMSF and DOAA maybe explored to get a tailored view of the neighborhood. For example, partial implementation of walking, cycling and public transportation combination should be explored. More STI should be introduced in future research works get a more accurate picture for different scenarios.

This study looks into multi-functional neighborhood such as 15-minute cities from amenity-mobility combined perspective. However, government policies and community opinion or acceptability pertaining to this contemporary urban planning concept warrants more research work.

Future work should address the unexamined issues identified in this study to develop a more comprehensive and adaptable framework for sustainable urban planning. Such a framework would extend beyond the 15-minute city concept, incorporating a wider range of variables related to mobility, land use, energy systems, and community resilience. Building on this foundation, subsequent research can focus on real-world applications and validation across different urban contexts, enabling broader insights into how integrated planning approaches can contribute to emission reduction and improved livability.

6. Conclusion

The overall objective of this research was to develop a comprehensive framework that integrates multifunctional neighborhoods with eco-mobility strategies, guided by the principles of the 15-minute city, and to apply it in the Canadian context. Building on this objective, the study contributes to the literature on sustainable neighborhood development from both Canadian and global perspectives. The research work has shown the potential of integrating a multi-functional neighborhood (e.g., 15-minute city) with eco-mobility strategies (EMS) and form a framework where spatial redistribution of amenities coupled with sustainable transportation features have contributed in reduction of environmental, social and economic impact of sustainable development involving urban neighborhood and transportation system. This research work amalgamates spatial redistribution of resources with eco-mobility and the resultant is Eco-Mobility Strategic Framework (EMSF) and Decision-Making Metric (DMM). Novelty of this study is introduction of a DMM that has combined all the sustainable transportation indicators (STIs) and yielded Framework Performance Coefficient (FPC) and Decision-Making Metric Value (DMMV). DMMV is a single number that aids the policy makers to select strategies.

The EMSF selects EMS and degree of its application in different Neighborhood Scenario (NS) and Degree of Amenity Availability (DOAA) and finally measures the impacts of EMS with the aid of STIs. Combining EMSF with DMM, this research work proposes framework of a guideline named “Mobility on neighborhood: Amenity-Mobility Integration” (Mon-AMI). This application takes input from EMSF, NS and DOAA related data and applies them on Mon-AMI and computes the STIs. Using the STIs in the DMM, Mon-AMI produces results showing comparative effectiveness of different Eco-Mobility Strategies.

West-5, Ontario – largest solar neighborhood in North America has been taken as base case scenario for this study and it yielded maximum results for the selected STIs (e.g., annual CO₂ emission, annual energy consumption, annual travel time and annual net cost). Three degrees of EMSF is examined in this study that describes EMSF₁ i.e., walking only, EMSF₂ i.e., walking and cycling and EMSF₃ i.e., walking, cycling and public transportation system. All the EMSFs show significant reduction in all STIs. However, a more focused scrutiny shows that EMSF₁ and EMSF₂ yields lowest annual CO₂ emission, annual energy consumption and annual net cost while EMSF₃ has lowest annual travel time. EMSF₁ and EMSF₂ comprises of active mode of transportation which are non-carbon emitting modes while EMSF₃ has modes that have higher speed.

All the STI values are significantly reduced from their base case values due to reduction of trip length which resulted from availability of amenities in multi-functional neighborhood. NS perused in this study are multi-functional urban neighborhoods where the principals of 15-minute city have been applied resulting in trip lengths that are less than 15-minute walking distance i.e., 1.2 km. EMSF₁ reduces number of automobile-based trips while increasing walking-based trips. As a result of trip length and Carbon emitting trip reduction, all the STI values i.e., annual CO₂ emission, annual energy consumption, annual travel time and annual net cost have been significantly reduced (e.g., about 97%). It is obvious from the studies that increase in number of

amenities in the neighborhood generates more trips and trip length also increases which results in increased STI values.

Both EMSF₁ and EMSF₂ peruses same Neighborhood Scenarios (NS) thus the trip lengths for both the cases remain same. However, number of trips using automobile and/or walking and/or cycling mode of transportation changes. This results in same annual CO₂ emission and energy consumption for both EMSF₁ and EMSF₂. But annual travel time is reduced in EMSF₂ from EMSF₁. Across different Neighborhood Scenarios (NS), it is observed that rectangular NS has less STI values or impact than corresponding radial NS having same area.

Eco-Mobility Strategic Framework-3 (EMSF₃) implements walking, cycling and public transportation in Neighborhood Scenarios (NS) at different Degree of Amenity Availability (DOAA). Inclusion of public transportation reduces the annual travel time further by 23% but annual CO₂ emission, annual energy consumption and annual net cost in EMSF₃ increases by two folds in EMSF₃. Again, the Neighborhood Scenario (NS) in EMSF₃ shows similar results for previous EMSF where rectangular NS shows lower STI than radial NS.

In line with the final objective of this research work, effectivity of EMSF is quantified and measured using DMM comprising a FPC where STIs for EMSF₁ to EMSF₃ are compared against base case EMSF₀ and a DMMV that sums up the FPCs with respect to weightage on importance of STI. FPC values in this research work depict significant reduction of environmental, social and economic impacts upon introduction of Eco-Mobility Strategic Framework (EMSF). FPC shows least value for least for EMSF₁ i.e., walking only and highest value for EMSF₃ i.e., walking, cycling & public transportation. Finally, the DMMV in this study have been applied where all the indicators are given equal weightage which resulted in one single number for each EMSF. The policy-makers have the flexibility to modify the weightage for each indicator as per their preference.

Flexibility and versatility of the integrated amenity-mobility framework presented in this research work permits for its adaptation and implementation to different urban scenarios, contexts and transportation systems, making it an effective tool for urban planners and policy makers worldwide.

This study proposes a framework on Eco-Mobility and spatially redistributes the amenities in a multi-functional neighborhood that effects the traffic behavior of neighborhood dwellers resulting in reduced GHG emission. The framework is applied in multiple neighborhood scenarios and effect of the Eco-Mobility Strategic Framework (EMSF) at different Degree of Amenity Availability (DOAA) is perused. Impact of EMSF is measured using Sustainable Transportation Indicators (STI). Application of EMSF significantly reduces the STI values with respect to base case scenario. A Decision-Making Metric (DMM) is proposed where Framework Performance Coefficient (FPC) and Decision Making Metric Value (DMMV) are introduced to aid the policy-makers. Finally, a scalable framework called “Mobility on Neighborhood: Amenity-Mobility Integration” (Mon-AMI) is developed depicting the spatial redistribution of amenities alongside introduction of eco-mobility in urban neighborhood. Significant reduction in annual CO₂ emission, annual energy consumption, annual travel time and annual net cost from

execution of EMSF introduced in this study further signifies the importance of EMS in context of sustainable development.

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Appendices

Appendix-1: Sustainable Transportation Indicator ($STI_{1 \text{ to } 4}$) [Annual CO_2 emission (STI_1), Annual Energy Consumption (STI_2), Annual Travel Time (STI_3) and Net Annual Cost (STI_4)] for Eco-Mobility Strategic Framework (EMS_{F0-3}) [base case (EMS_{F0}), walking only (EMS_{F0}), walking & cycling (EMS_{F0}) and walking, cycling & public transportation (EMS_{F0})] in different Degree of Amenity Availability (DOAA) [Residence & working (AR+AW), Residence & supplying (AR+AS), Residence & learning (AR+AL), Residence & caring (AR+AC), Residence & leisure/enjoying (AR+AE), Residence, working, supplying & learning (AR+AW+AS+AL), Residence, working, supplying, learning, caring and leisure/enjoying (AR+AW+AS+AL+AC+AE)]

Appendix-2: Framework Performance Coefficient (FPC) for Eco-Mobility Strategic Framework (EMS_F) with respect to different Neighborhood Scenarios (NS) and Degree of Amenity Availability (DOAA).

Appendix-3: Decision Making Metric Value (DMMV) for Eco-Mobility Strategic Framework (EMS_F) with respect to different Neighborhood Scenarios (NS) and Degree of Amenity Availability (DOAA).

Appendix-4: Decision Making Metric Value (DMMV) for Eco-Mobility Strategic Framework (EMS_F) with respect to Neighborhood Scenarios-2 and 5 (NS-2 & 5), different ratio of utilization of neighborhood amenity by dwellers and Degree of Amenity Availability (DOAA). [WeightFactor for $STI_{1 \text{ to } 4} = 0.25$]

Appendix-1

Sustainable Transportation Indicator (STI_{1 to 4}) [Annual CO₂ emission (STI₁), Annual Energy Consumption (STI₂), Annual Travel Time (STI₃) and Net Annual Cost (STI₄)] for Eco-Mobility Strategic Framework (EMSF₀₋₃) [base case (EMSF₀), walking only (EMSF₀), walking & cycling (EMSF₀) and walking, cycling & public transportation (EMSF₀)] in different Degree of Amenity Availability (DOAA) [Residence & working (AR+AW), Residence & supplying (AR+AS), Residence & learning (AR+AL), Residence & caring (AR+AC), Residence & leisure/enjoying (AR+AE), Residence, working, supplying & learning (AR+AW+AS+AL), Residence, working, supplying, learning, caring and leisure/enjoying (AR+AW+AS+AL+AC+AE)]

Serial No of Iteration	Eco-Mobility Strategic Framework (EMSF)** (i=0to4)	Neighborhood Scenario (NS)*** (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	<u>Combined STI*</u> <u>(Auto+walk+cycle+bus)</u>			
				STI1 (kg/ye ar)	STI2 (kW- Hr/ye ar)	STI3 (Hr/Ye ar)	STI4 (C\$/Ye ar)
1	EMSF0 = Base Case		DOAA2 (AR + AW)	474.20	735.73	110.37	327.11
2	EMSF0 = Base Case		DOAA2 (AR + AS)	452.41	750.36	98.55	311.53
3	EMSF0 = Base Case		DOAA2 (AR + AL)	91.15	138.88	22.10	62.91
4	EMSF0 = Base Case		DOAA2 (AR + AC)	221.68	367.67	48.29	152.65
5	EMSF0 = Base Case		DOAA2 (AR + AE)	294.07	487.73	64.06	202.49
6	EMSF0 = Base Case		DOAA4 (AR + AW + AS + AL)	924.65	1467.5 2	211.62	637.46
7	EMSF0 = Base Case		DOAA6 (AR + AW + AS + AL + AC + AE)	1454.1 8	2352.8 2	325.88	1002.0 1
8	EMSF1 = Walking only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AW)	5.13	4.35	11.90	138.16
9	EMSF1 = Walking only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AS)	7.70	6.52	17.13	132.42
10	EMSF1 = Walking only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AL)	2.36	2.00	5.48	26.03
11	EMSF1 = Walking only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AC)	6.12	5.18	13.62	63.25

Serial No of Iteration	Eco-Mobility Strategic Framework (EMSF)** (i=0to4)	Neighborhood Scenario (NS)*** (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	<u>Combined STI*</u> <u>(Auto+walk+cycle+bus)</u>			
				STI1 (kg/ye ar)	STI2 (kW- Hr/ye ar)	STI3 (Hr/Ye ar)	STI4 (C\$/Ye ar)
12	EMSF1 = Walking only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AE)	5.53	4.68	12.30	85.71
13	EMSF1 = Walking only	NS1 = Rectangular NU (31.85 acre)	DOAA4 (AR + AW + AS + AL)	14.94	12.64	34.10	268.75
14	EMSF1 = Walking only	NS1 = Rectangular NU (31.85 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	26.39	22.34	59.58	422.30
15	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	7.37	6.24	17.08	136.61
16	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	11.06	9.36	24.60	130.08
17	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	3.59	3.04	8.33	25.17
18	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	8.49	7.19	18.89	61.59
19	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	8.49	7.19	18.89	83.64
20	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	21.64	18.31	49.39	264.08
21	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	39.13	33.12	88.34	413.41
22	EMSF1 = Walking only	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AW)	6.92	5.86	16.04	136.92
23	EMSF1 = Walking only	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AS)	6.32	5.35	14.06	133.38
24	EMSF1 = Walking only	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AL)	2.93	2.48	6.80	25.64

Serial No of Iteration	Eco-Mobility Strategic Framework (EMSF)** (i=0to4)	Neighborhood Scenario (NS)*** (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Combined STI* (Auto+walk+cycle+bus)			
				STI1 (kg/ye ar)	STI2 (kW- Hr/ye ar)	STI3 (Hr/Ye ar)	STI4 (C\$/Ye ar)
25	EMSF1 = Walking only	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AC)	6.12	5.18	13.62	63.25
26	EMSF1 = Walking only	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AE)	6.12	5.18	13.62	85.29
27	EMSF1 = Walking only	NS3 = Rectangular NC (700 acre)	DOAA4 (AR + AW + AS + AL)	15.97	13.52	36.46	268.04
28	EMSF1 = Walking only	NS3 = Rectangular NC (700 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	28.21	23.88	63.69	421.03
29	EMSF1 = Walking only	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AW)	6.25	5.29	14.49	137.38
30	EMSF1 = Walking only	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AS)	7.90	6.69	17.57	132.28
31	EMSF1 = Walking only	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AL)	2.83	2.40	6.58	25.70
32	EMSF1 = Walking only	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AC)	7.11	6.02	15.81	62.56
33	EMSF1 = Walking only	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AE)	7.70	6.52	17.13	84.19
34	EMSF1 = Walking only	NS4 = Radial NU (31.83 acre)	DOAA4 (AR + AW + AS + AL)	17.00	14.39	38.81	267.32
35	EMSF1 = Walking only	NS4 = Radial NU (31.83 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	31.85	26.96	71.91	418.49
36	EMSF1 = Walking only	NS5 = Radial NU (70 acre)	DOAA2 (AR + AW)	8.93	7.56	20.70	135.52
37	EMSF1 = Walking only	NS5 = Radial NU (70 acre)	DOAA2 (AR + AS)	10.86	9.19	24.16	130.21

Serial No of Iteration	Eco-Mobility Strategic Framework (EMSF)** (i=0to4)	Neighborhood Scenario (NS)*** (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Combined STI* (Auto+walk+cycle+bus)			
				STI1 (kg/ye ar)	STI2 (kW- Hr/ye ar)	STI3 (Hr/Ye ar)	STI4 (C\$/Ye ar)
38	EMSF1 = Walking only	NS5 = Radial NU (70 acre)	DOAA2 (AR + AL)	3.68	3.12	8.55	25.11
39	EMSF1 = Walking only	NS5 = Radial NU (70 acre)	DOAA2 (AR + AC)	9.28	7.86	20.64	61.04
40	EMSF1 = Walking only	NS5 = Radial NU (70 acre)	DOAA2 (AR + AE)	9.68	8.19	21.52	82.81
41	EMSF1 = Walking only	NS5 = Radial NU (70 acre)	DOAA4 (AR + AW + AS + AL)	23.18	19.62	52.92	263.00
42	EMSF1 = Walking only	NS5 = Radial NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	41.86	35.43	94.51	411.51
43	EMSF1 = Walking only	NS6 = Radial NU (700 acre)	DOAA2 (AR + AW)	7.81	6.61	18.11	136.29
44	EMSF1 = Walking only	NS6 = Radial NU (700 acre)	DOAA2 (AR + AS)	10.86	9.19	24.16	130.21
45	EMSF1 = Walking only	NS6 = Radial NU (700 acre)	DOAA2 (AR + AL)	3.68	3.12	8.55	25.11
46	EMSF1 = Walking only	NS6 = Radial NU (700 acre)	DOAA2 (AR + AC)	6.12	5.18	13.62	63.25
47	EMSF1 = Walking only	NS6 = Radial NU (700 acre)	DOAA2 (AR + AE)	8.69	7.35	19.33	83.50
48	EMSF1 = Walking only	NS6 = Radial NU (700 acre)	DOAA4 (AR + AW + AS + AL)	22.15	18.75	50.57	263.72
49	EMSF1 = Walking only	NS6 = Radial NU (700 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	37.31	31.58	84.23	414.68
50	EMSF2 = Walking & Cycling only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AW)	5.13	4.35	6.77	138.16

Serial No of Iteration	Eco-Mobility Strategic Framework (EMSF)** (i=0to4)	Neighborhood Scenario (NS)*** (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Combined STI* (Auto+walk+cycle+bus)			
				STI1 (kg/ye ar)	STI2 (kW- Hr/ye ar)	STI3 (Hr/Ye ar)	STI4 (C\$/Ye ar)
51	EMSF2 = Walking & Cycling only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AS)	7.70	6.52	9.91	132.42
52	EMSF2 = Walking & Cycling only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AL)	2.36	2.00	3.05	26.03
53	EMSF2 = Walking & Cycling only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AC)	6.12	5.18	7.88	63.25
54	EMSF2 = Walking & Cycling only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AE)	5.53	4.68	7.11	85.71
55	EMSF2 = Walking & Cycling only	NS1 = Rectangular NU (31.85 acre)	DOAA4 (AR + AW + AS + AL)	14.94	12.64	19.44	268.75
56	EMSF2 = Walking & Cycling only	NS1 = Rectangular NU (31.85 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	26.39	22.34	34.17	422.30
57	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	7.37	6.24	9.71	136.61
58	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	11.06	9.36	14.23	130.08
59	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	3.59	3.04	4.63	25.17
60	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	8.49	7.19	10.93	61.59
61	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	8.49	7.19	10.93	83.64
62	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	21.64	18.31	28.15	264.08
63	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	39.13	33.12	50.67	413.41

Serial No of Iteration	Eco-Mobility Strategic Framework (EMSF)** (i=0to4)	Neighborhood Scenario (NS)*** (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Combined STI* (Auto+walk+cycle+bus)			
				STI1 (kg/ye ar)	STI2 (kW- Hr/ye ar)	STI3 (Hr/Ye ar)	STI4 (C\$/Ye ar)
64	EMSF2 = Walking & Cycling only	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AW)	6.92	5.86	9.12	136.92
65	EMSF2 = Walking & Cycling only	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AS)	6.32	5.35	8.13	133.38
66	EMSF2 = Walking & Cycling only	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AL)	2.93	2.48	3.78	25.64
67	EMSF2 = Walking & Cycling only	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AC)	6.12	5.18	7.88	63.25
68	EMSF2 = Walking & Cycling only	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AE)	6.12	5.18	7.88	85.29
69	EMSF2 = Walking & Cycling only	NS3 = Rectangular NC (700 acre)	DOAA4 (AR + AW + AS + AL)	15.97	13.52	20.78	268.04
70	EMSF2 = Walking & Cycling only	NS3 = Rectangular NC (700 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	28.21	23.88	36.53	421.03
71	EMSF2 = Walking & Cycling only	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AW)	6.25	5.29	8.24	137.38
72	EMSF2 = Walking & Cycling only	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AS)	7.90	6.69	10.16	132.28
73	EMSF2 = Walking & Cycling only	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AL)	2.83	2.40	3.66	25.70
74	EMSF2 = Walking & Cycling only	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AC)	7.11	6.02	9.15	62.56
75	EMSF2 = Walking & Cycling only	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AE)	7.70	6.52	9.91	84.19
76	EMSF2 = Walking & Cycling only	NS4 = Radial NU (31.83 acre)	DOAA4 (AR + AW + AS + AL)	17.00	14.39	22.12	267.32

Serial No of Iteration	Eco-Mobility Strategic Framework (EMSF)** (i=0to4)	Neighborhood Scenario (NS)*** (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Combined STI* (Auto+walk+cycle+bus)			
				STI1 (kg/ye ar)	STI2 (kW- Hr/ye ar)	STI3 (Hr/Ye ar)	STI4 (C\$/Ye ar)
77	EMSF2 = Walking & Cycling only	NS4 = Radial NU (31.83 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	31.85	26.96	41.25	418.49
78	EMSF2 = Walking & Cycling only	NS5 = Radial NU (70 acre)	DOAA2 (AR + AW)	8.93	7.56	11.77	135.52
79	EMSF2 = Walking & Cycling only	NS5 = Radial NU (70 acre)	DOAA2 (AR + AS)	10.86	9.19	13.97	130.21
80	EMSF2 = Walking & Cycling only	NS5 = Radial NU (70 acre)	DOAA2 (AR + AL)	3.68	3.12	4.76	25.11
81	EMSF2 = Walking & Cycling only	NS5 = Radial NU (70 acre)	DOAA2 (AR + AC)	9.28	7.86	11.94	61.04
82	EMSF2 = Walking & Cycling only	NS5 = Radial NU (70 acre)	DOAA2 (AR + AE)	9.68	8.19	12.45	82.81
83	EMSF2 = Walking & Cycling only	NS5 = Radial NU (70 acre)	DOAA4 (AR + AW + AS + AL)	23.18	19.62	30.16	263.00
84	EMSF2 = Walking & Cycling only	NS5 = Radial NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	41.86	35.43	54.21	411.51
85	EMSF2 = Walking & Cycling only	NS6 = Radial NU (700 acre)	DOAA2 (AR + AW)	7.81	6.61	10.30	136.29
86	EMSF2 = Walking & Cycling only	NS6 = Radial NU (700 acre)	DOAA2 (AR + AS)	10.86	9.19	13.97	130.21
87	EMSF2 = Walking & Cycling only	NS6 = Radial NU (700 acre)	DOAA2 (AR + AL)	3.68	3.12	4.76	25.11
88	EMSF2 = Walking & Cycling only	NS6 = Radial NU (700 acre)	DOAA2 (AR + AC)	6.12	5.18	7.88	63.25
89	EMSF2 = Walking & Cycling only	NS6 = Radial NU (700 acre)	DOAA2 (AR + AE)	8.69	7.35	11.18	83.50

Serial No of Iteration	Eco-Mobility Strategic Framework (EMSF)** (i=0to4)	Neighborhood Scenario (NS)*** (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Combined STI* (Auto+walk+cycle+bus)			
				STI1 (kg/ye ar)	STI2 (kW- Hr/ye ar)	STI3 (Hr/Ye ar)	STI4 (C\$/Ye ar)
90	EMSF2 = Walking & Cycling only	NS6 = Radial NU (700 acre)	DOAA4 (AR + AW + AS + AL)	22.15	18.75	28.82	263.72
91	EMSF2 = Walking & Cycling only	NS6 = Radial NU (700 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	37.31	31.58	48.32	414.68
92	EMSF3 = Walking, Cycling and Public Transportation	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AW)	9.63	41.96	5.18	244.44
93	EMSF3 = Walking, Cycling and Public Transportation	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AS)	14.18	60.73	7.49	230.29
94	EMSF3 = Walking, Cycling and Public Transportation	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AL)	4.32	18.35	2.26	44.96
95	EMSF3 = Walking, Cycling and Public Transportation	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AC)	11.27	48.27	5.95	109.99
96	EMSF3 = Walking, Cycling and Public Transportation	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AE)	10.18	43.60	5.37	149.06
97	EMSF3 = Walking, Cycling and Public Transportation	NS1 = Rectangular NU (31.85 acre)	DOAA4 (AR + AW + AS + AL)	27.70	119.34	14.72	470.32
98	EMSF3 = Walking, Cycling and Public Transportation	NS1 = Rectangular NU (31.85 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	48.79	209.65	25.85	737.04
99	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	13.82	60.20	7.43	241.69
100	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	20.36	87.20	10.75	226.22
101	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	6.56	27.89	3.44	43.48
102	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	15.64	66.95	8.25	107.12

Serial No of Iteration	Eco-Mobility Strategic Framework (EMSF)** (i=0to4)	Neighborhood Scenario (NS)*** (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Combined STI* (Auto+walk+cycle+bus)			
				STI1 (kg/ye ar)	STI2 (kW- Hr/ye ar)	STI3 (Hr/Ye ar)	STI4 (C\$/Ye ar)
103	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	15.64	66.95	8.25	145.46
104	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	40.11	172.84	21.31	462.14
105	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	72.34	310.86	38.33	721.52
106	EMSF3 = Walking, Cycling and Public Transportation	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AW)	12.98	56.55	6.98	242.24
107	EMSF3 = Walking, Cycling and Public Transportation	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AS)	11.64	49.83	6.14	231.97
108	EMSF3 = Walking, Cycling and Public Transportation	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AL)	5.35	22.75	2.80	44.28
109	EMSF3 = Walking, Cycling and Public Transportation	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AC)	11.27	48.27	5.95	109.99
110	EMSF3 = Walking, Cycling and Public Transportation	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AE)	11.27	48.27	5.95	148.34
111	EMSF3 = Walking, Cycling and Public Transportation	NS3 = Rectangular NC (700 acre)	DOAA4 (AR + AW + AS + AL)	29.61	127.57	15.73	469.06
112	EMSF3 = Walking, Cycling and Public Transportation	NS3 = Rectangular NC (700 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	52.15	224.11	27.63	734.82
113	EMSF3 = Walking, Cycling and Public Transportation	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AW)	11.72	51.08	6.30	243.07
114	EMSF3 = Walking, Cycling and Public Transportation	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AS)	14.55	62.28	7.68	230.05
115	EMSF3 = Walking, Cycling and Public Transportation	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AL)	5.18	22.02	2.71	44.39

Serial No of Iteration	Eco-Mobility Strategic Framework (EMSF)** (i=0to4)	Neighborhood Scenario (NS)*** (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Combined STI* (Auto+walk+cycle+bus)			
				STI1 (kg/ye ar)	STI2 (kW- Hr/ye ar)	STI3 (Hr/Ye ar)	STI4 (C\$/Ye ar)
116	EMSF3 = Walking, Cycling and Public Transportation	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AC)	13.09	56.05	6.91	108.80
117	EMSF3 = Walking, Cycling and Public Transportation	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AE)	14.18	60.73	7.49	146.42
118	EMSF3 = Walking, Cycling and Public Transportation	NS4 = Radial NU (31.83 acre)	DOAA4 (AR + AW + AS + AL)	31.52	135.80	16.75	467.80
119	EMSF3 = Walking, Cycling and Public Transportation	NS4 = Radial NU (31.83 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	58.88	253.03	31.20	730.39
120	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Radial NU (70 acre)	DOAA2 (AR + AW)	16.75	72.97	9.00	239.76
121	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Radial NU (70 acre)	DOAA2 (AR + AS)	20.00	85.64	10.56	226.46
122	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Radial NU (70 acre)	DOAA2 (AR + AL)	6.73	28.63	3.53	43.37
123	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Radial NU (70 acre)	DOAA2 (AR + AC)	17.09	73.18	9.02	106.16
124	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Radial NU (70 acre)	DOAA2 (AR + AE)	17.82	76.30	9.41	144.02
125	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Radial NU (70 acre)	DOAA4 (AR + AW + AS + AL)	42.98	185.19	22.83	460.26
126	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Radial NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	77.39	332.55	41.00	718.20
127	EMSF3 = Walking, Cycling and Public Transportation	NS6 = Radial NU (700 acre)	DOAA2 (AR + AW)	14.66	63.85	7.88	241.14
128	EMSF3 = Walking, Cycling and Public Transportation	NS6 = Radial NU (700 acre)	DOAA2 (AR + AS)	20.00	85.64	10.56	226.46

Serial No of Iteration	Eco-Mobility Strategic Framework (EMSF)** (i=0to4)	Neighborhood Scenario (NS)*** (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Combined STI* (Auto+walk+cycle+bus)			
				STI1 (kg/ye ar)	STI2 (kW-Hr/ye ar)	STI3 (Hr/Ye ar)	STI4 (C\$/Ye ar)
129	EMSF3 = Walking, Cycling and Public Transportation	NS6 = Radial NU (700 acre)	DOAA2 (AR + AL)	6.73	28.63	3.53	43.37
130	EMSF3 = Walking, Cycling and Public Transportation	NS6 = Radial NU (700 acre)	DOAA2 (AR + AC)	11.27	48.27	5.95	109.99
131	EMSF3 = Walking, Cycling and Public Transportation	NS6 = Radial NU (700 acre)	DOAA2 (AR + AE)	16.00	68.51	8.45	145.22
132	EMSF3 = Walking, Cycling and Public Transportation	NS6 = Radial NU (700 acre)	DOAA4 (AR + AW + AS + AL)	41.07	176.95	21.82	461.51
133	EMSF3 = Walking, Cycling and Public Transportation	NS6 = Radial NU (700 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	68.97	296.40	36.54	723.74
*Combined STI values are summation of 4 modes of transportation - automobiles, walking, cycling and public transportation.							
**EMSF ₀ = Base Case at West-5 where walking, cycling and public transportation related strategies are not implemented; EMSF ₁ = Walking related strategies are implemented; EMSF ₂ = Walking & Cycling related strategies are implemented; EMSF ₃ = Walking, Cycling and Public Transportation related strategies are implemented.							
***NS ₁ = Rectangular NU (31.85 acre); NS ₂ = Rectangular NU (70 acre); NS ₃ = Rectangular NC (700 acre); NS ₄ = Radial NU (31.83 acre); NS ₅ = Radial NU (70 acre); NS ₆ = Radial NU (700 acre).							

Appendix-2

Framework Performance Coefficient (FPC) for Eco-Mobility Strategies with respect to different Neighborhood Scenarios (NS) and Degree of Amenity Availability (DOAA)

Eco-Mobility Strategic Framework (EMSF) (i=0to3)	Neighborhood Scenario (NS) (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Framework Performance Coefficient (FPC)			
			STI-1	STI-2	STI-3	STI-4
EMSF₀ = Base Case	Base Case at West-5	DOAA2 (AR + AW)	1.00	1.00	1.00	1.00
		DOAA2 (AR + AS)	1.00	1.00	1.00	1.00
		DOAA2 (AR + AL)	1.00	1.00	1.00	1.00
		DOAA2 (AR + AC)	1.00	1.00	1.00	1.00
		DOAA2 (AR + AE)	1.00	1.00	1.00	1.00
		DOAA4 (AR + AW + AS + AL)	1.00	1.00	1.00	1.00
		DOAA6 (AR + AW + AS + AL + AC + AE)	1.00	1.00	1.00	1.00
EMSF₁ = Walking only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AW)	0.01	0.01	0.11	0.42
		DOAA2 (AR + AS)	0.02	0.01	0.17	0.43
		DOAA2 (AR + AL)	0.03	0.01	0.25	0.41
		DOAA2 (AR + AC)	0.03	0.01	0.28	0.41
		DOAA2 (AR + AE)	0.02	0.01	0.19	0.42
		DOAA4 (AR + AW + AS + AL)	0.02	0.01	0.16	0.42
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.02	0.01	0.18	0.42
	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	0.02	0.01	0.15	0.42
		DOAA2 (AR + AS)	0.02	0.01	0.25	0.42
		DOAA2 (AR + AL)	0.04	0.02	0.38	0.40
		DOAA2 (AR + AC)	0.04	0.02	0.39	0.40
		DOAA2 (AR + AE)	0.03	0.01	0.29	0.41

Eco-Mobility Strategic Framework (EMSF) (i=0to3)	Neighborhood Scenario (NS) (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Framework Performance Coefficient (FPC)			
			STI-1	STI-2	STI-3	STI-4
		DOAA4 (AR + AW + AS + AL)	0.02	0.01	0.23	0.41
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.03	0.01	0.27	0.41
	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AW)	0.01	0.01	0.15	0.42
		DOAA2 (AR + AS)	0.01	0.01	0.14	0.43
		DOAA2 (AR + AL)	0.03	0.02	0.31	0.41
		DOAA2 (AR + AC)	0.03	0.01	0.28	0.41
		DOAA2 (AR + AE)	0.02	0.01	0.21	0.42
		DOAA4 (AR + AW + AS + AL)	0.02	0.01	0.17	0.42
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.02	0.01	0.20	0.42
	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AW)	0.01	0.01	0.13	0.42
		DOAA2 (AR + AS)	0.02	0.01	0.18	0.42
		DOAA2 (AR + AL)	0.03	0.02	0.30	0.41
		DOAA2 (AR + AC)	0.03	0.02	0.33	0.41
		DOAA2 (AR + AE)	0.03	0.01	0.27	0.42
		DOAA4 (AR + AW + AS + AL)	0.02	0.01	0.18	0.42
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.02	0.01	0.22	0.42

Eco-Mobility Strategic Framework (EMSF) (i=0to3)	Neighborhood Scenario (NS) (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Framework Performance Coefficient (FPC)			
			STI-1	STI-2	STI-3	STI-4
	NS5 = Radial NU (70 acre)	DOAA2 (AR + AW)	0.02	0.01	0.19	0.41
		DOAA2 (AR + AS)	0.02	0.01	0.25	0.42
		DOAA2 (AR + AL)	0.04	0.02	0.39	0.40
		DOAA2 (AR + AC)	0.04	0.02	0.43	0.40
		DOAA2 (AR + AE)	0.03	0.02	0.34	0.41
		DOAA4 (AR + AW + AS + AL)	0.03	0.01	0.25	0.41
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.03	0.02	0.29	0.41
	NS6 = Radial NU (700 acre)	DOAA2 (AR + AW)	0.02	0.01	0.16	0.42
		DOAA2 (AR + AS)	0.02	0.01	0.25	0.42
		DOAA2 (AR + AL)	0.04	0.02	0.39	0.40
		DOAA2 (AR + AC)	0.03	0.01	0.28	0.41
		DOAA2 (AR + AE)	0.03	0.02	0.30	0.41
		DOAA4 (AR + AW + AS + AL)	0.02	0.01	0.24	0.41
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.03	0.01	0.26	0.41
EMSF₂ = Walking & Cycling only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AW)	0.01	0.01	0.06	0.42
		DOAA2 (AR + AS)	0.02	0.01	0.10	0.43
		DOAA2 (AR + AL)	0.03	0.01	0.14	0.41
		DOAA2 (AR + AC)	0.03	0.01	0.16	0.41
		DOAA2 (AR + AE)	0.02	0.01	0.11	0.42

Eco-Mobility Strategic Framework (EMSF) (i=0to3)	Neighborhood Scenario (NS) (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Framework Performance Coefficient (FPC)			
			STI-1	STI-2	STI-3	STI-4
		DOAA4 (AR + AW + AS + AL)	0.02	0.01	0.09	0.42
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.02	0.01	0.10	0.42
	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	0.02	0.01	0.09	0.42
		DOAA2 (AR + AS)	0.02	0.01	0.14	0.42
		DOAA2 (AR + AL)	0.04	0.02	0.21	0.40
		DOAA2 (AR + AC)	0.04	0.02	0.23	0.40
		DOAA2 (AR + AE)	0.03	0.01	0.17	0.41
		DOAA4 (AR + AW + AS + AL)	0.02	0.01	0.13	0.41
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.03	0.01	0.16	0.41
	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AW)	0.01	0.01	0.08	0.42
		DOAA2 (AR + AS)	0.01	0.01	0.08	0.43
		DOAA2 (AR + AL)	0.03	0.02	0.17	0.41
		DOAA2 (AR + AC)	0.03	0.01	0.16	0.41
		DOAA2 (AR + AE)	0.02	0.01	0.12	0.42
		DOAA4 (AR + AW + AS + AL)	0.02	0.01	0.10	0.42
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.02	0.01	0.11	0.42

Eco-Mobility Strategic Framework (EMSF) (i=0to3)	Neighborhood Scenario (NS) (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Framework Performance Coefficient (FPC)			
			STI-1	STI-2	STI-3	STI-4
	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AW)	0.01	0.01	0.07	0.42
		DOAA2 (AR + AS)	0.02	0.01	0.10	0.42
		DOAA2 (AR + AL)	0.03	0.02	0.17	0.41
		DOAA2 (AR + AC)	0.03	0.02	0.19	0.41
		DOAA2 (AR + AE)	0.03	0.01	0.15	0.42
		DOAA4 (AR + AW + AS + AL)	0.02	0.01	0.10	0.42
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.02	0.01	0.13	0.42
	NS5 = Radial NU (70 acre)	DOAA2 (AR + AW)	0.02	0.01	0.11	0.41
		DOAA2 (AR + AS)	0.02	0.01	0.14	0.42
		DOAA2 (AR + AL)	0.04	0.02	0.22	0.40
		DOAA2 (AR + AC)	0.04	0.02	0.25	0.40
		DOAA2 (AR + AE)	0.03	0.02	0.19	0.41
		DOAA4 (AR + AW + AS + AL)	0.03	0.01	0.14	0.41
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.03	0.02	0.17	0.41
	NS6 = Radial NU (700 acre)	DOAA2 (AR + AW)	0.02	0.01	0.09	0.42
		DOAA2 (AR + AS)	0.02	0.01	0.14	0.42
		DOAA2 (AR + AL)	0.04	0.02	0.22	0.40
		DOAA2 (AR + AC)	0.03	0.01	0.16	0.41
		DOAA2 (AR + AE)	0.03	0.02	0.17	0.41

Eco-Mobility Strategic Framework (EMSF) (i=0to3)	Neighborhood Scenario (NS) (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Framework Performance Coefficient (FPC)			
			STI-1	STI-2	STI-3	STI-4
EMSF ₃ = Walking, Cycling and Public Transportation	NS1 = Rectangular NU (31.85 acre)	DOAA4 (AR + AW + AS + AL)	0.02	0.01	0.14	0.41
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.03	0.01	0.15	0.41
		DOAA2 (AR + AW)	0.02	0.06	0.05	0.75
		DOAA2 (AR + AS)	0.03	0.08	0.08	0.74
		DOAA2 (AR + AL)	0.05	0.13	0.10	0.71
		DOAA2 (AR + AC)	0.05	0.13	0.12	0.72
		DOAA2 (AR + AE)	0.03	0.09	0.08	0.74
		DOAA4 (AR + AW + AS + AL)	0.03	0.08	0.07	0.74
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.03	0.09	0.08	0.74
	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	0.03	0.08	0.07	0.74
		DOAA2 (AR + AS)	0.05	0.12	0.11	0.73
		DOAA2 (AR + AL)	0.07	0.20	0.16	0.69
		DOAA2 (AR + AC)	0.07	0.18	0.17	0.70

Eco-Mobility Strategic Framework (EMSF) (i=0to3)	Neighborhood Scenario (NS) (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Framework Performance Coefficient (FPC)			
			STI-1	STI-2	STI-3	STI-4
		DOAA2 (AR + AE)	0.05	0.14	0.13	0.72
		DOAA4 (AR + AW + AS + AL)	0.04	0.12	0.10	0.72
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.05	0.13	0.12	0.72
	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AW)	0.03	0.08	0.06	0.74
		DOAA2 (AR + AS)	0.03	0.07	0.06	0.74
		DOAA2 (AR + AL)	0.06	0.16	0.13	0.70
		DOAA2 (AR + AC)	0.05	0.13	0.12	0.72
		DOAA2 (AR + AE)	0.04	0.10	0.09	0.73
		DOAA4 (AR + AW + AS + AL)	0.03	0.09	0.07	0.74
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.04	0.10	0.08	0.73
	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AW)	0.02	0.07	0.06	0.74
		DOAA2 (AR + AS)	0.03	0.08	0.08	0.74

Eco-Mobility Strategic Framework (EMSF) (i=0to3)	Neighborhood Scenario (NS) (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Framework Performance Coefficient (FPC)			
			STI-1	STI-2	STI-3	STI-4
		DOAA2 (AR + AL)	0.06	0.16	0.12	0.71
		DOAA2 (AR + AC)	0.06	0.15	0.14	0.71
		DOAA2 (AR + AE)	0.05	0.12	0.12	0.72
		DOAA4 (AR + AW + AS + AL)	0.03	0.09	0.08	0.73
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.04	0.11	0.10	0.73
	NS5 = Radial NU (70 acre)	DOAA2 (AR + AW)	0.04	0.10	0.08	0.73
		DOAA2 (AR + AS)	0.04	0.11	0.11	0.73
		DOAA2 (AR + AL)	0.07	0.21	0.16	0.69
		DOAA2 (AR + AC)	0.08	0.20	0.19	0.70
		DOAA2 (AR + AE)	0.06	0.16	0.15	0.71
		DOAA4 (AR + AW + AS + AL)	0.05	0.13	0.11	0.72
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.05	0.14	0.13	0.72

Eco-Mobility Strategic Framework (EMSF) (i=0to3)	Neighborhood Scenario (NS) (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Framework Performance Coefficient (FPC)			
			STI-1	STI-2	STI-3	STI-4
	NS6 = Radial NU (700 acre)	DOAA2 (AR + AW)	0.03	0.09	0.07	0.74
		DOAA2 (AR + AS)	0.04	0.11	0.11	0.73
		DOAA2 (AR + AL)	0.07	0.21	0.16	0.69
		DOAA2 (AR + AC)	0.05	0.13	0.12	0.72
		DOAA2 (AR + AE)	0.05	0.14	0.13	0.72
		DOAA4 (AR + AW + AS + AL)	0.04	0.12	0.10	0.72
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.05	0.13	0.11	0.72

Appendix-3

Decision Making Metric Value (DMMV) for Eco-Mobility Strategic Framework (EMSF) with respect to different Neighborhood Scenarios (NS) and Degree of Amenity Availability (DOAA). [Weight_{Factor} for STI_{1to4} = 0.25]

Eco-Mobility Strategic Framework (EMSF) (i=0to3)	Neighborhood Scenario (NS) (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Decision Making Metric Value (DMMV)
EMSF ₀ = Base Case	Base Case at West-5	DOAA2 (AR + AW)	1.00
		DOAA2 (AR + AS)	1.00

		DOAA2 (AR + AL)	1.00
		DOAA2 (AR + AC)	1.00
		DOAA2 (AR + AE)	1.00
		DOAA4 (AR + AW + AS + AL)	1.00
		DOAA6 (AR + AW + AS + AL + AC + AE)	1.00
EMSF₁ = Walking only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AW)	0.14
		DOAA2 (AR + AS)	0.16
		DOAA2 (AR + AL)	0.18
		DOAA2 (AR + AC)	0.18
		DOAA2 (AR + AE)	0.16
		DOAA4 (AR + AW + AS + AL)	0.15
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.16
	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	0.15
		DOAA2 (AR + AS)	0.18
		DOAA2 (AR + AL)	0.21
		DOAA2 (AR + AC)	0.21
		DOAA2 (AR + AE)	0.19
		DOAA4 (AR + AW + AS + AL)	0.17
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.18
	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AW)	0.15
		DOAA2 (AR + AS)	0.15
		DOAA2 (AR + AL)	0.19
		DOAA2 (AR + AC)	0.18
		DOAA2 (AR + AE)	0.17
		DOAA4 (AR + AW + AS + AL)	0.15
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.16
	NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AW)	0.14
		DOAA2 (AR + AS)	0.16
		DOAA2 (AR + AL)	0.19
		DOAA2 (AR + AC)	0.20

		DOAA2 (AR + AE)	0.18
		DOAA4 (AR + AW + AS + AL)	0.16
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.17
NS5 = Radial NU (70 acre)		DOAA2 (AR + AW)	0.16
		DOAA2 (AR + AS)	0.17
		DOAA2 (AR + AL)	0.21
		DOAA2 (AR + AC)	0.22
		DOAA2 (AR + AE)	0.20
		DOAA4 (AR + AW + AS + AL)	0.18
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.19
NS6 = Radial NU (700 acre)		DOAA2 (AR + AW)	0.15
		DOAA2 (AR + AS)	0.17
		DOAA2 (AR + AL)	0.21
		DOAA2 (AR + AC)	0.18
		DOAA2 (AR + AE)	0.19
		DOAA4 (AR + AW + AS + AL)	0.17
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.18
EMSF₂ = Walking & Cycling only	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AW)	0.13
		DOAA2 (AR + AS)	0.14
		DOAA2 (AR + AL)	0.15
		DOAA2 (AR + AC)	0.15
		DOAA2 (AR + AE)	0.14
		DOAA4 (AR + AW + AS + AL)	0.13
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.14
	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	0.13
		DOAA2 (AR + AS)	0.15
		DOAA2 (AR + AL)	0.17
		DOAA2 (AR + AC)	0.17
		DOAA2 (AR + AE)	0.16
		DOAA4 (AR + AW + AS + AL)	0.15

NS3 = Rectangular NC (700 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	0.15
	DOAA2 (AR + AW)	0.13
	DOAA2 (AR + AS)	0.13
	DOAA2 (AR + AL)	0.16
	DOAA2 (AR + AC)	0.15
	DOAA2 (AR + AE)	0.14
	DOAA4 (AR + AW + AS + AL)	0.14
	DOAA6 (AR + AW + AS + AL + AC + AE)	0.14
NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AW)	0.13
	DOAA2 (AR + AS)	0.14
	DOAA2 (AR + AL)	0.16
	DOAA2 (AR + AC)	0.16
	DOAA2 (AR + AE)	0.15
	DOAA4 (AR + AW + AS + AL)	0.14
	DOAA6 (AR + AW + AS + AL + AC + AE)	0.14
NS5 = Radial NU (70 acre)	DOAA2 (AR + AW)	0.14
	DOAA2 (AR + AS)	0.15
	DOAA2 (AR + AL)	0.17
	DOAA2 (AR + AC)	0.18
	DOAA2 (AR + AE)	0.16
	DOAA4 (AR + AW + AS + AL)	0.15
	DOAA6 (AR + AW + AS + AL + AC + AE)	0.16
NS6 = Radial NU (700 acre)	DOAA2 (AR + AW)	0.13
	DOAA2 (AR + AS)	0.15
	DOAA2 (AR + AL)	0.17
	DOAA2 (AR + AC)	0.15
	DOAA2 (AR + AE)	0.16
	DOAA4 (AR + AW + AS + AL)	0.15
	DOAA6 (AR + AW + AS + AL + AC + AE)	0.15

EMSF₃ = Walking, Cycling and Public Transportation	NS1 = Rectangular NU (31.85 acre)	DOAA2 (AR + AW)	0.22
		DOAA2 (AR + AS)	0.23
		DOAA2 (AR + AL)	0.25
		DOAA2 (AR + AC)	0.26
		DOAA2 (AR + AE)	0.24
		DOAA4 (AR + AW + AS + AL)	0.23
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.23
	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	0.23
		DOAA2 (AR + AS)	0.25
		DOAA2 (AR + AL)	0.28
		DOAA2 (AR + AC)	0.28
		DOAA2 (AR + AE)	0.26
		DOAA4 (AR + AW + AS + AL)	0.25
		DOAA6 (AR + AW + AS + AL + AC + AE)	0.25
	NS3 = Rectangular NC (700 acre)	DOAA2 (AR + AW)	0.23

	DOAA2 (AR + AS)	0.22
	DOAA2 (AR + AL)	0.26
	DOAA2 (AR + AC)	0.26
	DOAA2 (AR + AE)	0.24
	DOAA4 (AR + AW + AS + AL)	0.23
	DOAA6 (AR + AW + AS + AL + AC + AE)	0.24
NS4 = Radial NU (31.83 acre)	DOAA2 (AR + AW)	0.22
	DOAA2 (AR + AS)	0.23
	DOAA2 (AR + AL)	0.26
	DOAA2 (AR + AC)	0.27
	DOAA2 (AR + AE)	0.25
	DOAA4 (AR + AW + AS + AL)	0.23
	DOAA6 (AR + AW + AS + AL + AC + AE)	0.24
NS5 = Radial NU (70 acre)	DOAA2 (AR + AW)	0.24
	DOAA2 (AR + AS)	0.25

	DOAA2 (AR + AL)	0.28
	DOAA2 (AR + AC)	0.29
	DOAA2 (AR + AE)	0.27
	DOAA4 (AR + AW + AS + AL)	0.25
	DOAA6 (AR + AW + AS + AL + AC + AE)	0.26
NS6 = Radial NU (700 acre)	DOAA2 (AR + AW)	0.23
	DOAA2 (AR + AS)	0.25
	DOAA2 (AR + AL)	0.28
	DOAA2 (AR + AC)	0.26
	DOAA2 (AR + AE)	0.26
	DOAA4 (AR + AW + AS + AL)	0.25
	DOAA6 (AR + AW + AS + AL + AC + AE)	0.25

Appendix-4

Decision Making Metric Value (DMMV) for Eco-Mobility Strategic Framework (EMSF) with respect to Neighborhood Scenarios-2 and 5 (NS-2 & 5), different ratio of utilization of neighborhood amenity by dwellers and Degree of Amenity Availability (DOAA).
[Weight_{Factor} for STI_{1to4} = 0.25]

Serial Number of Iteration	Eco-Mobility Strategic Framework (EMSF) (i=0to4)	Neighborhood Scenario (NS) (j=1to6)	Degree of Amenity Availability (DOAA) (k=1to6)	Ratio for utilization of neighborhood-amenity by dwellers (Percentage)	Decision Making Metric Value (DMMV)
1	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	0%	1.00
2	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	0%	1.00
3	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	0%	1.00
4	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	0%	1.00
5	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	0%	1.00
6	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	0%	1.00
7	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	0%	1.00

8	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	0%	1.00
9	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AW)	0%	1.00
10	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AS)	0%	1.00
11	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AL)	0%	1.00
12	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AC)	0%	1.00
13	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AE)	0%	1.00
14	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	0%	1.00
15	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	0%	1.00
16	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	0%	1.00
17	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	0%	1.00
18	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	0%	1.00
19	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	0%	1.00
20	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	0%	1.00

21	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	0%	1.00
22	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	0%	1.00
23	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	0%	1.00
24	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	0%	1.00
25	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AW)	0%	1.00
26	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AS)	0%	1.00
27	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AL)	0%	1.00
28	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AC)	0%	1.00
29	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AE)	0%	1.00
30	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	0%	1.00
31	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	0%	1.00

32	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	0%	1.00
33	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	0%	1.00
34	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	0%	1.00
35	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	0%	1.00
36	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	0%	1.00
37	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	0%	1.00
38	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	0%	1.00
39	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	0%	1.00

40	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	0%	1.00
41	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AW)	0%	1.00
42	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AS)	0%	1.00
43	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AL)	0%	1.00
44	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AC)	0%	1.00
45	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AE)	0%	1.00
46	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	0%	1.00
47	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	0%	1.00

48	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	0%	1.00
49	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	33%	0.72
50	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	33%	0.73
51	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	33%	0.74
52	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	33%	0.74
53	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	33%	0.73
54	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	33%	0.71
55	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	33%	0.73
56	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	33%	0.73
57	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AW)	33%	0.72
58	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AS)	33%	0.73

59	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AL)	33%	0.74
60	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AC)	33%	0.74
61	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AE)	33%	0.74
62	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	33%	0.71
63	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	33%	0.73
64	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	33%	0.73
65	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	33%	0.71
66	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	33%	0.72
67	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	33%	0.73
68	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	33%	0.73
69	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	33%	0.72
70	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	33%	0.71
71	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	33%	0.72

72	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	33%	0.72
73	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AW)	33%	0.72
74	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AS)	33%	0.72
75	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AL)	33%	0.73
76	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AC)	33%	0.73
77	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AE)	33%	0.72
78	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	33%	0.71
79	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	33%	0.72
80	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	33%	0.72
81	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	33%	0.75

82	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	33%	0.75
83	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	33%	0.76
84	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	33%	0.76
85	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	33%	0.76
86	EMSF3 = Walking, Cycling and public transportation	NS2 = Rectangular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	33%	0.73
87	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	33%	0.75
88	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	33%	0.75
89	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AW)	33%	0.75

90	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AS)	33%	0.75
91	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AL)	33%	0.76
92	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AC)	33%	0.77
93	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AE)	33%	0.76
94	EMSF3 = Walking, Cycling and public transportation	NS5 = Circular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	33%	0.73
95	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	33%	0.75
96	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	33%	0.76
97	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	66%	0.44

98	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	66%	0.46
99	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	66%	0.48
100	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	66%	0.48
101	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	66%	0.46
102	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	66%	0.43
103	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	66%	0.45
104	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	66%	0.46
105	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AW)	66%	0.44
106	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AS)	66%	0.46
107	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AL)	66%	0.48
108	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AC)	66%	0.49
109	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AE)	66%	0.47
110	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	66%	0.43

111	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	66%	0.46
112	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	66%	0.46
113	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	66%	0.43
114	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	66%	0.44
115	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	66%	0.45
116	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	66%	0.45
117	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	66%	0.44
118	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	66%	0.41
119	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	66%	0.44
120	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	66%	0.44
121	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AW)	66%	0.43

122	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AS)	66%	0.44
123	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AL)	66%	0.45
124	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AC)	66%	0.46
125	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AE)	66%	0.45
126	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	66%	0.41
127	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	66%	0.44
128	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	66%	0.44
129	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	66%	0.49
130	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	66%	0.50
131	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	66%	0.52

132	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	66%	0.53
133	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	66%	0.51
134	EMSF3 = Walking, Cycling and public transportation	NS2 = Rectangular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	66%	0.46
135	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	66%	0.50
136	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	66%	0.51
137	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AW)	66%	0.50
138	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AS)	66%	0.50
139	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AL)	66%	0.53

140	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AC)	66%	0.53
141	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AE)	66%	0.52
142	EMSF3 = Walking, Cycling and public transportation	NS5 = Circular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	66%	0.46
143	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	66%	0.51
144	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	66%	0.51
145	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	100%	0.15
146	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	100%	0.18
147	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	100%	0.21
148	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	100%	0.21

149	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	100%	0.19
150	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	100%	0.13
151	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	100%	0.17
152	EMSF1 = Walking only	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	100%	0.18
153	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AW)	100%	0.16
154	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AS)	100%	0.17
155	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AL)	100%	0.21
156	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AC)	100%	0.22
157	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AE)	100%	0.20
158	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	100%	0.14
159	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	100%	0.18
160	EMSF1 = Walking only	NS5 = Circular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	100%	0.19
161	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	100%	0.13

162	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	100%	0.15
163	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	100%	0.17
164	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	100%	0.17
165	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	100%	0.16
166	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	100%	0.11
167	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	100%	0.15
168	EMSF2 = Walking & Cycling only	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	100%	0.15
169	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AW)	100%	0.14
170	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AS)	100%	0.15
171	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AL)	100%	0.17
172	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AC)	100%	0.18

173	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA2 (AR + AE)	100%	0.16
174	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	100%	0.11
175	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	100%	0.15
176	EMSF2 = Walking & Cycling only	NS5 = Circular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	100%	0.16
177	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AW)	100%	0.23
178	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AS)	100%	0.25
179	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AL)	100%	0.28
180	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AC)	100%	0.28
181	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA2 (AR + AE)	100%	0.26

182	EMSF3 = Walking, Cycling and public transportation	NS2 = Rectangular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	100%	0.19
183	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	100%	0.25
184	EMSF3 = Walking, Cycling and Public Transportation	NS2 = Rectangular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	100%	0.25
185	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AW)	100%	0.24
186	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AS)	100%	0.25
187	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AL)	100%	0.28
188	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AC)	100%	0.29
189	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA2 (AR + AE)	100%	0.27

190	EMSF3 = Walking, Cycling and public transportation	NS5 = Circular NU (70 acre)	DOAA3 (AR + 33% of AW + 66% of AS)	100%	0.19
191	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA4 (AR + AW + AS + AL)	100%	0.25
192	EMSF3 = Walking, Cycling and Public Transportation	NS5 = Circular NU (70 acre)	DOAA6 (AR + AW + AS + AL + AC + AE)	100%	0.26