BENEFITS OF ACTIONS TO REDUCE GREENHOUSE GAS EMISSIONS IN TORONTO: CLIMATE RESILIENCE

PREPARED FOR:
City of Toronto

PREPARED BY:
Sustainability Solutions Group

SSG SUSTAINABILITY SOLUTIONS GROUP

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This report was prepared for the Environment and Energy Division of the City of Toronto. It is one report in a series of studies exploring the benefits of greenhouse gas reduction actions in Toronto under the City's TransformTO strategy. An Advisory Group provided support to this project.

This analysis was undertaken based on literature and secondary sources to identify indicators that would illustrate relationships between efforts to reduce greenhouse gas emissions and climate resilience. The indicators are intended to be directional in nature and are not intended to be precise to the context of the City of Toronto.

Reference: City of Toronto. Benefits of Actions to Reduce Emissions in Toronto: Climate Resilience. January 2019.

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ANALYSIS TAKEAWAYS

This report examines the relationships between climate mitigation actions and its climate resilience co-benefits, focusing on developing quantifiable relationships between the two. The scope of this exercise is limited to seven TransformTO actions.

There is considerable literature on mitigation co-benefits, and climate resilience, but little literature examining resilience as a co-benefit to climate change mitigation. These links are being made, but the practice is not widespread. Existing co-benefit/resilience frameworks examine resilience qualitatively, and therefore did not accurately capture the intent of this exercise.

Quantifying resilience is rarely accomplished because climate resilience - and resilience more broadly - is a nebulous concept that involves some level of forward-looking. Quantifying complex systems in linear relationships does not fully convey the dynamics of, and interactions between, climate mitigation and resilience. One individual relationship would require considerable analysis to be verified in a Toronto context. Therefore, very few studies found in the literature attempt to quantify resilience in simple numerical equations. The method outlined in this report is innovative and experimental.

Despite the absence of methodological precedents, the exercise proved beneficial in identifying mitigation/resilience co-benefit linkages and exploring the variables involved in the relationship. Strong relationships were supported by a greater availability of literature, and existing quantification of benefits. Strong relationships include:

1. The relationship between green infrastructure as a mitigation tool and its resilience benefit. There is considerable literature supporting the benefits of green infrastructure in minimizing flood damage, as well as reducing urban heat island effect and reducing energy loss in buildings.
2. Energy storage has a strong link to resilience. Energy storage supports deployment of solar PV, but also directly minimizes issues associated with power outages.

It should also be noted that the relationship between air pollution and health have been extensively documented in studies and global reporting for the World Health Organization and the IPCC. There is also wide literature that shows that improved health minimizes risks to climate stressors. There has been extensive work undertaken at the City of Toronto on the public health risks of climate impacts. However, attempting to pinpoint specific relationships related to TransformTO and resilience benefits has not been supported by rigorous analysis and verification. The overarching relationships have been widely documented, but how these manifest on a local scale at one instance in time is more difficult to ascertain, and is difficult to support through simple numerical relationships.

A key outcome of this analysis is the extent of the resilience benefit is often dependent on inclusion of specific resilience considerations. This is relevant to almost all TransformTO actions. For retrofits, improvements to indoor air quality are dependent on including specific ventilation strategies. For decentralized energy, the resilience benefit is enhanced by the inclusion of energy storage. Active transportation infrastructure minimizes flooding impacts only if green infrastructure is included. This emphasizes the importance of the intentionality during design to deliver resilience as a co-benefit of mitigation. For Toronto, this means that explicit considerations of climate resilience in program and policy design will be a key tool in minimizing climate risk in the City.

PURPOSE OF THE REPORT

This report summarizes a method for quantifying climate resilience co-benefits related to a selection of greenhouse gas (GHG) mitigation actions described in the City of Toronto's TransformTO Climate Action Strategy. This analysis is a theoretical exercise that explores linkages between mitigation and resilience, which could be used in further mitigation and resilience planning by the City of Toronto.

The scope of this exercise is limited to seven TransformTO actions: building retrofits, Toronto Green Standard (TGS), district energy systems, decentralized renewable energy, active transportation, electric vehicles and public transit. Climate resilience is a broad concept; this analysis therefore captures what can be considered health, social and economic co-benefits as contributors to climate resilience.

METHOD

The following method was used to develop the relationship between resilience and TransformTO.

1. Definitions of climate resilience and co-benefits were reviewed to situate the analysis within the current field of study and in the Toronto context;
2. Academic and grey literature was examined that outlines the determinants of climate resilience in cities and in human and physical systems, as well as existing frameworks on co-benefits;
3. Mapping of the TransformTO actions and relevant climate resilience impacts: for each TransformTO action, the potential influences on climate resilience were identified. These relationships were informed by literature review and the knowledge of the team;
4. Weak or strong correlation with resilience co-benefit were identified. This step provided literature support for the resilience link to determine which resilience co-benefits are likely to be realized in practice;
5. Indicators were identified. Building off the strong resilience correlations, numerical equations were developed to quantify the influence of the action on resilience outcomes. Where possible, assumptions specific to Toronto were identified.

It is important to note that the resilience equations developed in this analysis have not been verified through rigorous economic, statistical or epidemiological testing and verification. Therefore, the results should be interpreted as directionally correct but not scientifically precise. The equations are presented separately from the values found in the literature so the numbers can be updated as new information and data becomes available. These equations describe the relationships between mitigation and resilience and would require further testing and validation for use.

DEFINING CLIMATE RESILIENCE

Resilience has been defined in multiple ways, which has added confusion to its meaning in regard to climate change planning.[1] From its origin in disciplines including ecology and psychology, resilience has been applied more broadly to the social sciences, and as a bridging and all-encompassing concept that unifies an urban system with its social and physical constituents. Various tensions are intrinsic as resilience has been described as a process, an end state and a way of being. The formulations range from resilience as the transition from one form to another, resilience as the persistence of human and natural systems, resilience as the ability to survive and recover and resilience as the presence of social infrastructure.[2] Some interpretations can seem contradictory, emphasizing both change and resistance to change, and even controversial. As one author asks, why is it an objective to preserve a social system that marginalizes so many and benefits so few?[3]

The City of Toronto has been engaging in resilience planning. ResilientTO examines resilience more broadly, which includes climate resilience, but also resilience to other economic and social stressors. In contrast, this exercise is specifically examining resilience to climate stressors.

Given the number and breadth of the definitions, this report will align with the definition proposed by the Intergovernmental Panel on Climate Change (IPCC). Climate Resilience is "*the capacity of social, economic, and environmental systems to cope with hazardous events, trends or disturbances, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation*."[4]

In terms of a response to climate change, one source of confusion is the relationship between adaptation and resilience. The IPCC describes adaptation as "*the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.*" One argument, which is aligned with the IPCC definitions, is that resilience is a trait, enabling individuals or communities to gain new capabilities in the context of a struggle, while adaptation is an approach to addressing the challenges with a focus on preserving existing resources.[5]

The distinction made in this analysis is that adaptation actions are specific measures taken to minimize impacts, while resilience is a wider system attribute. Therefore, while this analysis is examining resilience, some of the resilience co-benefits explored in this report contribute to resilience through adaptation measures. For example,

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[1] Bahadur, A., Ibrahim, M., Tanner, T. (2010). The resilience renaissance? Unpacking of resilience for tackling climate change and disasters. Strengthening Climate Resilience.

[2] Ibid

[3] Olsson, L., Jerneck, A., Thoren, H., Persson, J., & O'Byrne, D. (2015). Why resilience is unappealing to social science: Theoretical and empirical investigations of the scientific use of resilience. Science Advances, 1(4), e1400217. https://doi.org/10.1126/sciadv.1400217

[4] Field, C. B. (Ed.). (2014). Climate change 2014–Impacts, adaptation and vulnerability: Regional aspects. Cambridge University Press.

[5] Wong-Parodi, G., Fischhoff, B., & Strauss, B. (2015). Resilience vs. Adaptation: Framing and action. Climate Risk Management, 10, 1–7. https://doi.org/10.1016/j.crm.2015.07.002

specific adaptation features included in new buildings can make them less susceptible damage, which contributes to wider system resilience.

Hazard, Risks, Vulnerability, Sensitivity and Exposure

Climate change impacts physical, human and natural systems, which in turn influence each other, resulting in feedback cycles. The risks related to climate impacts are a function of the climate hazard, as well as the exposure and vulnerability of the impacted systems. Vulnerability represents the social nexus of climate risk and includes sensitivity to impacts (which is closely related to health), as well as adaptive capacity, which describes the ability of systems to respond to climate impacts. Increasing resilience therefore requires reducing the risks of climate impacts, which in turn requires reducing the hazard, system exposure, or vulnerability.

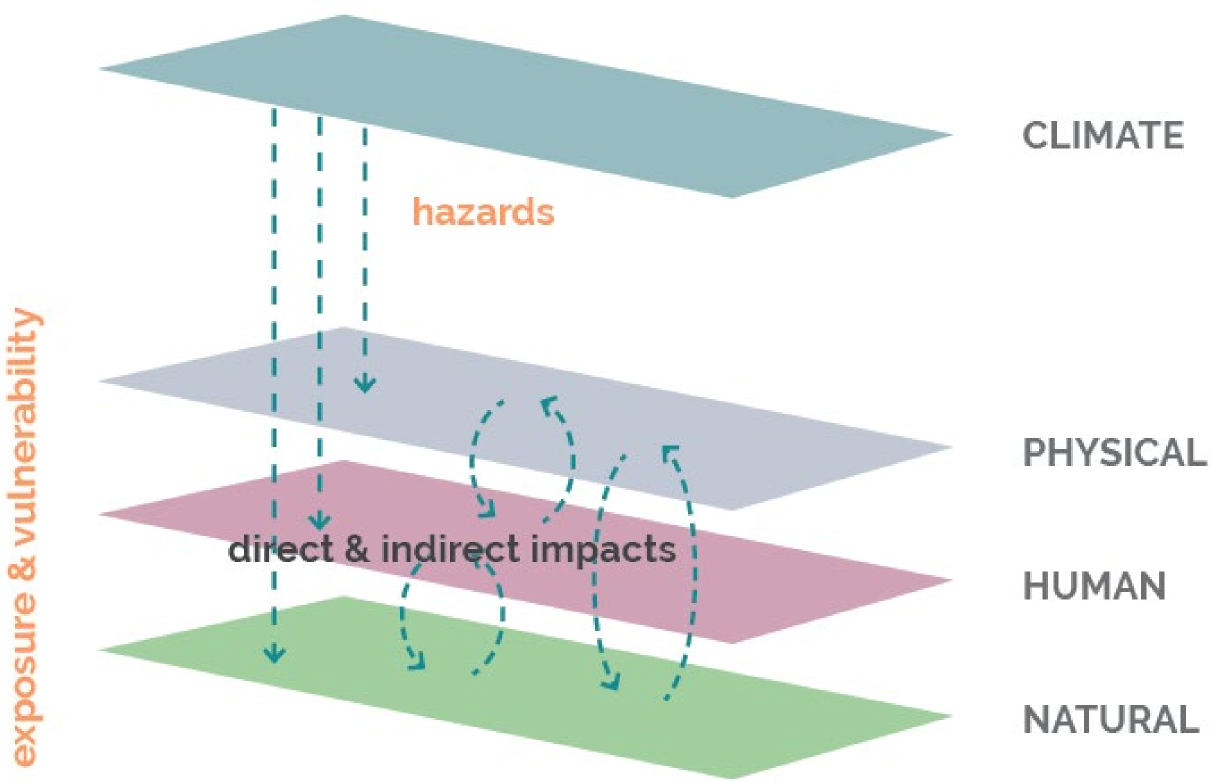

Figure 1. Schematic of climate impacts, including feedback cycles, on physical, human and natural systems.

The TransformTO actions in this report are related to three urban systems: energy supply, buildings, and transportation, which can all be considered ‘physical’ systems (Table 1). The primary climate hazards to these systems are related to more extreme weather events, such as increasing rainfall and heat waves, as well as long term climate impacts such as overall warmer temperatures. The potential risks to these systems are damage, disruption in service, or complete loss.

Table 1. Systems categories of TransformTO actions.

TransformTO action category	TransformTO system
Building retrofits	Buildings
TGS	Buildings
Low carbon thermal networks	Energy supply
Decentralized renewable energy	Energy supply
Active transportation infrastructure	Transportation
Electric Vehicles	Transportation
Public transit	Transportation

Definitions of co-benefits

The IPCC defines co-benefits as "t*he positive effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare. Co-benefits are often subject to uncertainty and depend on local circumstances and implementation practices, among other factors.*"[6] Policy intention is an important feature of co-benefits; a co-benefit is generally not the primary intention of the policy, but it can be intentional.

Resilience co-benefits of climate mitigation action are secondary outcomes from climate mitigation policy that also reduce the risk of climate impacts on physical, human and natural systems, through reducing exposure, sensitivity or improving the adaptive capacity of persons in the system.

DETERMINANTS OF CLIMATE RESILIENCE

The determinants of climate resilience are the characteristics of systems that reduce climate risk, through reducing the climate hazard, reducing exposure or reducing the vulnerability of systems. The result is a broad tent, as any intervention which improves human and ecological well-being increases resilience. As examples, interventions could improve natural systems, human-created infrastructure, the health of people, information, knowledge and wisdom, and the ability to respond or change in the face of stresses. Examples of principles common to each of these interventions which enhanced climate resilience are as follows:[7]

- *Flexibility:* the ability to perform essential tasks under a wide range of conditions;

[6] IPCC. (2014). Annex II: Glossary [Agard, J., E.L.F. Schipper, J. Birkmann, M. Campos, C. Dubeux, Y. Nojiri, L. Olsson, B. Osman-Elasha, M. Pelling, M.J. Prather, M.G. Rivera-Ferre, O.C. Ruppel, A. Sallenger, K.R. Smith, A.L. St. Clair, K.J. Mach, M.D. Mastrandrea, and T.E. Bilir (eds.)]. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1757-1776. p. 1762.

[7] Tyler, S., Moench, M. (2012). A framework for urban climate resilience. Climate and Development, 4(4), 311-326.

- *Diversity:* key assets and functions are physically distributed so they are not all affected by a given event (spatial diversity), and have multiple ways of meeting a given need (functional diversity);
- *Redundancy:* spare capacity available should some function be lost, or multiple pathways complete a function. This also includes buffer systems which can replace affected systems; and
- *Safe failure:* ability to avoid catastrophic failure, where failure or impacts to one system is unlikely to results in a cascading impact.

Current discussions related to climate change adaptation have generally focused on incorporating consideration for the impacts of climate change into plans for infrastructure, essentially tweaking existing strategies to accommodate a new reality.[8] This approach is characterized as incremental and does not keep pace with the rate and magnitude of climate change, which will overwhelm current practices, adapted or not. For this reason, many authors have focused on the notion of transformational change, with some indicating that in the context of 4°C of warming, no adaptation strategies, incremental or transformational, will be adequate.[9]

RESILIENCE AS MANAGING (EMBRACING) CHANGE

Much of the school of thought with respect to urban resilience has focused on the ability of a city or a society to pick up and get back to normal following a severe weather event. Climate change, however, requires more than a reactionary approach; it requires efforts to mitigate GHG emissions, the primary intention of TransformTO. But climate change also requires different ways of thinking about the functioning of society, in order to accommodate the dramatic changes that accompany already inevitable rates of climate change and broader issues of inequality and social justice. From this perspective, a foundational determinant of climate resilience is about being able to think differently, to continuously learn and to challenge one's worldview, a process that the IPCC has defined as "transformational change."

Transformational change is focused explicitly on governance processes that encourage learning, questioning of paradigms, leadership and co-production, and not on the technical efforts such as the height of a sea wall or the size of pipes.[10] This requirement for transformational change applies to mitigation and responding to climate impacts.

See Table 2 for a summary on the dimensions of incremental vs transformational change. Depth refers to the level of change. Superficial change implies changes in current practice without altering assumptions, whereas deep or in-depth change involves altering values and frames that underpin the system.

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[8] Wise, R. M., Fazey, I., Stafford Smith, M., Park, S. E., Eakin, H. C., Archer Van Garderen, E. R. M., & Campbell, B. (2014). Reconceptualizing adaptation to climate change as part of pathways of change and response. *Global Environmental Change*, *28*, 325–336. https://doi.org/10.1016/j.gloenvcha.2013.12.002

[9] Smith, M.S., L. Horrocks, A. Harvey, and C. Hamilton. (2011). "Rethinking Adaptation for a 4_C World." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 369 (1934): 196_216.

[10] Termeer, C. J. A. M., Dewulf, A., & Biesbroek, G. R. (2017). Transformational change: governance interventions for climate change adaptation from a continuous change perspective. Journal of Environmental Planning and Management, 60(4), 558–576. https://doi.org/10.1080/09640568.2016.1168288

Table 2. Summary of the assumptions of the incremental–transformational change dichotomy on the three dimensions of change.[11]

Dimension	Incremental	Transformational
Depth of change	First-order change Improve existing practices in the same direction	Second-/third-order change Alter paradigms, values, and worldviews
Scope of change	Small scale, micro, only parts of the system	Large scale, macro, system-wide
Speed of change	Slow, step by step, short term	Quick, big jumps, long term

Various authors also refer to the depth of change in terms of orders of learning. Incremental change is also defined as first order change, and single loop learning, when the current practice is improved; hazard and vulnerability assessments could generally be considered first order change. Second-order change, or double loop learning questions the assumptions underlying the system and seeks to reframe problems from a different perspective. Third-order change, or triple loop learning, refers to changing the way we change, root change or radical change. Climate resilience, therefore requires that both individuals and communities can remain grounded and stable in a whirlwind of change with respect not only to economic and technological shifts but also different knowledge systems.

Various authors have sought to systematically articulate the principles which define climate resilience. An evaluation of many of these papers identified ten core dimensions that underpin resilient systems, which capture the uncertainty of climate change, social dimensions and the need for transformation.[12] The dimensions are as follows:

1. A high level of diversity in groups performing different functions in an ecosystem; in the availability of economic opportunities; in the voices included in a resilience-building policy process; in partnerships within a community; in the natural resources on which communities may rely; and in planning, response and recovery activities.
2. Effective governance and institutions which may enhance community cohesion. These should be decentralized, flexible and in touch with local realities; should facilitate system-wide learning; and perform other specialized functions such as translating scientific data on climate change into actionable guidance for policymakers.
3. The inevitable existence of uncertainty and change is accepted. The non-linearity or randomness of events in a system is acknowledged, which shifts policy from an attempt to control change and create stability to managing the capacity of systems to cope with, adapt to, and shape change.
4. There is community involvement and the use of local knowledge in any resilience-building projects; communities enjoy ownership of natural resources; communities have a voice in relevant policy processes.

[11] Ibid.

[12] Bahadur, A., Ibrahim, M., Tanner, T. (2010). The resilience renaissance? Unpacking of resilience for tackling climate change and disasters.

5. Preparedness activities aim not at resisting change but preparing to live with it; this could be by building in redundancy within systems or by incorporating failure scenarios in Disaster Management (DM) plans.
6. A high degree of social and economic equity exists in systems; resilience programs consider issues of justice and equity when distributing risks within communities.
7. The importance of social values and structures is acknowledged because association between individuals can have a positive impact on cooperation in a community which may lead to more equal access to natural resources and greater resilience; it may also bring down transaction costs as agreements between community members would be honoured.
8. The non-equilibrium dynamics of a system are acknowledged. Any approach to building resilience should not work with an idea of restoring equilibrium because systems do not have a stable state to which they should return after a disturbance.
9. Continual and effective learning is important. This may take the form of iterative policy/institutional processes, organizational learning, reflective practice, adaptive management and may merge with the concept of adaptive capacity.
10. Resilient systems take a cross-scalar perspective of events and occurrences. Resilience is built through social, political, economic and cultural networks that reach from the local to the global scale.

Evaluations of climate resilience highlight the importance of diversity and redundancy to reduce exposure of physical systems. Others have extended the importance of diversity to planning, economic activities and livelihoods, and the inclusion of diverse voices included in planning activities.[13] Determinants of resilience in human systems can also address the nature and structure of governance,[14] and in social structures with the premise that cooperation is more effective than individualism in confronting climate change.[15]

[13] Ibid.

[14] Ibid.

[15] Arup. (2016). Climate vulnerability Index.

FRAMEWORKS FOR RESILIENCE AS A CO-BENEFIT OF CLIMATE CHANGE MITIGATION

A framework is a high-level set of principles, focuses, and processes related to long-term goals that create a basis for actions; essentially a structure for ordering one's thoughts on a particular topic. Typically, frameworks include a hierarchy of principles or objectives, supported by indicators.

This analysis is examining resilience as a co-benefit of mitigation policies, which does not fit neatly with existing co-benefit frameworks in the literature. This concept overlaps with three existing frameworks: those that describe the co-benefits of climate mitigation; those that integrate mitigation and adaptation; and those that describe the determinants of resilience and the co-benefits of resilience and adaptation policies. The three existing frameworks/literature conceptualizations are described below.

Climate mitigation co-benefit frameworks

The objective of these frameworks is to identify the array of possible co-benefits of policy choices to support decision-making through a consistent approach to achieve the highest net-benefit with regards to climate (foremost), as well as economic, social and environmental dimensions.[16]

Most mitigation co-benefit frameworks focus on economic and social benefits such as financial costs and health,[17] and often qualitatively explore socio-economic connections.[18] Some co-benefit frameworks attempt to quantify the co-benefit relationship by monetizing impacts.[19] Other methods for the quantification of co-benefits include social cost benefit analysis, integrated assessment modelling and multi-criteria analysis.[20]

As an example of this framework, the London School of Economics Cities program and C40 developed a comprehensive co-benefits framework based on the sectors of health, mobility, buildings, resources and the economy.[21] Many of the indicators identified as co-benefits in this analysis contribute to climate resilience.

Climate resilience is often indirectly included in co-benefit frameworks but is not explicitly defined as resilience. Indirect references include socioeconomic benefits that make human systems more resilient to climate impacts by reducing human exposure and vulnerability. For example, energy use reduction is frequently described as an economic benefit to governments and households from mitigation policies, but it also influences the resilience of

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[16] Floater, G., Heeckt, C., Ulterino, M., Mackie, L., Rode, P., Bhardwaj, A., ... Huxley, R. (2016). Co-benefits of urban climate action: A framework for cities. LSE Cities. Retrieved from http://www.c40.org/researches/c40-lse-cobenefits

[17] ibid.

[18] Urge-Vorsatz, D., Herrero, S., Dubash, N., Lecocq, F. (2014). Measure the co-benefits of climate change mitigation. Annual Reviews Environmental Resources, 39, 549-582.

[19] Ibid.

[20] Ibid.

[21] Floater, G., Heeckt, C., Ulterino, M., Mackie, L., Rode, P., Bhardwaj, A., ... Huxley, R. (2016). Co-benefits of urban climate action: A framework for cities. LSE Cities. Retrieved from: http://www.c40.org/researches/c40-lse-cobenefits

energy systems by reducing electricity demand, which can minimize the risk of power outages. Health benefits from reduced air pollution are an important co-benefit of climate mitigation.[22] Better health contributes to resilience by reducing the sensitivity of individuals to climate impacts such as extreme heat.[23]

Resilience frameworks

Resilience frameworks are focused on the determinants of climate resilience and do not address climate mitigation. Examples include the Grosvenor Resilient Cities Index and the UN-Habitat City Resilience Profiling Programme and ISO 37210. One of the highest profile is the City Resilience Framework (CRF), developed by Arup for the Rockefeller Foundation's 100 Resilient Cities program.[24] The CRF includes the four dimensions of health and wellbeing, economy and society, infrastructure and environment and leadership and strategy within a city. These four dimensions are subdivided into twelve drivers of resilience. Cities can evaluate the qualities of resilience against a set of 52 indicators to identify areas of strength and weakness in relation to stressors such as climate change. The breadth of the CRF aligns the concept of resilience with sustainability or sustainable development, using a very broad scope for climate resilience.

Integrated adaptation/mitigation frameworks

Resilience as a mitigation co-benefit overlaps with frameworks that analyze synergies between mitigation policies and adaptation/resilience policies. In these frameworks, resilience is not considered a co-benefit, but a primary intention of the policy. The following two frameworks include resilience as a primary policy intention:

1. The IPCC's Climate Resilient Pathways consider resilience as a primary policy intention, alongside mitigation.[25] This framework understands mitigation as contributing to resilience in two broad ways: it reduces the rate and magnitude of climate change, which can reduce climate related stresses, such as extreme weather and climate effects, and resilience policies can encourage livelihood improvements.[26]

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[22] Wolkinger, B., Haas, W., Bachner, G., Weisz, U., Steininger, K., Hutter, H. P., Delcour, J., Griebler, R., Mittelbach, B., Maier, P., … Reifeltshammer, R. (2018). Evaluating Health Co-Benefits of Climate Change Mitigation in Urban Mobility. *International journal of environmental research and public health*, *15*(5), 880. doi:10.3390/ijerph15050880

[23] Oppenheimer, M., M. Campos, R. Warren, J. Birkmann, G. Luber, B. O'Neill, and K. Takahashi, 2014: Emergent risks and key vulnerabilities. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1039-1099.

[24] Arup. (2015). City resilience framework. Retrieved from https://assets.rockefellerfoundation.org/app/uploads/20160105134829/100RC-City-Resilience-Framework.pdf

[25] Denton, F., T.J. Wilbanks, A.C. Abeysinghe, I. Burton, Q. Gao, M.C. Lemos, T. Masui, K.L. O'Brien, and K. Warner, 2014: Climate-resilient pathways: adaptation, mitigation, and sustainable development. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1101-1131.

[26] Ibid.

2. The Green Resilience Strategies framework looks at the integration between adaptation and mitigation synergies.[27] Green resilience strategies include actions such as:
    - Green infrastructure, which reduces flood damage, reduces heat island effect, reduces building energy use and increases thermal comfort;
    - Solar + storage can reduce emissions, increase electricity reliability and security, and increase business continuity, especially during outages;
    - Resilient urban transport can reduce emissions, increase network efficiency and reliability;
    - Water and energy conservation, which reduces energy use and increase preparedness for floods;
    - Building weatherization reduces energy use and energy demand, reduces emissions, increases business opportunities, and reduces flood and weather damage; and
    - Low-input agriculture, which may increase soil organic carbon storage, increase flood water retention and increase food security

Finally, only one framework identified in the literature review used a co-benefit framework that explicitly identified adaptation as a co-benefit of mitigation.[28] In this paper, the interactions between mitigation and adaptation are described in the following categories:

1. Co-benefits: explicit reference to co-benefits and tradeoffs between mitigation, adaptation and non-climate
    a. Adaptation with mitigation co-benefits;
    b. Adaptation with other co-benefits;
    c. Mitigation with adaptation co-benefits;
    d. Mitigation with other co-benefits;
    e. Non-climate actions with co-benefits for mitigation;
    f. Non-climate actions with co-benefits for adaptation; and
2. Integrated approach: pursuing both adaptation and mitigation objectives together in an integrated manner aimed at realizing mutual benefits
3. Pursuing mitigation and adaptation without mention of interactions. In this framework, benefits were not quantified.

An assessment of the mutual benefits between actions which reduce GHG emissions and actions which increase resilience to climate change found that in many cases the high priority actions are mutually exclusive or result indirect resilience benefits.[29] For example, a key action for climate resilience is green infrastructure and the GHG mitigation of green infrastructure are minimal in relation to other actions. On the GHG mitigation side of the equation, a key action is the electrification of transportation and the climate resilience benefits of this action are minimal or indirect.

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[27] Winkelman, S., Nichol, E., Harford, D. (2017). Taking Action on Green Resilience: Climate Change Adaptation and mitigation Synergies. Green Resilience Strategies. Retrieved from: http://act-adapt.org/wp-content/uploads/2017/11/ACT_ALTGR_Web4.pdf

[28] Gregorio, M., Fatorelli, L., Pramova, E., May, P., Locatelli, B., Brockhaus, M. (2016). Integrating mitigation and adaptation in climate and land use policies in brazil: A Policy document analysis. Sustainability Research Institute Paper No. 94. Centre for Climate Change Economics and Policy Working Paper No. 257. University of Leeds.

[29] This assessment was an internal exercise undertaken by SSG.

Observations & Takeaways for Analysis

Resilience is a concept that cannot be easily contained or pinned down, either in the literature or in practice. The frameworks that exist tackle resilience from various perspectives and broadly describe system attributes and policy relations. While the frameworks reviewed helped define the way in which climate resilience is being examined in other jurisdictions, none of the frameworks examined attempted to quantify resilience co-benefits from mitigation actions, and none accurately capture the intended objectives of this study. Instead, most frameworks examine resilience qualitatively, due to the difficulty in quantifying complex processes, feedback loops, correlation and causation in physical urban systems.

As a result of this finding, no specific framework was applied. Rather a mapping of the relationship between the actions in TransformTO and climate resilience was undertaken. Relationships are exploratory and were not verified using statistical analysis.

TRANSFORMTO RELATIONSHIPS

TRANSFORMTO RESILIENCE MAPPING

This section attempts to quantify the ways in which TransformTO actions contribute to climate resilience. In order to identify pathways in which the TransformTO actions achieves climate resilience objectives, a mind map was developed that identifies ways in which resilience is influenced by mitigation actions. These pathways are the sub-headings under each action below.

For each mitigation action to resilience benefit relationship pathway, a literature review of relevant indicators and data was performed to represent each pathway in a numerical equation. Where possible, local and sector-specific data was used to enhance the Toronto relevance.[30] However, due to a lack of Toronto-specific data, some of the relationships rely on data assumptions from other regions and contexts. While all sources are indicated, the results should be interpreted as directionally correct but not scientifically precise. Additionally, the equations are presented separately from the values found in the literature, so the numbers can be updated as new information and data becomes available.

Finally, many of the relationships below rely on the assumption that the TransformTO actions can increase the climate resilience if they are implemented with resilience considerations. In this case, thoughtful implementation generally requires the incremental adoption of climate resilience objectives as part of the TransformTO action, if the climate resilience co-benefit is to be manifested. This fits with the mitigation-adaptation policy frameworks, where resilience is not a co-benefit, but a primary policy consideration. Without careful consideration, the resilience benefit may not result. A narrow focus on energy in a retrofit, for example, doesn't necessarily improve indoor environmental quality as new sources of volatile organic compounds or other chemical hazards may be introduced.[31] As another example, without careful consideration, a new building constructed to passive house standards could increase thermal discomfort during extreme heat events.[32]

[30] Miller, S., Yoon, S., Yu, B. (2013). Vulnerability Indicators of Adaptation to Climate change and Policy Implications for IDB Projects. Inter-American Development Bank Policy Brief No. IDB-PB-184. Retrieved from: http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=37725582

[31] Langer, S., Bekö, G., Bloom, E., Widheden, A., & Ekberg, L. (2015). Indoor air quality in passive and conventional new houses in Sweden. Building and Environment, 93, 92–100. https://doi.org/10.1016/j.buildenv.2015.02.004

[32] Coombs, K. C., Chew, G. L., Schaffer, C., Ryan, P. H., Brokamp, C., Grinshpun, S. A., … Reponen, T. (2016). Indoor air quality in green-renovated vs. non-green low-income homes of children living in a temperate region of US (Ohio). *The Science of the Total Environment*, *554–555*, 178–185. https://doi.org/10.1016/j.scitotenv.2016.02.136

TRANSFORM TO ACTION 1: BUILDING RETROFITS

This section relies on the assumption that all retrofits would be 'deep' retrofits. Deep retrofits are defined as retrofits that reduce energy use by 50%. This also assumes that a deep retrofit includes some sort of envelope improvements to meet high energy use reductions. It is likely that shallow and medium retrofits would also have resilience benefits, but the analysis is limited to deep retrofits to narrow the implications of the term 'retrofits'. Deep retrofits was also selected because it is generally associated with envelope improvements, which is where many resilience benefits are derived.

This section is examining residential retrofits. Commercial and institutional buildings have been excluded from the analysis because they have a wide range of purposes, and the extent to which people interact with these spaces varies widely. It should be noted that many relationships may still be relevant to commercial and institutional buildings, but the equation structure and values presented may not be applicable. For example, retrofitted office buildings may provide safety related to heat events and power outages, improved air quality and reductions in respiratory issues for occupants. Energy insecurity is less applicable to commercial and institutional buildings because this equation is related to home energy costs. In future analyses, equations could be developed for specific uses and building archetypes in commercial and institutional buildings, to adequately account for the ways in which people interact with these spaces and the contribution to resilience.

Safe dwellings during periods of extreme heat

Both seasonal and extreme heat events can impact the ability of people to function, through minor issues such as heat edema (swelling), heat rash and heat cramps, and more severe issues such as heat syncope (fainting), heat exhaustion and heat stroke. Relative death rates can begin to increase at temperatures as low as 20°C, rates which are influenced by pre-existing health conditions, social isolation, living conditions and other factors.[33]

In 2005, Toronto Public Health (TPH) estimated that heat conditions contribute to an average of 120 premature deaths annually, and the impact of climate change is projected to increase periods of extreme heat.[34]

Building retrofits that improve the building envelope can reduce the loss of heated or cooled air, which can improve thermal comfort.[35] A 2010 TPH survey found that 15% of Toronto residents do not have air conditioning, and for those with low incomes, 33% did not have air conditioning.[36]

The eight strategies identified by the City of Toronto for managing extreme heat overlap with strategies that are frequently aspects of deep retrofits including active cooling, weatherization and insulation, increasing air circulation,

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[33] Health Canada. (2012). Extreme heat events guidelines: technical guide for health care workers. Ottawa.

[34] City of Toronto. (2014). *Strategies to prevent heat-related illness and deaths from extreme heat emergencies*. Retrieved from https://www.toronto.ca/legdocs/mmis/2014/hl/bgrd/backgroundfile-70709.pdf

[35] Ribeiro, D., Mackres, E., Baatz, B., Cluett, R., Jarret, M, Kelly, M., Vaidyanathan, S. (2015). Enhancing community resilience through energy efficiency. Report U1508. Retrieved from: https://aceee.org/sites/default/files/publications/researchreports/u1508.pdf.

[36] City of Toronto. (2015). *Reducing health risk from extreme heat in apartment buildings*.

reducing solar gain through windows, increasing natural ventilation, cooling external surfaces and minimizing internal heat and cooling requirements of buildings.[37]

Quantifying the relationship

This relationship is using the avoided value of increasing heat-related mortality to quantify the benefit of safe homes during heat waves. This relationship relies on the assumption that heat mitigation strategies are applied as a part of deep retrofits and that retrofits eliminate 100% mortality risk for persons in retrofitted buildings. It follows that the number of retrofits is related to avoided value of mortality by the number of persons per unit, the heat mortality rate in Toronto, and the potential for increasing heat-related mortality related to climate change.

Heat-related mortality is a very complex relationship, with a myriad of influences, including pre-existing health status, demographics and heat exposure at different times (at work, outside and in other buildings). This equation assumes that 100% of mortality is eliminated for people in retrofitted units, which does not fully convey the complexities of heat exposure. This equation also understates the health value of retrofits in relation to extreme heat because morbidity is not included. Arriving at an equation that can accurately represent heat mortality in Toronto will require considerable epidemiological study and statistical analysis. Again, this equation is presented to consider the possible interactions between the variables.

Examples of the results for equation 1: retrofitting 4,000 dwellings results in 7 avoided deaths over the 20 year lifetime of those retrofits, assuming 2 people per household; retrofitting 100,000 dwellings results in 175 avoided deaths over a 20 year period.

Values used

Heat mortality rate: 120/2,500,000
The value for "heat mortality rate" currently used in the equation is 120 deaths per 2,500,000 people,[38] which is sourced from a 2014 study by Toronto Public Health.[39]

Increased mortality rate due to climate change: 1.02
According a study of cities in Quebec, increasing temperatures due to climate change increases heat mortality by 2%.[40]

Value of avoided death: A life is valued a $7.4 million (2006$).[41]
This value is sourced from an EPA whitepaper on valuing mortality. Monetizing mortality can be controversial and is difficult to attribute to one number.

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[37] Ibid.
[38] According to Statistics Canada, the population of Toronto was 2,503,281 in 2006. We are using 2,500,000 for simplicity. From https://www12.statcan.gc.ca/census-recensement/2006/dp-pd/92-596/P1-2.cfm?Lang=eng&T=CSD&GEOCODE=20005&PRCODE=35&TID=0
[39] City of Toronto. (2014). *Strategies to prevent heat-related illness and deaths from extreme heat emergencies*. Retrieved from https://www.toronto.ca/legdocs/mmis/2014/hl/bgrd/backgroundfile-70709.pdf
[40] Doyon, B., Bélanger, D., & Gosselin, P. (2008). The potential impact of climate change on annual and seasonal mortality for three cities in Québec, Canada. International Journal of Health Geographics, 7(1), 23. https://doi.org/10.1186/1476-072X-7-23
[41] US EPA. (2010). Valuing mortality risk reductions for environmental policy: A white paper. Retrieved from https://www.epa.gov/sites/production/files/2017-08/documents/ee-0563-1.pdf

Duration of the retrofit: 20 years

	Parameters	Premise
1	$\# \, dwellings\ with\ deep\ retrofits \times \frac{people}{household} \times heat\ mortality\ rate \times increasing\ mortality\ rate\ due\ to\ cliamte\ change \times duration\ of\ retrofit \times value\ of\ avoided\ mortality = value\ of\ avoided\ mortality\ from\ inc.temp.$	Heat mitigation strategies are applied as part of deep retrofits, which bring buildings to a thermally safe temperature range. Assuming that mortality is avoided in all retrofitted dwellings, the number of retrofits is multiplied by the value of avoided death. The calculation also assumes that the primary source of exposure for vulnerable people is in their dwelling.

Safe buildings during power outages

Improved building envelopes can better regulate temperature and therefore protect inhabitants in periods of extreme weather,[42] which the US Green Building Council has defined as passive survivability or thermal safety.[43] Thermal safety is defined as maintaining thermally safe conditions during a power outage that lasts four days during peak summertime and wintertime conditions.[44] A study of buildings in New York City found that homes with efficiency upgrades could maintain indoor temperatures of over 60°F (15.5°C) during a week-long power outage, whereas the temperature in average efficiency homes with no retrofit fell below 35°F (1.6°C) in three days.[45]

In a pilot for new LEED certification components, buildings can satisfy a thermal safety requirement by achieving Passive House certification. According to the LEED requirements, "the very high standards for energy performance with Passive House is an adequate indicator that the building will maintain passive survivability." [46] An assessment as part of an update of the Toronto Green Standard found a correlation between the achievement of higher levels of building energy performance and improved thermal resilience.[47]

[42] Ribeiro, D., Mackres, E., Baatz, B., Cluett, R., Jarret, M, Kelly, M., Vaidyanathan, S. (2015). Enhancing community resilience through energy efficiency. Report U1508. Retrieved from: https://aceee.org/sites/default/files/publications/researchreports/u1508.pdf.

[43] USGBC. Passive survivability and back-up power during disruptions. LEED BD+C: New construction. Retrieved from: https://www.usgbc.org/credits/passivesurvivability.

[44] What constitutes thermally safe varies in various buildings, and can also be dependent on humidity and other factors. See LEED pilot webpage for more information: https://www.usgbc.org/node/9836068?return=/pilotcredits/all/all

[45] C2ES. (2018). Resilience Strategies for Power Outages.

[46] USGBC. Passive survivability and back-up power during disruptions. LEED BD+C: New construction. Retrieved from: https://www.usgbc.org/credits/passivesurvivability.

[47] City of Toronto. (2017). *City of Toronto Zero Emissions Buildings Framework* (p. 118). Integral Group, Morrison Hershfield, & Provident.

Dwelling units which achieve this standard may also reduce the demand on emergency services during a power outage; a study in 2006 in Toronto found that ambulance calls increased by 10% during periods of extreme heat.[48] Residents that are in dwellings that cannot protect them from extreme heat or cold are likely to require support from emergency services.

Quantifying the relationship

The relationship between retrofits and safety during a power outage can be quantified by dwelling units or buildings with high energy performance. Building on the themes of the New York study and the LEED pilot, it is assumed that a deep retrofit, which achieves energy reductions of 50% or more, would include design specifications to provide at least three days of thermally safe temperatures.[49] With this assumption, the number of buildings that undergo deep retrofits, multiplied by the number of people per household results in the number of people who are safe in their own homes during power outages for at least three days.

Values used

# of dwellings with deep retrofits: a count of buildings that under a retrofit that reduced energy use by at least 50%.

	Parameters	Premise
2	$\# \, dwellings \; with \; deep \; retrofits \times \frac{people}{household} = \# \, people \; safe \; in \; their \; own \; home \; during \; power \; outages$	Deep retrofits achieve a standard of passive survivability or thermal safety.

Energy insecurity

In 2010, 44% of renter households and 28% of owner households faced affordability issues in the City of Toronto.[50] Households facing energy poverty or energy insecurity face challenges such as "pay the rent or feed the kids", "heat or eat," or "cool or eat".[51] In particular, energy insecurity disempowers low-income residents such as single parents, the elderly, persons with disabilities, and others with low or fixed incomes,[52] resulting in stresses such as utility-related debt, shutoffs, inefficient heating systems, antiquated appliances, and extreme home temperatures with

[48] Dolney, T. J., & Sheridan, S. C. (2006). The relationship between extreme heat and ambulance response calls for the city of Toronto, Ontario, Canada. *Environmental Research*, *101*(1), 94–103. https://doi.org/10.1016/j.envres.2005.08.008

[49] The idea of passive survivability is an emerging field and the relationship between deep retrofits and the ability of a dwelling to maintain a comfortable temperature in conditions of extreme heat and cold is variable and requires further analysis.

[50] City of Toronto. (2016). Housing and health: Unlocking opportunity.

[51] Cook, J. T., Frank, D. A., Casey, P. H., Rose-Jacobs, R., Black, M. M., Chilton, M., ... Cutts, D. B. (2008). A brief indicator of household energy security: Associations with food security, child health, and child development in US infants and toddlers. *PEDIATRICS*, *122*(4), e867–e875. https://doi.org/10.1542/peds.2008-0286

[52] Hernández, D. (2013). Energy insecurity: A framework for understanding energy, the built environment, and health among vulnerable populations in the context of climate change. American Journal of Public Health, 103(4), e32–e34. https://doi.org/10.2105/AJPH.2012.301179

significant health impacts.[53] Children may experience nutritional deficiencies, higher risks of burns from non-conventional heating sources, higher risks for cognitive and developmental behavior deficiencies, and increased incidences of carbon monoxide poisoning.[54] Subsequent impacts include parents being unable to work in order to look after children, missed school days, and lost productivity.

Energy retrofits can result in improved thermal satisfaction, fewer reported financial difficulties, increased satisfaction among participants with the repair of their homes, fewer reported housing-related problems and more social interactions.[55]

Quantifying the relationship

This equation links retrofits to avoided energy expenditures, which can then be used for other living expenses. This equation sees that the number of units with deep retrofits, multiplied by annual utility savings per household per year, multiplied by the duration of a retrofit equals avoided energy expenditures per household per year.

Values used

Utility savings per household: two values were identified as applicable to Toronto.
$800/unit/year - This value was retrieved from a study on TowerWise by the Atmospheric Fund. [56]
$560/household/year – This value is cited in the Toronto Home Energy Program Evaluation. [57]

	Parameters	**Premise**
3	$\# \, units\ with\ deep\ retrofits \times utility\ savings \times duration\ of\ retrofit = avoided\ energy\ expenditures$	Utility savings can be used for other household expenditures.

[53] Hernández, D., & Bird, S. (2010). Energy burden and the need for integrated low-income housing and energy policy. *Poverty & Public Policy*, *2*(4), 5–25. https://doi.org/10.2202/1944-2858.1095
[54] Ibid.
[55] Poortinga, W., Rodgers, S. E., Lyons, R. A., Anderson, P., Tweed, C., Grey, C., … Winfield, T. G. (2018). The health impacts of energy performance investments in low-income areas: a mixed-methods approach. Public Health Research, 6(5), 1–182. https://doi.org/10.3310/phr06050
[56] The Atmospheric Fund. (2018). Robert Cooke Co-op case study: A Towerwise retrofit project. Retrieved from http://taf.ca/wp-content/uploads/2018/07/TAF_Robert-Cooke-Co-op_Case-Study_Web_FINAL_2018-07-27.pdf
[57] City of Toronto. (March 21, 2017). Home Energy Loan Program and High-rise Retrofit Improvement Support Program Evaluation. PE 18.4 Report for Action. Retrieved from: https://www.toronto.ca/legdocs/mmis/2017/pe/bgrd/backgroundfile-102272.pdf

Quality of the indoor environment

The indoor environment can provide comfortable living conditions, limit the concentration of airborne contaminants, protect from precipitation and provide amenities such as light, power and food storage. A building with improved indoor environmental quality can also better manage chronic heat stress, dampness and mold,[58] conditions which can increase because of climate change.

Energy retrofits can contribute to better indoor environments, which can improve quality of life by improving thermal satisfaction,[59] and improving health outcomes, particularly for the elderly, those with poor health and the economically disadvantaged.[60]

Predicted percentage dissatisfied (ppd) is a metric of thermal comfort and dissatisfaction. [61] An analysis of a multi-family building in Sweden found that a retrofit that reduced heat demand by 44% decreased the ppd by 10%. [62] Similarly, a decrease in absenteeism was found in LEED-certified schools in Toronto.[63]

Another study found enhanced cognitive performance associated with a high-performance green building in contrast to a non-certified building, likely because of the improved indoor environmental quality. The participants in the certified green building had 30% fewer sick building symptoms, 26.4% higher cognitive function scores and 6.4% higher sleep scores than participants in the non-certified buildings even after controlling for annual earnings, job categories, and level of schooling.[64]

Quantifying the relationship

One way in which this relationship can be quantified is relating retrofits to reduction in colds and influenza. In this equation, the number of dwellings with deep retrofits is multiplied by the people per household, by the decrease in respiratory illness related to retrofits, and by the rate of colds and influenza per person per year. This equation gives the reduction in the number of colds and influenza per year. This equation assumes that indoor air quality components are a key feature of the retrofit.

Arriving at an equation that can accurately represent respiratory illness reductions from retrofits in Toronto will require considerable epidemiological study and statistical analysis. Again, this equation is presented to consider the possible interactions between the variables.

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[58] Fisk, W. J. (2015). Review of some effects of climate change on indoor environmental quality and health and associated no-regrets mitigation measures. Building and Environment, 86, 70–80. https://doi.org/10.1016/j.buildenv.2014.12.024

[59] Poortinga, W., Rodgers, S. E., Lyons, R. A., Anderson, P., Tweed, C., Grey, C., ... Winfield, T. G. (2018). The health impacts of energy performance investments in low-income areas: a mixed-methods approach. Public Health Research, 6(5), 1–182. https://doi.org/10.3310/phr06050

[60] Opp. cit.

[61] Schenck, P., Karim Ahmed, A., Bracker, A., & DeBernardo, R. (2010). Climate change, indoor air quality and health. Retrieved from https://www.epa.gov/sites/production/files/2014-08/documents/uconn_climate_health.pdf

[62] La Fleur, L., Rohdin, P., & Moshfegh, B. (2018). Energy use and perceived indoor environment in a Swedish multifamily building before and after major renovation. Sustainability, 10(3), 766. https://doi.org/10.3390/su10030766

[63] Issa, M. H., Rankin, J. H., Attalla, M., & Christian, A. J. (2011). Absenteeism, performance and occupant satisfaction with the indoor environment of green Toronto schools. *Indoor and Built Environment*, *20*(5), 511–523. https://doi.org/10.1177/1420326X11409114

[64] MacNaughton, P., Satish, U., Laurent, J. G. C., Flanigan, S., Vallarino, J., Coull, B., ... Allen, J. G. (2017). The impact of working in a green certified building on cognitive function and health. *Building and Environment*, *114*, 178–186. https://doi.org/10.1016/j.buildenv.2016.11.041

Values used

Decrease in respiratory illness (colds and influenza): 0.09 (low) 0.2 (high)
This value was sourced from a review that explored the annual productivity gains that are potentially achievable from improvements in indoor environmental conditions that reduce health impacts. The review linked indoor air quality to respiratory illnesses because of the impact of ventilation on airborne transmission in buildings in the United States and globally. The study found that retrofits that improved indoor air quality decreased respiratory illness of its occupants between 9% and 20%, with an average of 18%, across the multiple studies in various contexts. [65] [66] This value assumes that similar declines in respiratory illness could be experienced in Toronto. This value also assumes that respiratory illness can be used as a proxy for colds and flu, although respiratory illness is a much broader category of illness.

Rate of colds and influenza per person per year: 0.69
Sourced from a study on indoor air quality and health.[67]

	Parameters	Premise
4	$\# \, dwellings \; with \; retrofits \times \frac{people}{household} \times rate \; of \; respiratory \; illness$ $\times \, decrease \; in \; respiratory \; illness$ $= reduction \; in \; respiratory \; illness \; per \; year$	Indoor air quality is a key consideration of building retrofits, which can minimize respiratory illnesses.

Reduced energy use results in a more resilient grid

Energy retrofits reduce electricity demand in buildings, reducing strain on the electricity system and the risk of blackouts in periods of high demand.[68] During extreme weather events, electricity demand peaks. Any failure in the transmission lines further strains other lines, which can cause a blackout. Electricity operators plan for higher electricity demand and unexpected periods of loss through maintaining reserve capacity, although periods where demand exceeds supply can still happen.

Air conditioning used during heat waves are associated with rolling blackouts, where utilities apply planned outages to minimize overall grid strain to avoid a total electricity grid blackout, which can be detrimental to the electricity system, costly, and time consuming to restart.[69] In a recent example, four electricity generating systems failed in the

[65] Respiratory illness is defined as colds, influenza, pneumococcal disease, and respiratory infection in this study.
[66] Fisk, W. J. (2000). Review of health and productivity gains from better IEQ, 4, 12.
[67] Ibid.
[68] Ibid.
[69] The 2003 Northeast Blackout was estimated to cost $4-10 billion in the United States and caused Canada's GDP to decline 0.7%. See NRCan, US DOE. (2006). Final Report on the Implementation of the Task Force Recommendations. Retrieved from: http://www.ieso.ca/en/Corporate-IESO/Media/Also-of-Interest/Blackout-2003.

summer of 2012 in Alberta, which when coupled with high electricity demand during a heatwave, caused system rolling blackouts.[70]

Quantifying the relationship

High demand is costly because it requires increasing generation and transmission infrastructure. From this perspective, the benefit of energy demand reductions can be quantified by using the value of avoided peak demand. Value of avoided peak demand can be quantified by multiplying the number of units with deep retrofits, by the total electricity savings from retrofits, multiplied by the avoided electricity demand at peak, and finally, multiplied by the cost of avoided electricity demand in Ontario. This equation assumes that electricity demand reduction occurs at peak demand periods.

Values used

Avoided capacity cost at system peak in Ontario: $179.72/kW
This metric is valued at $170.72/kW including $162.15 (generation) + $3.83 (transmission) + $4.74 (distribution), according to the IESO.[71]

Avoided peak demand reduction factor: 0.862
Assumes that electricity peak savings are 0.862% of total electricity savings (%).[72] The value was found in a study on the relationship between total energy reductions and avoided impact on electricity peak savings for summer peak for a selection of 60 buildings in Toronto.[73] The value has been simplified from a regression curve; essentially x% reduction in electricity savings equals x%*0.862= reduction in peak summer demand.

	Parameters	**Premise**
5	$\# \, dwelling\ units\ with\ retrofits \times \%\ electricity\ savings \times peak\ reduction\ capacity\ factor \times peak\ demand \times avoided\ capacity\ cost\ at\ system\ peak = avoided\ cost\ of\ additional\ electricity\ peak\ in\ Ontario$	Peak demand reductions in the building occur at system peak. Value of avoided peak demand is a proxy for the increased resilience due to a reduction in demand.

[70] Tait, C., Walton, D. (July 9, 2012). Rolling blackouts hit Alberta as power-generating stations fail in heat wave. The Globe and Mail. Retrieved from: https://www.theglobeandmail.com/news/national/rolling-blackouts-hit-alberta-as-power-generating-stations-fail-in-heat-wave/article4401831/.

[71] IESO. (2015). Conservation & demand management energy efficiency cost effectiveness guide (p. 61).

[72] Bahy, D. S., & Nicolas, L. (2015). What is the relation between energy consumption savings and peak load savings and how can these affect future energy conservation requirements? International Journal of Sustainable Land Use and Urban Planning, 2(1). https://doi.org/10.24102/ijslup.v2i1.539

[73] Ibid.

TRANSFORMTO ACTION 2: TORONTO GREEN STANDARD

The Toronto Green Standard (TGS) is a set of building design standards for high energy and environmental performance. TGS has multiple tiers: the first tier is mandatory for all buildings. The voluntary higher tiers require higher energy and environmental performance in return for reductions on development charges.

Many equations used to quantify resilience benefits related to the Toronto Green Standard are similar to those above for building retrofits. While in practice there are great differences between retrofits and new buildings, each rely on the underlying premise of improved building envelopes and high energy performance. Unless otherwise noted, the equations will be assuming TGS Tier 1.

Safe buildings during periods of extreme heat

TGS buildings have high energy performance, which is often due to tighter building envelopes. This can minimize the impacts of extreme heat on persons within the building.

Quantifying the relationship

This equation mimics equation 1 for retrofits and values the avoided mortality from increased temperature. It assumes that persons within a Tier 4 TGS building are safe during an extreme heat event and are not susceptible to heat related mortality. The equation is relevant to Tier 4 because this tier can be satisfied by building to Passive House standards,[74] which is noted to be a more relevant influence on indoor building temperatures in heatwave conditions.[75] The equation uses the current heat mortality rate, increased mortality due to climate change and the life of a building to estimate the value of avoided mortality.

There is uncertainty in estimating heat related mortality in new TGS buildings, that cannot be accurately conveyed in a single equation. This equation is presented to consider the possible interactions between the variables. An interesting point of future analysis would be the relative difference in benefit between the various TGS tiers.

Values used

Heat mortality rate: 120/2,500,000
The value for heat mortality rate currently the equation is 120 deaths per 2,500,000 people,[76] which is the is sourced from a study by Toronto Public Health.[77]

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[74] City of Toronto. (2018). Toronto Green Standard v3. Retrieved from: https://www.toronto.ca/city-government/planning-development/official-plan-guidelines/toronto-green-standard/toronto-green-standard-version-3/low-rise-residential-version-3/energy-ghg-resilience-for-low-rise-residential-development/

[75] City of Toronto. (2017). Zero emissions building framework. p.35. Retrieved from: https://www.toronto.ca/wp-content/uploads/2017/11/9875-Zero-Emissions-Buildings-Framework-Report.pdf.

[76] According to Statistics Canada, the population of Toronto was 2,503,281 in 2006. We are using 2,500,000 for simplicity. From https://www12.statcan.gc.ca/census-recensement/2006/dp-pd/92-596/P1-2.cfm?Lang=eng&T=CSD&GEOCODE=20005&PRCODE=35&TID=0

[77] City of Toronto. (2014). *Strategies to prevent heat-related illness and deaths from extreme heat emergencies*. Retrieved from https://www.toronto.ca/legdocs/mmis/2014/hl/bgrd/backgroundfile-70709.pdf

Increased mortality rate due to climate change: 1.02

According a study of cities in Quebec, heat mortality rate from increasing temperatures due to climate change increases heat mortality by 2%.[78]

Value of avoided death: A life is valued a $7.4 million (2006$).[79]

This value is sourced from an EPA whitepaper on valuing mortality. Monetizing mortality can be controversial and is difficult to attribute mortality to a single value. This value is instead used to illustrate estimates of the value of avoided mortality.

	Parameters	Premise
6	$\# \, dwellings \, at \, TGS \, Tier \, 4 \times \frac{people}{household} \times heat \, mortality \, rate \times climate \, mortality \, rate \, increase \times duration \, of \, the \, building \times value \, of \, avoided \, mortality = value \, of \, avoided \, mortality \, from \, inc. temp.$	TGS Tier 4 is built to Passive House standards. Assumes that people can fully avoid heat exposure if their homes are thermally protected (i.e. that they do not experience heat exposure outside or in other buildings).

Life cycle unit costs

The high energy performance of TGS buildings can reduce lifecycle building costs for owners.

Quantifying the relationship

This equation is sourced from the Toronto Zero Emissions Building Framework. The equation links TGS dwellings to lifecycle building costs. This equation see that the number of units built to TGS Tier 1, multiplied by the lifecycle costs, equals avoided housing (ownership and energy) expenditures per year. The relationships between construction costs, unit ownership and rent are complex and is not adequately expressed in this equation.

Values used

Lifecycle cost savings: The values presented below are from the Toronto Zero Emissions building framework, which modelled lifecycle costs to own and operate a unit, relative to the Ontario Building Code. The lifecycle period is 25 years in this analysis.

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[78] Doyon, B., Bélanger, D., & Gosselin, P. (2008). The potential impact of climate change on annual and seasonal mortality for three cities in Québec, Canada. International Journal of Health Geographics, 7(1), 23. https://doi.org/10.1186/1476-072X-7-23

[79] US EPA. (2010). Valuing mortality risk reductions for environmental policy: A white paper. Retrieved from https://www.epa.gov/sites/production/files/2017-08/documents/ee-0563-1.pdf

Table 3. Modelled lifecycle costs for buildings to vs TGS Tier 1 and 2.[80]

Archetype	TGS Tier	Lifecycle cost savings
High Rise MURB	V3 Tier 1	$0.12/ft^2
	V3 Tier 2	$1.15/ft^2
Low Rise MURB	V3 Tier 1	-$0.03/ft^2
	V3 Tier 2	$1.97/ft^2

Area built to TGS Tier 1 or Tier 2: A count of square footage constructed to each tier.

	Parameters	Premise
7	$Area\ built\ to\ TGS\ Tier\ 1\ or\ 2 \times lifecycle\ cost\ savings = avoided\ building\ costs$	People have lower energy expenditures, which can lower stress and hardship.

Residents are safer during extreme weather or power outage

If large buildings have high energy performance, coupled with on-site power generation, storage or a backup energy system, the building may be more self-sufficient in the event of an outage. This is especially important for critical infrastructure, such as hospitals, water treatment facilities, among others.

Under the Toronto Green Standard Tier 2, mid- to high-rise buildings must be able to supply 72 hours of backup power in the event in an outage, and residential high-rise buildings must include a refuge area that is heated and cooled, some electrical function, and residents have access to potable water.[81] This is not a requirement for low rise buildings under the Toronto Green Standard. This policy is an explicit resilience consideration in TGS.

Quantifying the relationship

To quantify the impact of this policy on resilience, a simple count of buildings built to TGS Tier 2 can be performed. Because a backup system is a Tier 2 requirement, all high-rise buildings built under TGS Tier 2 can be considered self-sufficient during an outage. While a back-up system is not explicitly a GHG mitigation measure, battery backup systems can also serve as energy storage to optimize the use of renewable electricity, resulting in avoided GHG emissions.

Values used

All values used in this equation are related to the buildings constructed to TGS Tier 2 or higher.

[80] City of Toronto. (2017). Zero Emissions Building Framework. Integral Group, Morrison Hershfield, & Provident. Retrieved from: https://www.toronto.ca/wp-content/uploads/2017/11/9875-Zero-Emissions-Buildings-Framework-Report.pdf

[81] City of Toronto. (2018). Toronto Green Standard v3: Mid-High Rise Buildings. Retrieved from: https://www.toronto.ca/city-government/planning-development/official-plan-guidelines/toronto-green-standard/toronto-green-standard-version-3/mid-to-high-rise-residential-all-non-residential-version-3/energy-ghg-resilience-for-mid-to-high-rise-residential-all-non-residential-development/.

	Parameters	Premise
8	$$\# \, buildings\ at\ or\ above\ TGS\ Tier\ 2 \times \frac{people}{building} = \#\ of\ self\ sufficient\ people\ in\ an\ outage$$	TGS Tier 2 requires backup power supply for 72 hours. Therefore, a count of persons in TGS Tier 2 buildings is representative of persons that are self-sufficient during an outage.

High performance buildings result in a more resilient grid

High energy performance requirements in the Toronto Green Standard reduces energy use per capita and lowers local energy use as the building stock changes over time. Additionally, the greenhouse gas intensity cap targets reduce fossil fuel intensity by encouraging fuel switching using on-site renewables, grid supplied low carbon fuel sources or low carbon district energy. Inclusion of green roofs can also reduce energy loss in buildings through the roof.[82] Minimizing energy demand from buildings is especially important in Toronto as increasing electrification of transportation, growing population and infrastructure aging put strain on the electricity grid.

Quantifying the relationship

The resilience co-benefit of this relationship has similarities to the role of building retrofits on energy demand and can therefore be quantified using the avoided cost of peak demand in Equation 5. Retrofits will minimize existing energy demand, while the TGS will minimize new growth in demand.

Values used

Avoided capacity cost at system peak in Ontario: $170.72/kW
This metric is valued at $170.72/kW including $162.15 (generation) + $3.83 (transmission) + $4.74 (distribution), according to the IESO.[83]

Avoided peak demand: 0.862
Assumes that electricity peak savings are 0.862% of total electricity savings.[84]
The value was found in a study on the relationship between total energy reductions and avoided impact on electricity peak savings for summer peak for a selection of 60 buildings in Toronto.[85] The value has been simplified from a regression curve; essentially x% reduction in electricity savings equals x%*0.862= reduction in peak summer demand.

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[82] C2ES. (2018). Resilience Strategies for Flash Flooding.

[83] IESO. (2015). Conservation & demand management energy efficiency cost effectiveness guide (p. 61).

[84] Bahy, D. S., & Nicolas, L. (2015). What is the relation between energy consumption savings and peak load savings and how can these affect future energy conservation requirements? International Journal of Sustainable Land Use and Urban Planning, 2(1). https://doi.org/10.24102/ijslup.v2i1.539

[85] Bahy, D. S., & Nicolas, L. (2015). What is the relation between energy consumption savings and peak load savings and how can these affect future energy conservation requirements? International Journal of Sustainable Land Use and Urban Planning, 2(1). https://doi.org/10.24102/ijslup.v2i1.539

	Parameters	Premise
9	$\# \, dwellings \; at \; TGS \; Tier \; 1$ $\times \% \; electricity \; savings \; vs \; building \; stock$ $\times \; peak \; reduction \; capacity \; factor$ $\times \; peak \; demand$ $\times \; avoided \; capacity \; cost \; at \; system \; peak$ $= avoided \; cost \; of \; electricity \; at \; peak$	Peak demand reductions in the building occur at system peak. Value of avoided peak demand is a proxy for the increased resilience due to a reduction in demand.

Resilience considerations in buildings make them less susceptible to damage

Average annual total losses from hurricanes, convective storms, winter storms and floods in Canada totals $4.92 billion,[86] or approximately $134 per person, assuming a population of 36.7 million people. While these events are geographically distributed, it is likely that there will be storms in the near future that cause significant damage to the City of Toronto,[87] and the projections indicate that storm damage on cities in Canada will increase.[88]

TGS includes a climate change resilience checklist for new development that is required under Tier 2, which includes consideration of thermal resilience and safety, back-up generation, flood mitigation and preparedness during extreme events. While it is difficult to establish the reduction in risk that results from the application of the checklist, *as well as the general increase in care resulting from the TGS program*, at least one insurance company provides a 10% rebate on premiums,[89] an indicator that the risk is lower.

Quantifying the relationship

The relationship between resilience considerations in TGS Tier 2 buildings and withstanding damage can be quantified by the avoided costs of weather damage due to increased resilience of the building. The equation follows that the number of buildings built to TGS Tier 2 multiplied by the person per building, multiplied by the annual per capita damage from storms and the risk reduction from resilience considerations in construction can provide the avoided costs of weather damage. This equation assumes that risk is proportional to the cost of damage.

Values used

Annual per capita damage from storms: $134
This value was calculated from a report from the Parliamentary Budget Officer, relating total weather damages in Canada to a per capita value.[90]

Risk reduction from climate resilience considerations: 0.9

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[86] Parliamentary Budget Officer. (2016). Estimate of the average annual cost for disaster financial assistance arrangements due to weather events. Retrieved from https://www.pbo-dpb.gc.ca/web/default/files/Documents/Reports/2016/DFAA/DFAA_EN.pdf

[87] Between 2005 and 2017, community losses from major storms totaled nearly $2 billion in the City of Toronto, according to internal research by SSG.

[88] Team Green Analytics, & Ontario Centre for Climate Change Impacts. (2015). The economic impacts of the weather effects of climate change on communities (p. 201).

[89] Desjardins provides a 10% reduction in premiums for LEED certification; it is assumed that this reduction could apply to TGS.

[90] Parliamentary Budget Officer. (2016). Estimate of the average annual cost for disaster financial assistance arrangements due to weather events. Retrieved from https://www.pbo-dpb.gc.ca/web/default/files/Documents/Reports/2016/DFAA/DFAA_EN.pdf

This value assumes that reduction in risk from resilient buildings considerations is 10% (aligned with the premium reduction for a LEED-certified home), so that new risk is 0.9.

	Parameters	Premise
10	$\# \, buildings \; at \; TGS \; Tier \; 2 \times \frac{people}{building}$ $\times \, annual \; per \; capita \; damage \; from \; storms$ $\times \, risk \; reduction \; from \; climate \; resilience \; considerations$ $\times \, duration \; of \; the \; building$ $= avoided \; costs \; of \; weather \; damage \; due$	Resilience considerations minimize climate impact risk, which can be related to average storm damage costs per person.

Green roofs reduce flooding and stormwater

As a mitigation action, green roofs can also minimize energy loss through the roof and minimize the urban heat island effect. They also influence resilience by absorbing stormwater. About 23% of Toronto's stormwater and wastewater sewers are combined, which increases system volumes during periods of intense rain, which can lead to overflow onto streets and into water bodies.[91] Green roofs can mitigate flooding risks by retaining or delaying the release of a portion of rainfall during extreme weather events.

In a University of Toronto Study, green roofs in the city were found to absorb 85-90% more water than an impermeable surface. This is described by a peak runoff coefficient of 0.1-0.15.[92] This value is better than the 50% reduction value traditionally used by designers during construction, but is consistent with values found in the literature. In one study, stormwater runoff was reduced by 82.8% over an impermeable surface, and a gravel roof has a 48.7% mean rainfall retention.[93]

The Toronto Green Standard along with the Green Roof Bylaw make green roofs mandatory on most Part 3 buildings.

Quantifying the relationship

There are two equations that quantify the benefits of green roofs; equation 11 describes the environmental value of green roofs, while equation 12 describes the water runoff reduction. In equation 11, the area of green roofs installed is related to the annual environmental benefits, which is provided by net benefits intensity per area.

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[91] Howell, C., Drake, J., Margolis, L. (2017). How green roofs can protect city streets from flooding. University of Toronto News. Retrieved from: https://www.utoronto.ca/news/how-green-roofs-can-help-cities-sponge-away-excess-stormwater

[92] Hill, J., Drake, J., Sleep, B., Margolis, L. (2017). Influences of four extensive green roof design variables on stormwater hydrology. Journal of Hydrologic Engineering, 22 (8). https://doi.org/10.1061/(ASCE)HE.1943-5584.0001534

[93] VanWoert, N., Rowe, D., Andresen, J., Rugh, C., Fernandez, R., Xiao, L. (2005). Green Roof Stormwater Retention: Effects of Roof Surface, Slope and Media Depth. Journal of Environmental Quality, 34 (3), 1036-1044.

In equation 12, runoff reduction is calculated by multiplying annual precipitation by the total area of green roofs installed and the average precipitation retention rate. This equation is sourced from a report that quantifies the value of green infrastructure.[94]

Values used

Annual net benefit intensity of green roofs: \$500/m^2

A middle range benefit of green roofs is used based on a study that found a net present value of between \$42.30 and \$978.80.[95]

Precipitation retention: 0.85

This value was found in a University of Toronto study on green roof stormwater retention.[96] The 85% retention represents the more conservative value found in the study.

	Parameters	Premise
11	$Area\ of\ green\ roofs\ (m2) \times annual\ net\ benefit\ intensity = envrionmental\ benefit\ of\ green\ roof$	Calculating the value of green roofs based on the annual net benefit and the area of green roofs installed.
12	$Annual\ precipitation\ (m) \times greenroof\ area\ (m3) \times precipitation\ retention\ rate = total\ runoff\ reduction\ (m3)$	Runoff reduction is calculated by multiplying annual precipitation by the total area of green roofs installed and the average precipitation retention rate.

[94] Center for Neighborhood Technology. (2010). The value of green infrastructure. Retrieved from: https://www.cnt.org/sites/default/files/publications/CNT_Value-of-Green-Infrastructure.pdf

[95] Feng, H., & Hewage, K. N. (2018). Economic benefits and costs of green roofs. In Nature Based Strategies for Urban and Building Sustainability (pp. 307–318). Elsevier. https://doi.org/10.1016/B978-0-12-812150-4.00028-8

[96] Hill, J., Drake, J., Sleep, B., Margolis, L. (2017). Influences of four extensive green roof design variables on stormwater hydrology. Journal of Hydrologic Engineering, 22 (8). https://doi.org/10.1061/(ASCE)HE.1943-5584.0001534

Decreasing stress on water and wastewater systems

High efficiency water systems in buildings means there is less wastewater volume released into wastewater systems. During storm and high rainfall events, this can reduce stress on wastewater and stormwater systems. Stormwater management on site, using green roofs and rain barrels can also minimize pressures on stormwater systems and reduce flooding.[97] Reducing water consumption also reduces emissions associated with treating and distributing water.

To meet water efficiency requirements, the TGS requires the use of drought-tolerant landscape to reach Tier 1, and water efficient fixtures that minimizes potable water use by 40% in Tier 2, and 50% for Tier 3. For stormwater management, the TGS requires that the building retain runoff generated from a minimum of 5 mm depth of rainfall from site surfaces.[98]

TGS also requires that sites retain and manage stormwater. The TGS Tier 1 requires 5mm of stormwater retention, Tier 2 requires 10mm of stormwater retention and Tier 3 requires 25mm of stormwater retention for mid-high rise buildings.

Quantifying the relationship

To quantify the benefits of water efficiency, the number of buildings built to TGS are multiplied by the average annual water consumption and the percent reduction in water use for each respective TGS tier. This equation gives the annual potable water savings from each building built to its respective TGS tier.

This equation links TGS buildings to avoided costs of stormwater treatment. Due to stormwater retention requirements, the stormwater retention required of a given tier can be multiplied by the site area of a building and the estimated cost of stormwater treatment per cubic metre. When using this equation, it is important that the count (and area) of buildings in a given tier matches the stormwater retention requirement.

Values used

Potable water reduction: Tier 2: 0.4; Tier 3: 0.5
TGS version 3 requires 0.4% efficiency in potable water for Tier 2, and 0.5% efficiency in potable water for Tier 3.

Average annual water consumption: 72.1 m^3
The average water consumption value is from a City of Toronto report on water consumption.[99]

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[97] C2ES. (2018). Resilience Strategies for Flash Flooding.

[98] City of Toronto. (2018). Water balance, quality and efficiency for mid to high-rise residential and non-residential. Retrieved from: https://www.toronto.ca/city-government/planning-development/official-plan-guidelines/toronto-green-standard/toronto-green-standard-version-3/mid-to-high-rise-residential-all-non-residential-version-3/water-balance-quality-efficiency-for-mid-to-high-rise-residential-non-residential/.

[99] City of Toronto (2018). City of Toronto average water consumption. Retrieved from: https://www.toronto.ca/311/knowledgebase/kb/docs/articles/revenue-services/customer-service/call-centre/call-centre/city-of-toronto-average-water-consumption.html

Avoided stormwater requirement: Tier 1: 0.005m; Tier 2: 0.010m; Tier 3: 0.025mm
TGS Tier 1, 2 and 3 requires stormwater retention of 5mm, 10mm and 25mm, respectively for a 24 hour storm.[100]

Avoided cost intensity for stormwater management: \$100/m^3
This value is based on a lifecycle cost calculated from the Canadian Nursery Association.[101]

	Parameters	Premise
13	$\#\ of\ buildings\ at\ TGS\ Tier\ 2/3 \times \frac{people}{building} \times average\ annual\ water\ consumption \times potable\ water\ reduction\ by\ TGS\ Tier = Annual\ potable\ water\ savings$	Potable water consumption is reduced by 40% in Tier 2 and 50% in Tier 3.
14	$Total\ site\ area\ of\ buildings\ at\ TGS \times avoided\ stormwater \times cost\ intensity\ of\ stormwater\ management = avoided\ stormwater\ management\ cost$	Stormwater retention requirements in TGS minimize stormwater management costs.

[100] City of Toronto. (2018). Toronto Green Standard v3. Retrieved from: https://www.toronto.ca/legdocs/mmis/2017/pg/bgrd/backgroundfile-107487.pdf
[101] Based on a life cycle cost within the range described in: Canadian Nursery Landscape Association. (n.d.). *Life cycle cost analysis of natural on-site stormwater management methods*. Retrieved from https://cnla.ca/uploads/pdf/LCCA-Stormwater-Report.pdf

TRANSFORMTO ACTION 3: DISTRICT ENERGY SYSTEMS

Decentralized energy resources are more resilient to wide-scale outages

District energy (DE) systems are a mitigation action because they allow for easier integration of renewable heat and electricity in the future. DE systems also contribute to resilience in multiple ways.

District energy systems are distinct from the wider natural gas network or electricity grid. If the natural gas network or electricity grid experiences a failure, district energy systems can act as energy islands. This can minimize loss and damage if climate risks disrupt or damage the wider networks and can minimize the extent to which emergency response will need to be deployed and prevents business interruption.[102]

District energy systems are also more spatially diverse than centralized natural gas networks. Spatially diversified energy supply can enhance resilience because the extent of damage from a single extreme weather event or a single critical location can be minimized.[103] With a wider distribution of energy generation resources, the exposure to climate hazards is effectively reduced because the probability that all resources are affected is minimized. Furthermore, district energy systems can use local sources of waste heat, which are readily available and less subject to supply disruptions.

District energy is also more flexible and allows the integration and removal of different technologies, as methods of providing energy evolve.

While district energy systems benefit from economies of scale, the more people relying on a single district energy system reduces the spatial diversity of heating system and therefore minimizes the resilience benefits. Focusing on nodes is one approach to reduce this risk increasing the diversity of generation and storage capacity as developments progress.

Quantifying the equation

Diversity indices can be used to measure diversity in physical systems. Diversity indices quantify diversity as *variety* and *balance*, where variety is the number of different types of groups in a system, and balance is the number within each grouping.[104] Disparity, which describes the differences between groups, can also be used to measure

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[102] Van Nostrand, J. (n.d.). Keeping the lights on during superstorm Sandy: Climate change adaptation and the resiliency benefits of distributed generation. Retrieved from https://www.nyuelj.org/wp-content/uploads/2015/09/VanNostrand_ready_for_website_1.pdf

[103] Stout, S., Hotchkiss, E., Lee, N., Holm, A., Day, M. (2017). Distributed Energy Planning for Climate Resilience. NREL/PO-7A40-71310. National Renewable Energy Laboratory.

[104] Wu, T. Y., & Rai, V. (2017). Quantifying diversity of electricity generation in the U.S. *The Electricity Journal*, *30*(7), 55–66. https://doi.org/10.1016/j.tej.2017.09.001

diversity,[105] although it can be difficult to quantify[106] and is not included in the equation below. The Simpson Index has been used to quantify diversity in energy systems. [107] The Simpson index follows the equation below, resulting in a value between 0 and 1, where 0 is no diversity, and 1 is infinite diversity. [108]

Diversity indices are not inherently useful alone, but instead become useful when used to compare diversity between various systems. Existing studies have used diversity indices to compare the diversity of energy systems, with the general notion that greater diversity leads to improved resilience. In one study, researchers used diversity indices to compare the diversity of energy supply in four different countries.[109] The same study then examined the diversity in each countries' energy supply over time.[110] Another U.S. study used diversity indices to measure how the introduction of various technologies influenced energy system diversity over time.[111]

Energy diversity indices can be used in multiple ways in the Toronto context. First, it can be used to measure the diversity of district energy systems themselves, by examining the number of buildings on an individual system and the total number of buildings connected to district energy in the City. This can then be used to measure the diversity of district energy systems over time.

It can also be used to look at how the inclusion of district energy influences diversity of energy supply across all of Toronto. This value can be used to benchmark Toronto's heating system diversity against other cities or jurisdictions around the world. Similarly, heating system diversity can also be measured between different neighbourhoods, although this comparison would require some level of district energy penetration. Diversity indices can also be used to measure the relative diversity in district energy systems in Toronto over time by comparing a baseline diversity index to future diversity indices.

Values used

All values in this equation are related to the extent of district energy deployment.

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[105] Stirling, A. (2007). A general framework for analyzing diversity in science, technology and society. J R Soc Interface. 2007 Aug 22; 4(15): 707–719.
[106] Wu, T., Rai, V. (2017). Quantifying Diversity of Electricity Generation in the U.S. White Paper UTEI/2017-02-1. Retrieved from: http://energy.utexas.edu/the-full-cost-of-electricity-fce/.
[107] Wu, T., Rai, V. (2017). Quantifying Diversity of Electricity Generation in the U.S. White Paper UTEI/2017-02-1. Retrieved from: http://energy.utexas.edu/the-full-cost-of-electricity-fce/.
[108] Adapted from: https://www.rgs.org/CMSPages/GetFile.aspx?nodeguid=018f17c3-a1af-4c72-abf2-4cb0614da9f8&lang=en-GB
[109] Lo, L. (2011). Diversity, security, and adaptability in energy systems: a comparative analysis of four countries in Asia. World Renewable Energy Congress, May 12 2011, Sweden. Retrieved from: http://www.ep.liu.se/ecp/057/vol10/016/ecp57vol10_016.pdf
[110] Ibid.
[111] Wu, T., Rai, V. (2017). Quantifying Diversity of Electricity Generation in the U.S. White Paper UTEI/2017-02-1. Retrieved from: http://energy.utexas.edu/the-full-cost-of-electricity-fce/.

	Parameters	Premise
15	$1 - \frac{\Sigma \# \, of \, buildings \, per \, DE \, system \, * \, (\# \, of \, buildings \, per \, DE \, system \, - \, 1)}{total \, \# \, of \, buildings \, on \, a \, DE \, system * (total \, \# of \, buildings \, on \, a \, DE \, system \, - 1)}$ $1 - \frac{\Sigma \# \, of \, buildings \, by \, heating \, system \, type * \, (\# \, of \, buildings \, by \, heating \, type \, - \, 1)}{\# \, of \, buildings \, in \, study \, area * (\# of \, buildings \, in \, study \, area \, - 1)}$	Diversity can be quantified using a diversity index.

District energy can provide backup power

District energy systems can address backup energy needs in various ways. District energy systems can be operated with combined heat and power (CHP) systems, as well as thermal storage and on-site batteries. CHP enhances resilience through greater energy efficiency, an ability to alternate between thermal and electrical outputs, and many have electricity black start capabilities.[112] In event of grid disruption, DE CHP can provide backup power and thermal loads to buildings.[113]

Quantifying the relationship

Assuming that buildings that are connected to a DE system with CHP have access to backup energy in the event of a disruption, a count of units connected to a DE system with backup is proportionate to the number of people with access to back up power.

Values used

This equation does not rely on any additional values sourced from the literature.

	Parameters	Premise
16	$\# \, dwellings \, connected \, to \, DE \times \frac{people}{dwelling} = \# \, of \, people \, with \, access \, to \, backup \, power$	All buildings connected to a DE with CHP system have access to a back-up power system.

[112] US Department of Energy. (2013). Guide to using Combined Heat and Power for Enhancing Reliability and Resiliency in Buildings. Retrieved from: https://www.epa.gov/sites/production/files/2015-07/documents/guide_to_using_combined_heat_and_power_for_enhancing_reliability_and_resiliency_in_buildings.pdf.

[113] US Department of Energy. (2016). Combined Heat and Power Technical Potential in the United States. Retrieved from: https://www.energy.gov/sites/prod/files/2016/04/f30/CHP%20Technical%20Potential%20Study%203-31-2016%20Final.pdf

TRANSFORMTO ACTION 4: DECENTRALIZED RENEWABLE ENERGY

Energy system diversity reduces the risk of damage

Decentralized renewable energy increases diversity and redundancy in energy systems, both of which contribute to improved resilience to climate impacts.

Decentralized energy implies increased spatial diversification of electricity generation. This reduces the risk of damage from a single event at a single critical location.[114] It is less probable that all generating systems are affected by an extreme weather event if they are located at various points across the City, whereas when a considerable portion of energy comes from a single source, disruption or damage at a single point could have negative consequences for the entire system.

Additionally, decentralized renewable energy often comes from multiple energy sources: rooftop solar PV, storage, waste heat systems, wind, among others. This reduces the risk of widespread energy disruptions if some energy generation capacity is lost. The system can maintain reliability in the event that one energy source becomes unavailable.

Quantifying the relationship

Similar to quantifying diversity of district energy systems, diversity can be explored using a diversity Index, explained in Equation 17. This equation uses the Simpson's Diversity Index to describe the variety and balance in the electricity system. In relation to decentralized energy, variety would be described by the number of energy sources, and balance as the kw installed of each type. The index provides a value between 0 and 1, where 0 is no diversity, and 1 is infinite diversity. Although the index on its own is not inherently useful, it can be compared to the diversity in other systems, or to the system itself as it changes over time.

Various studies have used diversity indices to compare the diversity of energy systems, with the general notion that greater diversity leads to improved resilience. In one study, researchers used diversity indices to compare the diversity of energy supply in four different countries.[115] The study also examines diversity in each countries energy supply over time.[116] Another US study used diversity indices to measure how the introduction of various technologies influenced energy system diversity over time.[117]

Energy diversity indices can be used to look at how the inclusion of different energy sources influences diversity of energy supply across all of Toronto. This value can be used to benchmark Toronto's energy system diversity against other cities or jurisdictions around the world. Similarly, electricity diversity can also be measured between different

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[114] NREL. (2018). Valuing the Resilience Provided by Solar and Battery Energy Storage Systems. NREL. Retrieved from: https://www.nrel.gov/docs/fy18osti/70679.pdf

[115] Lo, L. (2011). Diversity, security, and adaptability in energy systems: a comparative analysis of four countries in Asia. World Renewable Energy Congress, May 12 2011, Sweden. Retrieved from: http://www.ep.liu.se/ecp/057/vol10/016/ecp57vol10_016.pdf

[116] Ibid.

[117] Wu, T., Rai, V. (2017). Quantifying Diversity of Electricity Generation in the U.S. White Paper UTEI/2017-02-1. Retrieved from: http://energy.utexas.edu/the-full-cost-of-electricity-fce/.

neighbourhoods, and could compare penetration of decentralized renewable electricity by neighbourhood. Diversity indices can also be used to measure the relative diversity in district energy systems in Toronto over time by comparing a baseline diversity index to future diversity indices.

Values used

All values used in this equation are related to the deployment of decentralized renewable energy.

	Parameters	Premise
17	$$1 - \frac{\Sigma\, kW\ per\ source\ \times\ (kW\ per\ source\ -\ 1)}{total\ kW \times\ (total\ kW\ \ - 1)}$$	Energy system diversity can be measured using a diversity index that considers system variety and balance.

Increases the ability of a building to function in the event of electricity outages (storage and islanding)

Solar with storage is being increasingly implemented in resilient power system designs.[118] Storage can allow for a building to draw power from the battery during an outage. Without a storage system, most solar PV systems shut down in the event of a grid outage.

For commercial and institutional buildings, storage can minimize disruptions to business and services. In an analysis by the National Renewable Energy Laboratory, the net present value of solar with storage was assessed against potential economic losses from an outage for various buildings.[119] In placing economic value to the potential losses in an outage, solar PV with storage was the least cost option over the system's lifetime for a school, an office building, and a hotel.[120]

For residential buildings, on-site storage can allow occupants to remain safe in their homes during an outage. For example, the Tesla Powerwall 2 is a 13.5 kWh lithium-ion battery.[121] The Ontario Energy Board reports that the average electricity customer in the Greater Toronto Area used 715 kWh per month from 2010-2014, or approximately 24 kWh per day.[122] This means a home battery system could support the average electrical load for just over half the day under normal operation conditions, although it is more realistic that during an outage, only

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[118] NREL. (2018). Valuing the Resilience Provided by Solar and Battery Energy Storage Systems. NREL. Retrieved from: https://www.nrel.gov/docs/fy18osti/70679.pdf
[119] NREL. (2018). Valuing the Resilience Provided by Solar and Battery Energy Storage Systems. NREL. Retrieved from: https://www.nrel.gov/docs/fy18osti/70679.pdf
[120] Ibid.
[121] Details on the Tesla Powerwall system are available here: https://www.tesla.com/en_CA/support/powerwall/faqs
[122] Ontario Energy Board. (2016). Defining Ontario's Typical Electricity Customer. Retrieved from: https://www.oeb.ca/oeb/_Documents/Documents/Report_Defining_Typical_Elec_Customer_20160414.pdf

basic electrical functions would be performed. Furthermore, many home storage systems are installed with a solar PV system, which could continuously charge the home storage system for longer power backup.

Decentralized renewables can also support building function during an outage through islanding. Islanding is when a portion of the grid operates separately from the larger electrical grid on its own closed circuit.[123] To successfully island, there must be sufficient energy resources, such as decentralized renewable energy and storage, present within the microgrid to supply electricity to the loads.

Islanding can improve the speed and priority of rebuilding efforts of the electricity grid by focusing on the repair of strategic grids, such as those with water treatment plants, police stations and other critical infrastructure.[124] Islanding can also isolate faults in the electricity grid, minimizing the extent of power outages. This minimizes the possibility for cascading outages, where a failure in one part of the system leads to widespread failure across the entire electrical grid.[125] Cascading outages were to blame for the 2003 Northeast blackout that hit Ontario and northeastern United States. When microgrids are sufficiently supplied by local energy resources, damage to transmissions lines does not necessarily mean the end users will be impacted.[126]

Quantifying the relationship

The benefits of avoiding a power outage through storage and islanding can be quantified by the avoided costs of a power outage. The benefits of microgrids and storage can be quantified by multiplying the number of buildings connected to a microgrid / storage by the average time that power is interrupted and the frequency of power outages, and then multiplied finally by the interruption cost per building type.

Values used

Interruption cost:

Table 4 below represents average costs from a one-hour interruption for various building types.

[123] This is also known as a microgrid

[124] EDF Blogs. (November 14, 2017). Microgrids can help prevent extreme power outages, and cities are taking notice. Retrieved from: http://blogs.edf.org/energyexchange/2017/11/14/microgrids-can-help-prevent-extreme-power-outages-and-cities-are-taking-notice/

[125] Hirsch, A., Parag, Y., Guerror, J. (2018). Microgrids: A review of technologies, key drivers and outstanding issues. Renewable and Sustainable Energy Reviews, 90, 402-411.

[126] Ibid.

Table 4. Weighted average customer interruption costs[127]

Building class	1 hour interruption
Medium and large commercial and institutional	$17,804
Small commercial and institutional	$647
Residential	$5.1

Number of hours that power is interrupted: 0.91 hours
This value is the average time that is interrupted in Toronto, retrieved from Toronto Hydro.[128]

Number of power outages: 1.28[129]

	Parameters	Premise
18	$\# \text{ customers with solar \& storage} \times \text{power interruption } (hours) \times \# \text{ of power outages} \times \text{interruption cost} = \text{avoided customer interruption cost}$	Avoided interruption cost is calculated by the number of customers with storage or on an islandable grid section, multiplied by average power outage length, frequency of power outages and the interruption cost.

[127] Sullivan, M., Schellenberg, J., & Blundell, M. (2015). Updated value of service reliability estimates for electric utility customers in the United States (No. LBNL--6941E, 1172643). https://doi.org/10.2172/1172643
[128] Toronto Hydro-Electric System Limited. (n.d.). *2017 Scorecard- Toronto Hydro- electric system*. Retrieved from https://www.oeb.ca/documents/scorecard/2017/Scorecard%20-%20Toronto%20Hydro-Electric%20System%20Limited.pdf
[129] Ibid.

TRANSFORMTO ACTION 5: ACTIVE TRANSPORTATION

Increases affordable mobility options

Well-connected transit systems contribute to community safety and connectedness, which increases the resilience of communities. Greater access to active transportation increases mobility options, which influences resilience because other modes can still be used in case one mode is disrupted.[130] Access to active transportation networks also brings affordability benefits because of its lower costs in relation to a private vehicle, which can be particularly important for low income households.

Quantifying the relationship

The monetary benefits can be quantified as the avoided costs of vehicle use, which is a function of the average trip distance in Toronto, multiplied by the average cost per kilometre to drive. This equation assumes that trip increases are proportionate to cycling infrastructure, and that cycling can displace average vehicle trip length, which is approximately 5.5km in Toronto.[131] The equation sees that the avoided cost of driving is a function of the number of trips by active transportation, average distance of vehicular trips, multiplied by the cost of driving per kilometre. This is then subtracted by the average cost of cycling to determine the cost difference between cycling and vehicular transport.

Values used

Existing cycling infrastructure (km): 640 km[132]

Annual active trips: 26,903,520
There are approximately 26.9 million trips by bicycle in Toronto annually, or 96,084 trips per day.[133]

Average vehicle trip length: 5.5km
This value for average vehicle trip length was retrieved from the Transportation Tomorrow Summary for the City of Toronto.[134]

Cost of vehicle travel: $0.54/km[135]

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[130] IISD. (2017). Building a Climate-Resilient City: Transportation Infrastructure. Retrieved from: https://www.iisd.org/library/building-climate-resilient-city-transportation-infrastructure
[131] Transportation Tomorrow. (2016). Transportation Tomorrow Survey Travel Summaries. P 15. Retrieved from: http://dmg.utoronto.ca/pdf/tts/2016/2016TTS_Summaries_Toronto_Wards.pdf
[132] Vijayakumar, N., Nurda, C. (2015). Cycle Cities: Supporting cycling in Canadian Cities. The Pembina Institute. Retrieved from: https://www.pembina.org/reports/cycle-cities-full-report-rev.pdf.
[133] ibid.
[134] Transportation Tomorrow. (2016). Transportation Tomorrow Survey Travel Summaries. P 15. Retrieved from: http://dmg.utoronto.ca/pdf/tts/2016/2016TTS_Summaries_Toronto_Wards.pdf
[135] Calculated using an average cost of annual ownership of $10,800, with 20,000km driven. Sourced from: https://globalnews.ca/news/3832649/car-ownership-costs-public-transit-canada/

Personal costs of cycling: \$0.06/km

The average cycling cost per kilometre is sourced from a Toronto report.[136]

	Parameters	Premise
19	$$\left[\left(1+\frac{new\ cycling\ inf.}{existing\ cycling\ inf.}\right)\times annual\ active\ trips \times displaced\ vehicular\ trip\ length \times cost\ of\ vehicular\ trip\right] - cost\ of\ cycling\ trip = avoided\ personal\ vehicle\ expenditures$$	Avoided cost of driving is a function of the number of trips by active transit, average distance of vehicular trips, multiplied by the cost of driving per km.

Reduces flooding when combined with green infrastructure

Green infrastructure for active transport can include bioswales, stormwater tree trenches, tree-lined sidewalks and paths, as well as permeable pavements and green space in close proximity to active transport networks.

Tree-lined active transportation networks can create a more stable microclimate which can minimize heat risk from direct sunlight on users. The inclusion of constructed wetlands and permeable surfaces improves natural drainage and can reduce the occurrence and risk of flooding from rainfall and stormwater runoff.[137] By including green infrastructure in public areas across the whole city, the health benefits and improvement in the livability of the city can be applied across all socioeconomic groups.[138] Furthermore, the public is more likely to use active transportation when the networks are combined with green infrastructure, including tree cover and green spaces.[139] The City is currently working to increase green infrastructure on its streets through the Green Streets Program.[140]

Quantifying the relationship

The value of green infrastructure for flood reduction can be quantified by calculating the area of green infrastructure installed along a bike lane or walking path, multiplied by the avoided stormwater runoff, which is a

[136] Toronto Centre for Active Transportation. (2012). The economic impacts of active transportation. Retrieved from: http://www.tcat.ca/wp-content/uploads/2014/10/Economic-Impacts-of-Active-Transportation-Backgrounder.pdf

[137] Vega, O. (2018). Application of Stormwater Tree Trenches in the City of Vancouver. Prepared for City of Vancouver. Retrieved from: https://sustain.ubc.ca/sites/sustain.ubc.ca/files/GCS/2018_GCS/Reports/2018-52%20Application%20of%20Stormwater%20Tree%20Trenches%20in%20the%20City%20of%20Vancouver_Vega.pdf

[138] Hughey, S. M., K. M. Walsemann, S. Child, A. Powers, J. A. Reed and A. T. Kaczynski, 2016. Using an environmental justice approach to examine the relationships between park availability and quality indicators, neighborhood disadvantage, and racial/ethnic composition. Landscape and Urban Planning. Vol. 148, pp 159-169.

[139] Yngve, L., K. Beyer, K. Malecki, AND L. Jackson. Street-scale green infrastructure and physical activity. Intl Society of Environmental Epidemiology (ISEE) Annual Meeting, Rome, ITALY, September 01 - 04, 2016.

[140] City of Toronto. (n.d.). Green Streets. Retrieved from: https://www.toronto.ca/services-payments/streets-parking-transportation/enhancing-our-streets-and-public-realm/green-streets/.

function of annual precipitation and the retention rate of green infrastructure. This is multiplied by the average cost of stormwater treatment.

Values used

Lane width: 0.003km
Engineering guidelines in Toronto encourage 3m wide bike lanes.[141]

Green infrastructure coverage: 0.60[142]

Cost of stormwater management: 100/m^3
This value is based on a lifecycle cost calculated from the Canadian Nursery Association.[143]

Precipitation retention: 0.85
Assuming that green infrastructure can retain 85% of rainfall, according to a Toronto study, and consistent with other studies of green infrastructure along active transit.[144]

Annual precipitation: 0.831 m
The value for annual precipitation in Toronto was retrieved from historical precipitation data.[145]

	Parameters	Premise
20	$\begin{aligned} &installed\ lanes \times lane\ width \\ &\quad \times green\ infrastructure\ coverage \\ &\quad \times precipitation\ retention\ rate \\ &\quad \times annual\ precipitation \\ &\quad \times stormwater\ management\ cost \\ &\quad = avoided\ cost\ of\ stormwater\ treatment \end{aligned}$	Avoided cost of stormwater treatment is related to the green infrastructure installed along active transportation networks.

[141] City of Toronto. (2017). Engineering Design Guidelines: Lane Widths. Retrieved from: https://www.toronto.ca/wp-content/uploads/2017/11/921b-ecs-specs-roaddg-Lane_Widths_Guideline_Version_2.0_Jun2017.pdf

[142] General assumption that 60% of the bike lane area can be permeable, generated by the authors.

[143] Based on a life cycle cost within the range described in: Canadian Nursery Landscape Association. (n.d.). *Life cycle cost analysis of natural on-site stormwater management methods*. Retrieved from https://cnla.ca/uploads/pdf/LCCA-Stormwater-Report.pdf

[144] Vega, O. (2018). Application of Stormwater Tree Trenches in the City of Vancouver. Prepared for City of Vancouver. Retrieved from: https://sustain.ubc.ca/sites/sustain.ubc.ca/files/GCS/2018_GCS/Reports/2018-52%20Application%20of%20Stormwater%20Tree%20Trenches%20in%20the%20City%20of%20Vancouver_Vega.pdf

[145] Environment and Climate change Canada. Canadian Climate Normals 1981-2010: Toronto. Retrieved from: http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?searchType=stnName&txtStationName=Toronto&searchMethod=contains&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=5051&dispBack=0

Displaces more extensive and intensive vehicular infrastructure

Active transportation infrastructure and transit systems enable people to get around without a personal vehicle.[146] If enough mode share can be transitioned away from private cars, the need for road infrastructure may be reduced, opening previously inaccessible urban spaces for community uses and transit. The King Street Pilot in Toronto is an example of active and public transit directly displacing vehicle infrastructure.[147] The City is encouraging art, bicycle parking and other community uses in the spaces previously used by cars.[148]

In already constrained urban spaces, active transportation networks can move more people than in private automobiles. Person throughput is a measure of the effectiveness of transportation in existing infrastructure. In an analysis by the National Association of Transport Officials, one 3-m lane can move 600-1,600 persons / hour by car; 9,000 persons/ on sidewalk by foot; 7,500 persons / hour in a dedicated two-way bike lane.[149]

Quantifying the relationship

This equation calculates the avoided infrastructure space required to move passengers per kilometre from cycling infrastructure to vehicle infrastructure. The equation assumes that trip increases are proportionate to cycling infrastructure kilometres, and that cycling can displace average vehicle trip lengths.

Values used

Existing cycling infrastructure (km): 640 km[150]

Annual active trips: 26,903,520
There are approximately 26.9 million trips by bicycle in Toronto annually, or 96,084 trips per day.[151]

Average vehicle trip length: 5.5km
This value for average vehicle trip length was retrieved from the Transportation Tomorrow Survey for the City of Toronto.[152]

Average bicycle trip length: 2km

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146 Waljasper, J. (2017). Bike breakthrough: Connecting neighbourhoods through low stress routes. Resilience. Retrieved from: https://www.resilience.org/stories/2017-10-25/bike-breakthrough/.
147 City of Toronto. (2018). King Street Pilot Overview. Retrieved from: https://www.toronto.ca/city-government/planning-development/planning-studies-initiatives/king-street-pilot/king-street-transit-pilot-overview/
148 City of Toronto. (2018). Kingston St Pilot Public Realm Transformation. Retrieved from: https://www.toronto.ca/city-government/planning-development/planning-studies-initiatives/king-street-pilot/public-realm/
149 National Association of Transit Officials. (2015). Designing to move people. Retrieved from: https://nacto.org/publication/transit-street-design-guide/introduction/why/designing-move-people/.
150 Vijayakumar, N., Nurda, C. (2015). Cycle Cities: Supporting cycling in Canadian Cities. The Pembina Institute. Retrieved from: https://www.pembina.org/reports/cycle-cities-full-report-rev.pdf.
151 Ibid.
152 Transportation Tomorrow. (2016). Transportation Tomorrow Survey Travel Summaries. P 15. Retrieved from: http://dmg.utoronto.ca/pdf/tts/2016/2016TTS_Summaries_Toronto_Wards.pdf

The value for average bicycle trip length was retrieved from the Transportation Tomorrow Survey for the City of Toronto.[153]

Infrastructure space/vehicle passenger per km: 0.0055 m^2/km[154]

Infrastructure space/bicycle passenger km: 0.0071 m^2/km[155]

	Parameters	Premise
21	$$\left[\left[\left(1+\frac{new\ cycling\ inf.}{existing\ cycling\ inf.}\right)\times\frac{bike\ trips}{year}\right]-\frac{bike\ trips}{year}\right]\times bike\ trip\ length = incremental\ cycling\ km\ per\ year$$ $$\left[\left[\left(1+\frac{new\ cycling\ inf.}{existing\ cycling\ inf.}\right)\times\frac{cycle\ trips}{year}\right]-\frac{cycle\ trips}{year}\right]\times vehicle\ trip\ length\times\frac{infrastructure\ space}{passenger\ km}-\left(incremental\ cycling\ km\ per\ year\times\frac{infrastructure\ space}{cycling\ passenger\ km}\right)= avoided\ infrastructure\ used\ by\ vehicles$$	Avoided infrastructure space to move passengers per km.

Improves health outcomes

Systematic reviews of health outcomes from increased physical activity show a reduced risk of cardiovascular disease, some cancers, depression, and dementia.[156] Active commuting, and commuting by bicycle in particular, has been shown to reduce overall mortality.[157] Initiatives that promote the use of active infrastructure can reduce the burden on healthcare systems from chronic conditions, and reduce the risk of death. However, it should be noted that there are mortality risks from cycling, especially from accidents with motor vehicles, but studies have determined the reduction in mortality from health improvements outweigh the potential mortality risks.[158]

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[153] Transportation Tomorrow. (2016). Transportation Tomorrow Survey Travel Summaries. P 15. Retrieved from: http://dmg.utoronto.ca/pdf/tts/2016/2016TTS_Summaries_Toronto_Wards.pdf

[154] Rietveld, P. (n.d.). The position of non-motorised transport modes in transport systems, 20.

[155] Ibid.

[156] Woodcock, J., Edwards, P., Tonne, C., Armstrong, B. G., Ashiru, O., Banister, D., ... Roberts, I. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. The Lancet, 374(9705), 1930–1943.

[157] Celis-Morales, C. A., Lyall, D. M., Welsh, P., Anderson, J., Steell, L., Guo, Y., ... Gill, J. M. R. (2017). Association between active commuting and incident cardiovascular disease, cancer, and mortality: prospective cohort study. BMJ, 357, j1456.

[158] Toronto Public Health. (2012). Road to Health: Improving Walking and Cycling in Toronto.

By increasing the use of active transportation for short and medium trips, congestion is eased and air quality improves.[159] Additionally, users of separated bike infrastructure are less exposed to air pollutants, reducing the health risks of this exposure.[160] Policies that reduce the number of car trips, and replace them with other travelling/commuting options, particularly active transportation, can have important health benefits, including reduce mortality, and risk of certain diseases.[161]

Reducing air pollution and improving health can increase the resilience of individuals to respond to extreme heat events.[162]

Quantifying the relationship

The value of the health benefit of cycling infrastructure per year is quantified by multiplying the increase in bicycle trips by the displaced vehicle trip length to get a total distance biked per year. This value is then multiplied by a cycling benefit per kilometre multiplier identified in the literature.

This equation has not undergone enough statistical and epidemiological review for appropriateness to the Toronto context. Therefore, there is considerable uncertainty in the relevance of this equation in Toronto but is meant to show the potential monetary benefit from improved health related to active transportation.

Values used

Existing cycling infrastructure (km): 640 km[163]

Annual cycling trips: 26,903,520
There are approximately 26.9 million trips by bicycle in Toronto annually, or 96,084 trips per day.[164]

Average vehicle trip length: 5.5km
This value for average vehicle trip length was retrieved from the Transportation Tomorrow Survey for the City of Toronto.[165]

Cycling benefit per kilometre: $1.20/km

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[159] Toronto Public Health. (2012). Road to Health: Improving Walking and Cycling in Toronto.

[160] Cole, C. A., Carlsten, C., Koehle, M., & Brauer, M. (2018). Particulate matter exposure and health impacts of urban cyclists: a randomized crossover study. *Environmental Health*, *17*(1), 78.

[161] Rojas-Rueda, D., de Nazelle, A., Teixidó, O., & Nieuwenhuijsen, M. (2013). Health impact assessment of increasing public transport and cycling use in Barcelona: A morbidity and burden of disease approach. *Preventive Medicine*, *57*(5), 573–579.

[162] De Sario, M., Katsouyanni, K., Michelozzi, P. (2013). Climate change, extreme weather events, air pollution and respiratory health in Europe. European Respiratory Journal, 42, 826-843.

[163] Vijayakumar, N., Nurda, C. (2015). Cycle Cities: Supporting cycling in Canadian Cities. The Pembina Institute. Retrieved from: https://www.pembina.org/reports/cycle-cities-full-report-rev.pdf.

[164] Vijayakumar, N., Nurda, C. (2015). Cycle Cities: Supporting cycling in Canadian Cities. The Pembina Institute. Retrieved from: https://www.pembina.org/reports/cycle-cities-full-report-rev.pdf.

[165] Transportation Tomorrow. (2016). Transportation Tomorrow Survey Travel Summaries. P 15. Retrieved from: http://dmg.utoronto.ca/pdf/tts/2016/2016TTS_Summaries_Toronto_Wards.pdf

This value is used by the New Zealand Transportation Authority to estimate health benefits of cycling in dollars.[166] In the absence of relevant numbers in Canada, the standard guidance for economic appraisals in New Zealand is referenced. The value was converted from NZ $1.30 to Can $1.20. This was currently the only way that was identified in the literature, although it should be noted that this equation would be strengthened by a more Toronto relevant value.

	Parameters	Premise
22	$\left(1+\frac{new\ cycling\ inf.}{existing\ cycling\ inf.}\right) \times annual\ cycling\ trips \times vehicle\ trip\ length \times cycling\ benefit\ per\ km = value\ of\ health\ benefit\ of\ cycling\ infrastructure\ per\ year$	Trip increases are proportionate to increase in active transportation infrastructure.

[166] NZ Transport Agency. (n.d.). *Economic evaluation model*. Page 5 479; Table A20.4. Retrieved from https://www.nzta.govt.nz/assets/resources/economic-evaluation-manual/economic-evaluation-manual/docs/eem-manual-2016.pdf

TRANSFORMTO ACTION 6: ELECTRIC VEHICLES

Vehicle power can be used to provide electricity to buildings

Vehicle to grid (V2G) power capabilities use bi-directional energy flows to supply residential buildings with electricity during a power outage. V2G is still in development, and requires conscious design to align manufacturing requirements with utility design and system communication systems.[167] If successfully implemented, vehicles could act as wide scale energy storage to the electricity grid, which provides economic benefits and can be used to power buildings in the event of power disruptions.[168] Because V2G is not yet widespread practice, this equation has little relevance today, but could be a resilience benefit of electric vehicles in the future.

V2G as backup to grid does present some risks to resilience in that in a power outage, vehicles cannot be used for transportation. Plug in hybrids provide an additional layer of security as power from the vehicle can be used to power homes, while gasoline fuel can still be used for transportation.[169]

Quantifying the relationship

The number of hours that households with EVs can be supported by V2G capabilities can be calculated by dividing the average battery capacity of a car battery by the average power a home requires for basic functions. This equation can be expanded city wide by multiplying this value by the number of households with EVs. This relationship relies on the assumptions that car batteries will be fully charged during an outage and that homeowners would choose to power their homes over using their vehicle. This equation does not adequately describe the more complex relationship of EV use in multi-unit residential buildings.

Values used

Average battery storage per vehicle: 30kWh
Most car batteries have a minimum energy capacity of 30 kWh.[170]

Average building daily energy requirements: 24 kWh/day
The average Toronto customer uses 715 kWh/month, or 24 kWh/day under normal conditions.[171]

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[167] Steward, D. (2017). Critical Elements of Vehicle-to-Grid (V2G) Economics. National Renewable Energy Laboratory. Task No. DSEV1030.

[168] US DOE. (2018). Enhancing Grid Resilience with Integrated Storage from Electric Vehicles. Energy Advisory Committee. Retrieved from: https://www.energy.gov/sites/prod/files/2018/06/f53/EAC_Enhancing%20Grid%20Resilience%20with%20Integrated%20Storage%20from%20EVs%20%28June%202018%29.pdf.

[169] Rahimi, K., Davoudi, M. (2018). Electric vehicle for improving resilience of distribution systems. Sustainable Cities and Society, 36, 246-256.

[170] Natural Resources Canada. (2018). 2018 model year electric vehicles. Retrieved from: https://www.nrcan.gc.ca/energy/efficiency/transportation/21363

[171] Ontario Energy Board. (2015). Defining Ontario's Typical Electricity Customer. Retrieved from: https://www.oeb.ca/oeb/_Documents/Documents/Report_Defining_Typical_Elec_Customer_20160414.pdf.

	Parameters	Premise
23	$\frac{\#\ of\ EVs \times average\ battery\ storage\ per\ vehicle}{daily\ home\ energy\ requirements} = days\ that\ households\ with\ EVs\ can\ rely\ on\ vehicle\ battery$	Battery power can be used to power homes during an outage. This equation assumes that batteries are fully charged; EV owners choose to power homes over use vehicle for transportation.

Reduced air pollution

Transportation emissions made up 31% of Toronto's emissions in 2011.[172] Toronto Public Health estimates that air pollution is related to 1,300 premature deaths and 3,550 hospital visits, annually in Toronto, with vehicle traffic being the primary contributor.[173] Air pollutants from vehicle emissions that are harmful to human health include ground level ozone, particulate matter, carbon monoxide, sulfur dioxide and nitrogen dioxide. Illness and disease associated with exposure to vehicle related air pollution include respiratory illnesses, cardiovascular disease, certain cancers, and others. Air pollution from vehicles disproportionately impacts the elderly and children and persons with existing health conditions.[174]

Replacing internal combustion engine vehicles with electric vehicles reduces air pollution associated with vehicle exhaust. Light duty vehicles emit approximately 2.33g/km estimated over a five year period from 2016-2020.[175] In contrast, electric vehicles have no tailpipe emissions. Because Ontario's electricity is generated from predominantly low carbon sources, there are minimal emissions associated with electricity generation.[176]

Quantifying the relationship

The benefits of increasing electric vehicles can be quantified by calculating avoided air pollution. Avoided air pollution can be calculated using the emissions per km per vehicle, multiplied by the average distance travelled a vehicle travels per year.

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[172] City of Toronto. (2017). TransformTO: Results of Modelling Greenhouse Gas Emissions to 2050. Prepared by SSG and whatIf? Technologies. Retrieved from: https://www.toronto.ca/wp-content/uploads/2018/02/9490-TransformTO-Report-2-Attachment-B-Results-of-Modelling-GHG-Emissions-to-2050-Apr17-Revised-Compressed.pdf

[173] Toronto Public Health. (2014). Path to healthier air: Toronto air pollution burden of illness update. Retrieved from: http://www1.toronto.ca/City%20Of%20Toronto/Toronto%20Public%20Health/Healthy%20Public%20Policy/Report%20Library/PDF%20Reports%20Repository/2014%20Air%20Pollution%20Burden%20of%20Illness%20Tech%20RPT%20final.pdf

[174] Ibid.

[175] California Air Resource Board. (2018). Emission Factor Tables. In Methods to Find the Cost-Effectiveness of Funding Air Quality Projects. P.7. Retrieved from: https://www.arb.ca.gov/planning/tsaq/eval/evaltables.pdf

[176] Calculated from: National Energy Board. (2018). How much CO2 do electric vehicles, hybrids and gasoline vehicles emit? Retrieved from: https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/ftrrtcl/2018-09-12hwmchcrbndxd-eng.html. Assuming CO2 makes up 95% of tailpipe emissions.

Values used

Average vehicle kms/year: 20,000
This equation assumes the average vehicle travels 20,000 kms per year.

Air pollutant emissions/km: 2.33g/km
This value is from the California Air Resources Board, and includes NOx, particulate matter, carbon monoxide and Reactive organic gas emissions.[177]

	Parameters	**Premise**
24	$\# \; of \; EVs \times average \; kms \; per \; year \times average \; air \; pollutant \; emissionsper \; vehicle \; km = avoided \; air \; pollutants$	EVs will replace gasoline vehicles, thereby avoiding pollutants emitted by the average vehicle.

[177] California Air Resource Board. (2018). Emission Factor Tables. In Methods to Find the Cost-Effectiveness of Funding Air Quality Projects. P.7. Retrieved from: https://www.arb.ca.gov/planning/tsaq/eval/evaltables.pdf

TRANSFORMTO ACTION 7: PUBLIC TRANSIT

Increases affordable transportation options

Greater connectivity and access to public transit increases transit system diversity, which lowers the risk of loss within the system. Multiple modes also reduce the trip burden on other options.[178] Access to public transit increases access to low cost mobility and can increase affordability of travel in Toronto.

For many residents of Toronto, the cost of car ownership and use is cost prohibitive; in Ontario the annual cost of owning and driving a vehicle is approximately $10,800.[179] Increasing access to transit can enhance mobility for people that cannot afford a personal vehicle. However, it should be noted that the relationship between affordability, proximity to transit and commuting is complex, and that increasing transit infrastructure can increase housing and living costs in Toronto, which can make living expenses unaffordable for many residents of Toronto.[180]

Quantifying the relationship

Transit affordability can be calculated by calculating the cost difference between vehicular and transit mobility. This equation assumes that transit can replace average length vehicles trips as they are comparable at median vehicle trip length is 5.5km, and median transit trip length is 6.5km.[181] It is still unclear how to accurately represent the potential dynamics between rising housing costs; this is not considered in this equation.

Values used

Trip length: 5.5km[182]
This value represents the median vehicle trip length. It is assumed that transit can directly replace median trip length distances.

Cost of vehicle travel: $0.54/km[183]

Cost of transit travel: $0.5/km
Current adult cash fare for the TTC is $3.25.[184] Using the median transit length in Toronto of 6.5km,[185] the average cost per person per kilometre is $0.5/km/person.

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[178] Pregnolato M, Ford A, Robson C, Glenis V, Barr S, Dawson R. (2016). Assessing urban strategies for reducing the impacts of extreme weather on infrastructure networks. Royal Society Open Science, 3: 160023.

[179] Calculated using an average cost of annual ownership of $10,800, with 20,000km driven. Sourced from: https://globalnews.ca/news/3832649/car-ownership-costs-public-transit-canada/

[180] Saxe, S., Miller, E. (2016). Transit and land value uplift: An introduction. University of Toronto. iCity: Urban Informatics for Sustainable Metropolitan Growth.

[181] Transportation Tomorrow. (2016). Transportation Tomorrow Survey Travel Summaries. P 15. Retrieved from: http://dmg.utoronto.ca/pdf/tts/2016/2016TTS_Summaries_Toronto_Wards.pdf

[182] Ibid.

[183] Calculated using an average cost of annual ownership of $10,800, with 20,000km driven. Sourced from: https://globalnews.ca/news/3832649/car-ownership-costs-public-transit-canada/

[184] https://www.ttc.ca/Fares_and_passes/Prices/Prices.jsp

[185] Transportation Tomorrow. (2016). Transportation Tomorrow Survey Travel Summaries. P 15. Retrieved from: http://dmg.utoronto.ca/pdf/tts/2016/2016TTS_Summaries_Toronto_Wards.pdf

	Parameters	Premise
25	$(\#vehicle\ trips \times trip\ length \times cost\ of\ vehicle\ travel) - (\#of\ trips\ by\ transit \times trip\ length \times cost\ of\ transit\ travel) = avoided\ vehicle\ costs$	The avoided vehicle costs can be calculated by the cost of vehicle trips subtracted by the cost of transit trips that can displace vehicle trips.

Transit if combined with green infrastructure, can reduce flooding

Inclusion of green infrastructure such as permeable surface, bioswales, artificial wetlands and other green infrastructure technologies reduces the risk of flooding in the transit system and in other systems. Green roofs retain rainfall and reduce water volumes released into stormwater systems, minimizing localized flooding.

Green infrastructure such as permeable pavement has been shown to reduce storm runoff volume by 70-90%.[186] In another study, flood damage was reduced by 75% when grey infrastructure was accompanied by green infrastructure with a cost to benefit ratio of 1.8:1.[187] Because green infrastructure can minimize flooding, it can also reduce the system delays that are caused by floods. For example, installation of green roofs in proximity to roadways reduced network person delays by 22.3% in 10-year flood.[188]

TTC has been installing green roofs at multiple TTC stations, including the Leslie Barns rooftop which collects water from the nearby parking lot for watering the green roof.[189] The Victoria Park Station is estimated to divert 300,000 gallons of water from stormwater systems.[190]

Quantifying the relationship

Avoided treatment cost of stormwater is used as an indicator for flood reduction from green infrastructure. The avoided cost of stormwater is calculated by multiplying the area of transit infrastructure by the green infrastructure coverage, the annual precipitation and the cost of stormwater treatment per m^3.

Values used

Green infrastructure coverage: 0.6
This value assumes that for every m^2 of transit infrastructure, 60% of the total site/corridor can be permeable.

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[186] Foster, J., Lowe, A., Winkelman, S. (2011). The value of green infrastructure for urban climate adaptation. Centre for Clean Air Policy. Retrieved from: http://ccap.org/assets/The-Value-of-Green-Infrastructure-for-Urban-Climate-Adaptation_CCAP-Feb-2011.pdf
[187] New York City Department of Environmental Protection. (2017). Cloudburst Resiliency Planning Study. Retrieved from: http://www.nyc.gov/html/dep/pdf/climate/nyc-cloudburst-study.pdf.
[188] Pregnolato M, Ford A, Robson C, Glenis V, Barr S, Dawson R. (2016). Assessing urban strategies for reducing the impacts of extreme weather on infrastructure networks. Royal Society Open Science, 3: 160023.
[189] http://www.ttc.ca/Riding_the_TTC/green_initiatives.jsp
[190] Ibid.

Cost of stormwater management: $100/m^3
This value is based on a lifecycle cost calculated from the Canadian Nursery Association.[191]

Precipitation retention: 0.85
Assuming that green infrastructure can retain 85% of rainfall, according to a Toronto study, and consistent with other studies of green infrastructure along active transit.[192]

Annual precipitation: 0.831m
The value for annual precipitation in Toronto was retrieved from historical precipitation data.[193] As precipitation values are expected to change with climate change, this value can be scaled up or down as required.

	Parameters	Premise
26	$Area\ of\ transit\ infrastructure\ (m2) \times green\ inf.coverage \times precipitation\ retention\ rate \times annual\ precipitation \times stormwater\ cost\ intensity = avoided\ stormwater\ treatment\ cost$	Installing green infrastructure will increase retention and reduce peak stormwater runoff, reducing the flooding risk and reducing the cost of stormwater treatment.

Increases walking and cycling which can lead to improved health

Increasing access to public transit is also correlated to greater use of active transit, because of the need to walk or bike to a nearby transit station.[194] A significant proportion (30%) of transit users meet their daily recommended levels of physical activity just from transit use, and transit users were 3.5 times more likely to be sufficiently active when compared with car drivers.[195] Policies that reduce the number of car trips, replacing them with public transit and active transportation can therefore reduce negative health impacts, including cardiovascular disease and certain cancers.[196]

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191 Based on a life cycle cost within the range described in: Canadian Nursery Landscape Association. (n.d.). *Life cycle cost analysis of natural on-site stormwater management methods*. Retrieved from https://cnla.ca/uploads/pdf/LCCA-Stormwater-Report.pdf

192 Vega, O. (2018). Application of Stormwater Tree Trenches in the City of Vancouver. Prepared for City of Vancouver. Retrieved from: https://sustain.ubc.ca/sites/sustain.ubc.ca/files/GCS/2018_GCS/Reports/2018-52%20Application%20of%20Stormwater%20Tree%20Trenches%20in%20the%20City%20of%20Vancouver_Vega.pdf

193 Environment and Climate change Canada. (n.d.). Canadian Climate Normals 1981-2010: Toronto. Retrieved from: http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?searchType=stnName&txtStationName=Toronto&searchMethod=contains&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=5051&dispBack=0

194 Sener, I., Lee., R., Elgard, Z. (2016). Potential health implications and health cost reductions of transit-induced physical activity. Journal of Transportation Health, 3 (2), 133:140.

195 Rissel, C., Curac, N., Greenaway, M., & Bauman, A. (n.d.). Key health benefits associated with public transport: a rapid review, 38.

196 Rojas-Rueda, D., de Nazelle, A., Teixidó, O., & Nieuwenhuijsen, M. (2013). Health impact assessment of increasing public transport and cycling use in Barcelona: A morbidity and burden of disease approach. *Preventive Medicine*, *57*(5), 573–579.

Integrating cycling and public transit has the benefit of increasing ridership of public transit by increasing the catchment area of a transit station.[197] Well integrated public and active transit improves transportation access associated with the 'first/last kilometre' and encourages improved transit ridership.

Quantifying the relationship

Under the premise that increasing transit ridership will increase active transit in the first/last kilometre, the health benefits of shifting transit modes towards public transit can be quantified by multiplying the number of new riders by the average distance to transit users walk or bike to the station, by the estimated health benefits (in $/km). This equation is simplified in that expanding transit service may effectively minimize the distance to transit stations, which would modify the health benefit relationship.

This equation has not undergone statistical and epidemiological review for appropriateness to the Toronto context, therefore, there is considerable uncertainty in the relevance of this equation in Toronto. The equation is meant to show the potential monetary benefit from improved health related to active transportation.

Values used

Distance to station for transit users: 0.5km
In a Toronto study, it was found that 80% of transit users live within 500m of a transit stop.[198]

Walking or cycling health benefit: $2.40/km for walking; $1.20km for cycling
This value is used by the New Zealand Transportation Authority to estimate health benefits of cycling and walking in dollars.[199] In the absence of relevant numbers in Canada, the standard guidance for economic appraisals in New Zealand is referenced. The value was converted from NZ to CAD. This was the only method identified in the review, although it should be noted that this equation would be strengthened by a more Toronto relevant value.

Likelihood of walking or cycling: a value has not yet been identified

	Parameters	**Premise**
27	$\#\ of\ riders\ within\ 500m\ of\ transit\ station \times likelihood\ of\ walking\ or\ cycling \times distance\ to\ station\ for\ transit\ users \times active\ benefit\ per\ km = health\ benefit\ of\ public\ transit\ (\$)$	Transit users will be more likely to meet physical activity guidelines from transit use.

[197] Kager, R., Harms, L. (2017). Synergies from improved cycling-transit integration: Towards an integrated urban mobility system Discussion Paper 2017-23
[198] Alshalalfah, B., & Shalaby, A. (2007). Case study: Relationship of walk access distance to transit 10 with service, travel, and personal characteristics. Journal of Urban Planning and 11 Development, 133(2), 114-118.
[199] NZ Transport Agency. (n.d.). *Economic evaluation model*. Page 5 479; Table A20.4. Retrieved from https://www.nzta.govt.nz/assets/resources/economic-evaluation-manual/economic-evaluation-manual/docs/eem-manual-2016.pdf

Health benefits from switching from diesel to electric transit modes

Switching to diesel to electric transit modes will reduce air pollution from diesel engine exhaust, which will have positive health benefits. Illness and disease associated with exposure to vehicle related air pollution include respiratory illnesses, cardiovascular disease, certain cancers, and others.[200] Air pollution from vehicles disproportionately impacts the elderly and children and persons with existing health conditions.[201] Replacing diesel buses with electric buses will have positive health benefits by minimizing air pollution.

Toronto Transit Commission's fleet already includes electric streetcars, and is planning for 255 hybrid electric vehicles, and 60 battery electric buses by the end of 2019.[202]

Quantifying the relationships

The benefits of increasing electric vehicles can be quantified in avoided air pollution. Avoided air pollution can be calculated using the emissions per km per bus, multiplied by the average distance travelled by a single bus per year.

Values used

Air pollutants in g/km: 10.39g/km
According to data from the California Air Resources Board, urban transit buses emit approximately 10.39g/km of criteria air pollutants for 2007-2009 models.[203]

Average distance travelled per bus: 74,944 km
TTC's 1,920 buses operated 141,974,000 kms in 2017, for an average annual mileage of 73,944 km.[204]

	Parameters	Premise
28	$\# \ of \ electric \ buses \times average \ bus \ milage \times air \ pollutant \ emissions \ per \ km = avoided \ air \ pollutant$	Electric transit will replace diesel transit vehicles, thereby avoiding pollutants emitted by the average vehicle.

[200] World Health Organization. (n.d.). Air Pollution. Retrieved from: https://www.who.int/sustainable-development/transport/health-risks/air-pollution/en/
[201] City of Toronto. (2017). Reducing Health Risks from Traffic-Related Air Pollution (TRAP) in Toronto. HL 22.3. Retrieved from: https://www.toronto.ca/legdocs/mmis/2017/hl/bgrd/backgroundfile-108179.pdf
[202] Toronto Transit Commission. TTC Green Initiatives. Retrieved from: http://www.ttc.ca/Riding_the_TTC/green_initiatives.jsp.
[203] California Air Resource Board. (2018). Emission Factor Tables. In Methods to Find the Cost-Effectiveness of Funding Air Quality Projects. Retrieved from: https://www.arb.ca.gov/planning/tsaq/eval/evaltables.pdf
[204] Toronto Transit Commission. (2018). Operating Statistics. Retrieved from: https://www.ttc.ca/About_the_TTC/Operating_Statistics/2017/section_one.jsp

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