Local Emissions for Net Zero (LENZ) Modelling Suite – Toronto

Non-technical documentation

Version 1.0 – August 2023

For the City of Toronto

Photo by Scott Webb from Pexels

Acknowledgements

Land acknowledgement

The City of Toronto acknowledges that we are on the traditional territory of many nations including the Mississaugas of the Credit, the Anishnabeg, the Chippewa, the Haudenosaunee, and the Wendat peoples and is now home to many diverse First Nations, Inuit, and Métis peoples. The City of Toronto also acknowledges that Toronto is covered by Treaty 13 signed with the Mississaugas of the Credit, and the Williams Treaties signed with multiple Mississaugas and Chippewa bands.

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About the project team

ESMIA Consultants

ESMIA provides expertise in 3E (energy-economy-environment) integrated system modelling for deriving and analyzing optimal economic, energy and climate strategies. ESMIA puts forward a scientific approach guided by sophisticated mathematical models. The goal behind our implication is to offer solutions that allow achieving energy and climate goals without compromising economic growth. For 20 years, the ESMIA consultants provide a full range of services for the development of economy-wide energy system models for high-profile organizations worldwide. They also provide advisory services that focus on analyzing complex problems such as energy security, electrification, technology roadmap and energy transitions. ESMIA benefits from its own integrated suite of models, including in particular: The North American TIMES Energy Model (NATEM) combined with the North American general Equilibrium Model (NAGEM).

Sustainable Energy Systems Integration and Transition Group (SESIT)

The Sustainable Energy Systems Integration and Transitions Group (SESIT) is led by Madeleine MacPherson at the University of Victoria. The group focuses on energy systems integration – the process of coordinating the operation and planning of our energy systems over a variety of spatial-temporal scales and infrastructure systems (transport, buildings, electricity, water). Their work involves the development and application of energy system software, designed to address research and policy questions related to variable renewable energy integration, demand response initiatives, utility-scale and behind-the-meter storage technologies, and electric vehicle integration.

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List of acronyms

ACRONYM	DEFINITION
3E	Energy-economy-environment
CO_2	Carbon dioxide
EV	Electric vehicles
GHG	Greenhouse gas
IESO	Independent Electricity System Operator
IPCC	Intergovernmental Panel on Climate Change
LENZ	Local Emissions for Net-Zero Modelling Suite - Toronto
NATEM	The North American TIMES Energy Model
NZS	Net Zero Strategy
OPT	Optimal net zero scenario
PV	Photovoltaic panel
SILVER	Strategic Integration of Large-capacity Variable Energy Resources
SILVER-TO	Strategic Integration of Large-capacity Variable Energy Resources - Toronto
TEMOA	Tools for Energy Model Optimization and Analysis
TEMOA-TO	Tools for Energy Model Optimization and Analysis - Toronto

Glossary

TERM	DEFINITION
Capacity expansion model	Model that is used for long-term planning in the GHG emitting system. This model allows to identify least-cost solutions in terms of future investments in energy and waste system given multiple factors such as demand projections, technology performance and costs, fuel prices and new policies. e.g., Tools for Energy Model Optimization and Analysis – Toronto (TEMOA-TO)
Deep retrofit	Deep retrofit refers to various measures that are mainly focused on the improvements of building envelops which achieve 75 per cent of thermal energy gain (energy savings from heating or cooling) and 15 per cent of electricity gain in residential, commercial, or institutional buildings.
Electrification of end-use energy	The electrification of end-use energy refers to the transition from using traditional fossil fuels for various end-use applications, such as transportation, heating, and cooling, to using electricity as the primary energy source. The goal of electrification of end-use energy is to reduce greenhouse gas emissions and increase energy efficiency.
Energy mix	Combination of energy sources that a country or a region uses to meet its energy needs.
Energy poverty	Energy burden defined as the percentage of household income spent on energy (electricity, natural gas, central heating etc.).
Energy service	Term used in energy modeling to refer to the service that is provided by energy (typically through the technologies), which is separated from the energy itself. For example, people want to travel from one place to another. They use energy (e.g., gasoline) for this service but the demand is for the service itself rather than a particular fuel. Thus, gasoline use can be replaced by electricity or physical activity to meet the same service (travel).
Equity (energy)	Evaluates the accessibility and affordability of energy within the city.
Greenhouse gas	Gases that trap heat in the Earth's atmosphere and contribute to the greenhouse effect. These gases are naturally present in the atmosphere but human activities, especially fossil fuel combustion and deforestation, are significantly increasing their concentration (anthropogenic greenhouse gases).
LENZ Modelling Suite – Toronto (LENZ)	A suite that comprises more than one model interacting via internal or external links (i.e., requiring the intervention of the user). *The LENZ Modelling Suite – Toronto is referred to as LENZ all through this document.* e.g., TEMOA-TO + the Linking Tool + SILVER-TO

TERM	DEFINITION
The Linking tool	A tool that ensures communication between the two or more models to maximize their complementarity and to reinforce the value for decision-makers. e.g., the Linking Tool for passing TEMOA-TO output to SILVER-TO
Load ramp	Load ramp provides an indication about the speed of electricity load change. Load ramp-down, referring to the speed of load decrease (MW/h), is typically associated with the load decrease from the morning peak to the intra-peak load level (around midday for current load profile). Load ramp-up, referring to the speed of load increase (MW/h), is typically associated with the load increase from the intra-peak load level to the evening peak.
Net load	Net load of the city refers to the difference between the total electricity demand, and the distributed electricity generation connected at the distribution grid level, and must be supplied by the transmission system. A particular case of a PV generation effect on electricity demand is the net load reshaped as a duck belly (so-called duck curve effect).
Net zero	Equilibrium where the quantity of greenhouse gases emitted is offset by the amount that is removed from the atmosphere and stored.
Optimal power flow	Optimal power flow represents the non-linear problem of determining the best operating levels for electric power plants to meet demand given throughout a transmission network by minimizing total operating cost.
Optimal dispatch	Optimal dispatch is the optimal allocation of individual generating units (units' commitment) to produce electric power at the lowest cost to reliably serve consumers, recognizing any operational limit of generation and transmission facilities.
Optimality	System configuration or net zero pathway which represented the lowest (or minimum) cost solution for satisfying service demands under various constraints.
Optimization model	Computational framework used to identify the optimal solution among a set of possible alternatives, subject to constraints and objectives, in order to maximize or minimize a specific outcome.
Peak load	Peak load is the highest amount of electric power that consumers (here the city) draw from the grid in a set period of time (here one hour).

TERM	DEFINITION
Production cost model	A model that is used for short-term planning in the electricity sector. These models allow to identify least-cost solutions in terms of electricity produced by different generation units and electricity production costs of a given power system, given multiple factors such as temporal and geographic load distribution, generating unit locations, and transmission constraints. They simulate unit commitments and optimal dispatch. e.g., Strategic Integration of Large-capacity Variable Energy Resources – Toronto (SILVER-TO)
Renewable energy	Energy source that is naturally replenished and can be used repeatedly without the depletion of resources (also called clean energy).
Resilience (energy)	The ability to avoid, prepare for, minimize, adapt to, and recover from anticipated and unanticipated energy disruptions in order to ensure energy availability sufficient to cover demand.
Simulation model	Computational representation of a real-world system or process used to understand and explore its potential behaviour under different scenarios or conditions.
Unit commitment	Unit commitment is the process of selecting the units from the available generators to meet the power demand.

List of scenarios

ACRONYM	DEFINITION	MODELLED WITH
DON	Do-nothing	LENZ
BAP-TTO	Business-as-planned	LENZ
NZ40-OPT	Net Zero by 2040 – Optimal	LENZ
NZ40-TTO	Net Zero by 2040 – TransformTO	LENZ
NZ50-OPT	Net Zero by 2050 – Optimal	LENZ
NZ50-TTO	Net Zero by 2050 – TransformTO	LENZ
BAP	Business-as-planned	CityInsight
NZ40	Net Zero by 2040	CityInsight
NZ50	Net Zero by 2050	CityInsight

How to use this document?

The present "Local Emissions for Net Zero (LENZ) Modelling Suite – Toronto" or LENZ as it is referred to in this document, is a powerful and efficient suite of tools that aims to support the City to actively test the implementation options of the net zero transition pathway and refine climate policies and programs as needed with cost optimality considerations, as well as investigate the operational aspect of the electricity grid.

This document is a general presentation of LENZ and its capabilities, specifically designed for non-technical modellers or users. It outlines the added value and advantages of LENZ by answering the following questions.

- **Section 1:** **What** is LENZ, what are its principal components, and what makes it special?
- **Section 2:** **How** can LENZ be used to model different scenarios and what is the scope of each of its components?
- **Section 3:** **What** are typical use cases of LENZ, and what kind of insights can it provide?

This is a non-technical documentation intended for decision makers or anyone with limited modelling background. As a stand-alone document, it encompasses all the fundamental knowledge needed to understand and interpret the results of LENZ and how it differs from the previous modelling approach. A video tutorial, also designed for non-technical users, is available and aligns with this document. Three other resource materials are also available as support materials to take a deeper dive into description of the three models and their main functionalities, as well as instructions on how to use them for scenario analysis. The first is a Case Study conducted on the five critical steps of the TransformTO NZS is the focus of a separate report and includes more extensive analysis of the results of LENZ. The other two resources the user can also refer to are the technical documentation[1] complemented by the suite of technical video tutorials for more in-depth information on the construction and the functionality of LENZ.

[1] ESMIA Consultants (2023). Local Emissions for Net Zero Modelling Suite – Toronto: Technical Documentation.

SECTION 1

1. Introduction to Local Emissions for Net Zero

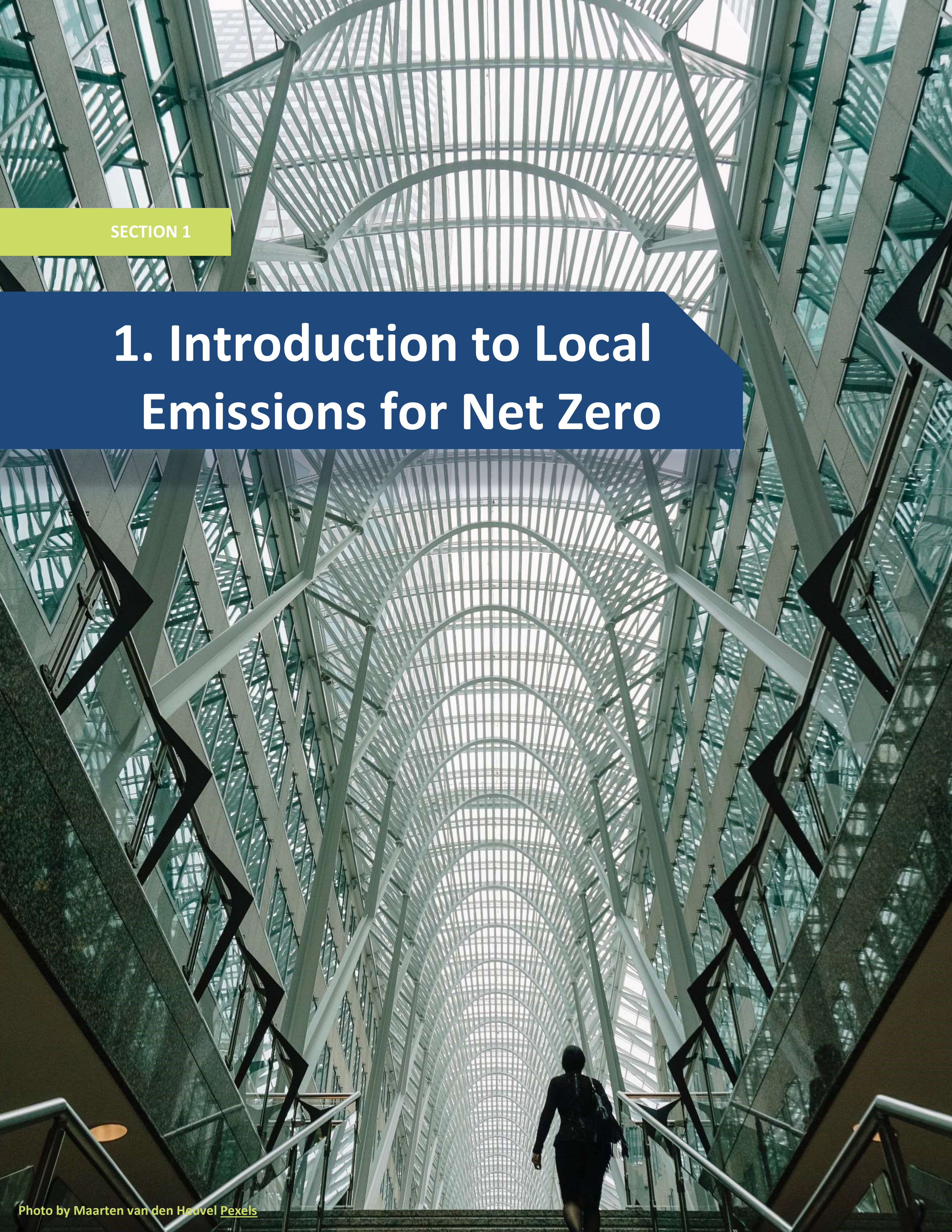


Photo by Maarten van den Heuvel Pexels

With proper understanding of the climate crisis, City Council's 2019 declaration of a climate emergency[2] shifts Toronto's focus to align its actions with the challenges of this crisis. In committing to the fight against climate change, the City has set a consistent target of reducing its emissions in line with Intergovernmental Panel on Climate Change's (IPCC) recommended pathway to meet net zero greenhouse gases (GHG) emissions by 2050 or sooner. To meet this ambitious target, one of the keys for the City is to provide itself with powerful and efficient tools such as the present LENZ. The reason LENZ was developed is presented through section 1.1. The main components and originality of the tool are explained in section 1.2, and section 1.3 ends with LENZ's modelling features and limitations.

1.1. What is the purpose of LENZ?

In December 2021, the City of Toronto adopted its TransformTO Net-zero Strategy (NZS) [3] that aims to outline a pathway to reach net zero GHG emissions by 2040. The Technical Report[4] of the NZS contained the analysis of the technical, financial, and social/behavioural feasibility of the proposed climate actions. In this context, four main scenarios had been developed using the CityInsight[5] simulation model to identify priorities in terms of climate actions: "Do-Nothing", Business as Planned (BAP), Net Zero by 2050 (NZ50) pathway, and Net Zero 2040 (NZ40) pathway.

However, the NZS study did not provide the City with in-house modelling tools that could be used on a continuous basis to refine priorities as new information becomes available and underlying conditions change. The study considered long-term strategies at the scale of years but did not address operational challenges that can occur when analyzing energy systems at a higher time resolution such as days or hours. Some of these challenges that can occur are the inability of distributed energy resources to meet peak load demands, the load in transmission lines exceeding a threshold, and excessive load ramp up or down. Finally, the modelling exercise in the NZS was done using a proprietary model that is not easily accessible.

In this context, a subsequent project led to the development of LENZ based exclusively on open-source tools and code using Python language for greater transparency. Leading by example, the City can use LENZ to discussion with decision makers to contribute to the definition of net zero GHG and policies, and for the public to develop a sense of engagement. LENZ aims to support the City to actively test the implementation options of the net zero transition pathway and refine climate policies and programs as needed with cost optimality considerations, as well as investigate the operational aspect of the electricity grid. The model would also come with documentation in the form of manuals and videos.

[2] City of Toronto (2019). MM10.3 - Declaring a Climate Emergency and Accelerating Toronto's Climate Action Plan - by Mayor John Tory, seconded by Councillor Mike Layton.

[3] City of Toronto (2021). TransformTO Net Zero Strategy: A climate action pathway to 2030 and betond. p.8.

[4] City of Toronto (2021). TransformTO Net Zero Strategy Technical Report.

[5] SSG - Sustainable Solutions Group (2023). Tools: CityInsight.

1.2. What is LENZ made up of?

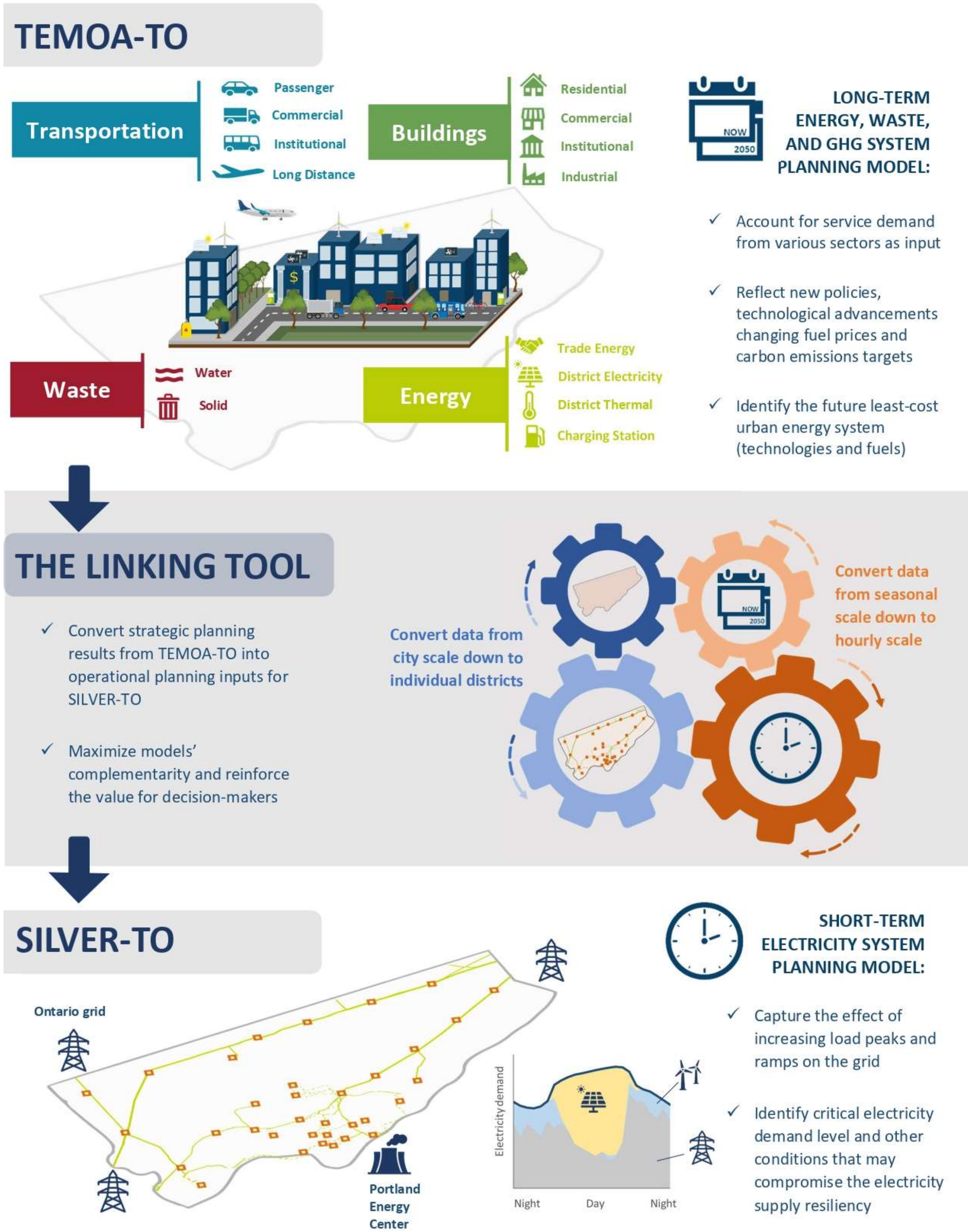
The project undertaken aimed at developing a suite of open-source energy and waste system and GHG emissions models to support TransformTO NZS implementation for the City. LENZ operates on two stand-alone models connected through the Linking Tool (Figure 1):

- **A long-term capacity expansion model** of the energy and waste management system from 2016 to 2050, defining pathways to reach the GHG commitments comparable to TransformTO NZS; and
- **A short-term electricity production cost model**, assuring hourly balance between power supply and demand and identifying where Toronto's electrical grid may face excessive load and load ramp, and understand what future upgrades might be required.

The long-term component of LENZ is based on the open-source platform named Tools for Energy Model Optimization and Analysis[6] (TEMOA), and the model developed is referred to as TEMOA-Toronto (TEMOA-TO). Similarly, the short-term component is based on the open-source platform named Strategic Integration of Large-capacity Variable Energy Resources[7] (SILVER) and the model developed is referred to as SILVER-Toronto (SILVER-TO). The two models are linked with the third component of LENZ, the Linking Tool. A complete overview of the three components of LENZ is provided in this document (see sections 2.2 and 2.3).

[6] TEMOA (2020). TEMOA Cloud. NC State University.
[7] SESIT Group (2022). SILVER.

Figure 1. Illustration of the components of LENZ



Long-term energy and waste system and GHG planning models excel at tracking changes in installed technology[8] – for example, purchases of new technology as the economy expands, the old technology retires, or new manufacturing needs emerge. These models (also known as capacity expansion models) typically cover the time of investment planning cycles, several decades for energy and waste system investment (such as 2016-2050 for this project). Therefore, long-term planning models, such as **TEMOA-TO**, are perfect for the development of net zero transition plans. By using this model, the decision-maker will be able to address questions like:

- How should the energy mix evolve and what type of energy must increase or decrease?
- What type of technology should be added or retired and with what capacity?
- When should investments be made?

TEMOA-TO tracks changes to the GHG emitting sectors by identifying the least-cost mix of energy and waste system resources (technologies and fuels) to meet a projected energy demand, taking into consideration new policies, technological advancement, changing fuel prices and carbon emission constraints. To do this, TEMOA-TO identifies and imports the total energy production required to address energy demands in Toronto. The model is built annually; however, it would require tremendous calculation power to solved it annually from 2016 to 2050 in a realistic time. By default, the resolution[9] used is a one-year basis from 2016 to 2025, and five-years increment until 2050, which provides a good balance between solving time and period resolution.


Photo by Nicholas C from Pexels

[8] Technology is the generic term for any equipment used in the energy system. The stock of technologies evolve over the model's timing horizon as equipment is purchased and/or retired and as the economy changes with evolving needs for goods and services.

[9] The resolution is the interval of time between each calculation in a model. Further details are provided in the technical documentation.

The downside of long-term energy and waste system and GHG planning models are not able to capture the full spectrum of the operation decisions that happen within one year. This disadvantage is a particular challenge for modelling the electric sector. The solution identified by TEMOA-TO, which is based on the total power generation over a year, may be not ideal for short-term operations (e.g., at hourly, daily basis). A common example is in the case of renewable energy generators, such as photovoltaic panels (PV), operating under net metering[10] can increase the load ramp-up and ramp-down on the grid, which requires additional investment to balance the variations and protect the grid equipment.

To address these issues, LENZ includes the short-term planning model **SILVER-TO**, developed for evaluating the impact of high variable renewable penetration on electricity grids. The model takes the electricity system configuration of Toronto, including power demand and generator centers, as well as transmission and distribution infrastructure, renewable generation, and demand profiles, and identifies the least-cost balancing strategy, as well as infrastructure risks and weak points. SILVER-TO uses hourly resolution for solving optimal power flow problem to optimize power generation unit commitment (optimal power dispatch) under various constraints, such as generator minimum output, transmission stability and voltage constraints. SILVER-TO is structured to address power production and consumption balancing, reliability of power grid and potential stress on the existing power grid, that may become vulnerable to blackouts.

Optimal power flow models such as SILVER-TO are also limited by the extent of their operational planning horizon due to the same computational limits as those of long-term planning models. Power flow models address this limit by typically covering shorter periods, such as a one-year period. By using this model, the decision-maker will be able to address questions like:

- When/how should power generators operate the equipment to meet power demand?
- What is the role of electric storage and what are optimal charging/discharging strategies?
- Will the transmission grid be able to ensure a resilient supply of electric power to address future demand under increasing demand peaks?

[10] Net metering is a billing mechanism that allows residential and commercial customers who generate their own electricity from solar power or other renewable sources to send excess electricity back to the grid and receive credits on their utility bills.

The **Linking Tool** is used to exchange data between TEMOA- TO and SILVER-TO, allowing the user to generate SILVER-TO inputs from TEMOA-TO results. In this way, a yearly capacity expansion plan for Toronto can be broken down and assigned to power infrastructure nodes depending on real constraints. For the inputs to TEMOA-TO from SILVER-TO, the Linking Tool transforms possible operational risks into recommendations that the decision-maker may use for the consequent run of TEMOA-TO. Linking both models is the key to identifying the least-cost pathway for GHG emitting sectors evolution in Toronto that is also operationally reliable and less costly.

TEMOA-TO is best used to:

- identify the least-cost energy system (technology and fuels);
- reflect new policies, technological advancements, changing fuel prices and carbon emissions targets;
- cover a long-term planning horizon.

SILVER-TO is best used to:

- identify the least-cost energy system operation strategy;
- address power supply and demand balancing under variable operational conditions;
- cover a short-term planning horizon.

LINKING TOOL is best used to:

- maximize the two models' complementarity and ensure data transfer;
- transforms possible operational risks into recommendations that the decision-maker may use for the consequent run of TEMOA-TO.

1.3. What are the key features and limitations of LENZ?

Many types of models exist that study the interactions between GHG emitting sectors and their impacts on the environment and the economy (referred to as 3E models (Energy-Environment-Economy). While historically 3E models were classified into two broad categories, most models today are hybrids and stand in between these two extremes:

- **Bottom-up models** use a techno-economic approach and include a very detailed description of energy systems, with supply-demand technologies and energy flows. They are typically used to study long-term evolution of energy systems, technology innovations, and GHG mitigation options and costs.
- **Top-down models** use a macro-economic approach and include a complete representation of the economy and monetary flows. They are typically used to study macroeconomic impacts (jobs, GDP, etc.) of energy and climate policies.

Achieving ambitious GHG reduction targets, such as net zero goals, necessarily involves major transformations of GHG emitting sectors. Consequently, bottom-up models are more appropriate to provide answers to this complex problem. This category can be further split into two main sub categories: simulation and optimization. A comparison between the two types is found in Table 1.

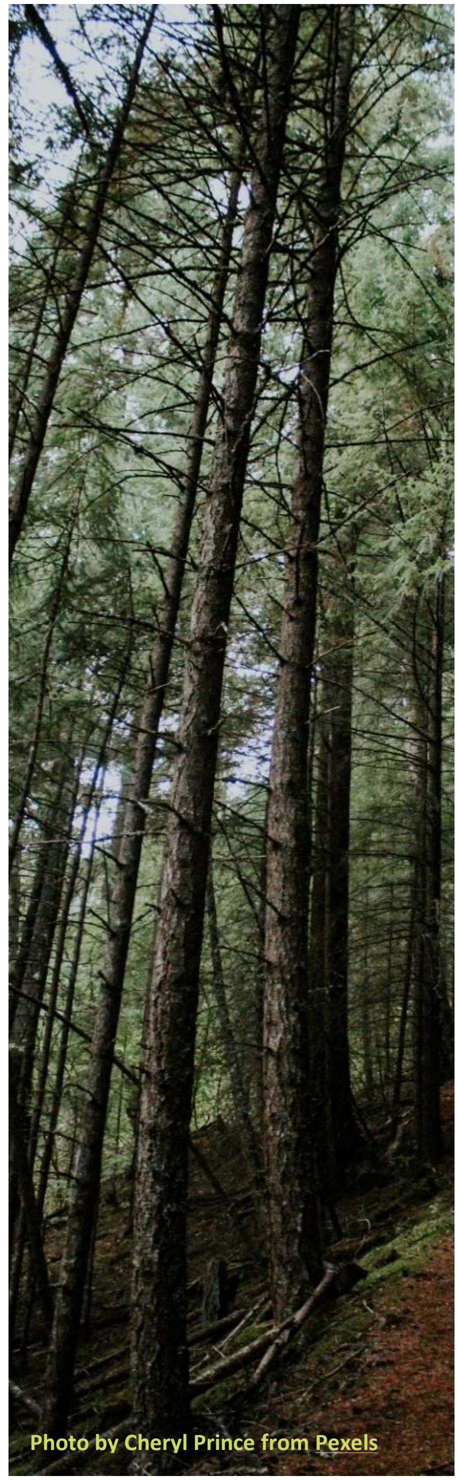
Table 1. Difference between simulation and optimization models

Type of model	Simulation	Optimization
Example of applications	CityInsight (Used in the NZS)	LENZ
Aim at	Assess impacts of changes/policies on GHG emitting sectors	Provide optimal GHG emitting sectors configuration (cost, energy, GHG)
Decision making	Biased, external decision provided by the user	Least biased, internally optimized by the model
Best suited for	Business as usual scenarios **Specific policy scenarios**	Energy transition scenarios **Deep GHG mitigation scenarios**
Policy types that can be modelled	Behavioral change Planned technology shift Energy switch	Behavioral change Planned technology shift Energy switch Financial incentive Carbon Tax

Optimization models of 3E systems provide a rigorous analytical basis for studying net zero transitions in a detailed multi-sector and multi-fuel framework.

- Optimization models provide a very detailed representation of the technological changes required in the long-term, as well as their costs, to meet growing demands and/or to reach specific goals.
- In addition, they provide advanced features that simulation models lack. Specifically, they optimize the system configuration to meet the total demand at the lowest cost. They consider system constraints such as resource limits, renewable targets, GHG taxes or mitigation targets, and energy policies. The optimization feature in models comes at a computational cost as it typically takes longer to run an optimization model than a simulation model.

The TEMOA platform used to build TEMOA-TO is gaining in popularity, as one of the most advanced open-source platforms; it has been used in several projects in Canada and the United States such as the study on US Energy-related GHG emissions in absence of federal climate policy[11], or on the symbiotic relationship of solar power and energy storage in providing capacity value[12]. It has a rigorous methodology, well documented and is constantly improved through a collaborative network of modellers. The optimization feature is an advantage over the previous simulation model CityInsight used to develop the NZS.



[11] H. Eshraghi A. R. de Queiroz J. F. DeCarolis (2018). US Energy-Related Greenhouse Gas Emissions in the Absence of Federal Climate Policy. Environmental Science & Technology, 52(17): 9595-604.
[12] D. Sodano J. F. DeCarolis A. R. de Queiroz J. X. Johnson (2021). The Symbiotic Relationship of Solar Power and Energy Storage in Providing Capacity Value. Renewable Energy, 177: 823-832.

LENZ CAN:

- Reproduce historical GHG emissions and provide future projections;
- Provide three types of computation modes to assess scenarios:
  - based on policies,
  - based on GHG targets, or
  - based on policies and GHG targets;
- Provide a least-cost investment roadmap following the City's NZS;
- Assist in the design of new policies and assess their impacts on energy mix, GHG emissions and cost;
- Assess energy security and resilience of the City's NZS against energy market disruptions (shocks on energy prices, shocks on energy availability);
- Identify the sectors and end-uses with the lowest and highest GHG emission abatement cost;
- Explore diverse scenarios that represent a range of possible futures, including system transformations in energy use and GHG emitting sectors (building, transportation, and waste);
- Annually verify the City's trajectory towards net zero emissions, audit the impact of existing policies and correct them to reach the target;
- Evaluate the implications of decarbonization pathways on hourly power demands and hourly net power demand in each transformer zone;
- Evaluate benefits and risks of different decarbonization pathways (i.e., transition cost to society, emission reduction potentials, risks in relation with power supply);
- Provide a decision-support tool (to be run together or separately) to the user with the possibility to customize and test various inputs (e.g., policies, technology characteristics and various assumptions).

LENZ CANNOT:

- Capture impacts of the COVID-19 pandemic on GHG emissions (but could capture impacts of defined similar extreme events);
- Account for some GHG emissions such as biogenic carbon, carbon embodied in material, non-organic waste recycling, and land use change (however, the tool reports GHGs as per the GHG Protocol for Cities);
- Evaluate GHG emissions based on consumption of imported goods. The methodology focuses on geographic boundaries (sector-based GHG emissions inventory) and mainly considers emissions generated within the limits of Toronto;
- Assess the physical impacts of climate change and corresponding adaptation measures (however, this report provides the analysis of mitigation actions that may help to enhance resilience);
- Capture detailed macroeconomic impacts such as the impact on GDP or employment;
- Evaluate the perspective of specific stakeholders, like households or investors, when assessing individual actions. This would involve applying varying discount rates based on which entity is making the investment.

SECTION 2

2. How can LENZ be used?

Photo by Lisa Simpson from Pexels

This section begins with the first part discussing the various scenarios that can be modelled using LENZ, followed by an overview of LENZ's individual models in the second and third part.

2.1. What types of scenarios can be modelled?

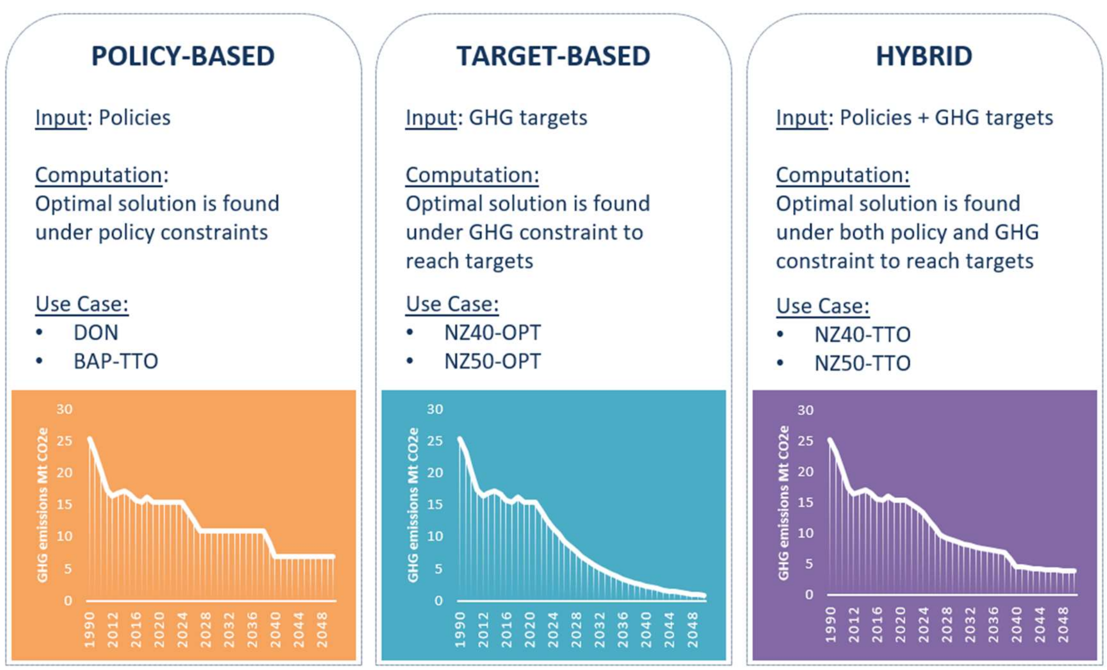
The types of scenarios that can be modelled with LENZ can be classified into three categories, namely: policy based, target based and hybrid scenarios (Figure 2).

Policy-based scenarios include planned policies but exclude explicit GHG emission goals such as net zero targets. While policy-based scenarios have a great value to analyse the impacts of planned policies on GHG emission reductions, there is no guarantee *a priori* that these policies will meet the net zero target.

Target-based scenarios, contrary to policy-based scenarios, exclude planned policies, but include explicit GHG emission goals such as net zero targets. In these scenarios, also called pure optimal scenarios, the model generates cost-optimal pathways to reach GHG emissions targets without being constrained by any other sector policies or goals. By default, they guarantee that the GHG emissions target is met, and their results can be used *a posteriori* to define the most cost optimal policies required to get there.

Hybrid scenarios, include both planned policies and GHG emission goals, such as net zero target. The planned policies will bring some GHG emission reductions while the GHG targets will guarantee that the solutions meet the net zero target. In these scenarios, the model generates cost-optimal pathways to reach net zero targets while being constrained by other sector policies or goals. By definition, there is less room for optimization in these scenarios and the solutions are likely to be more costly than with the target-based scenarios.

Figure 2. Type of scenarios modelled using LENZ

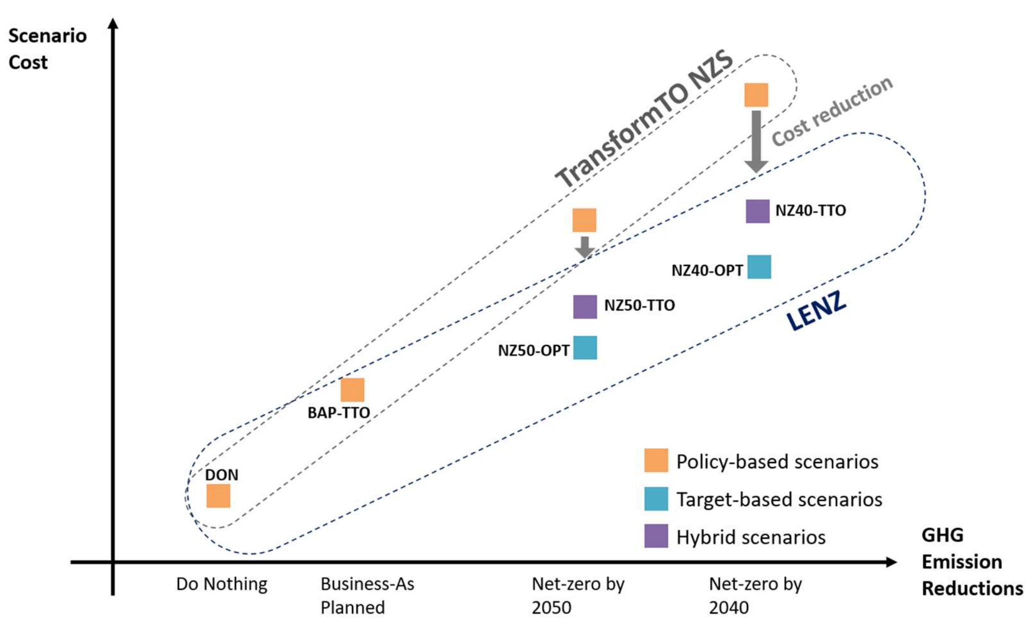


LENZ has been developed with six native scenarios based on the four scenarios as in the TransformTO NZS to provide insightful recommendations in terms of cost optimality and robustness of policies. In addition, the six different scenarios that are found in LENZ are:

1. **DON**: A **Do-Nothing** scenario to compare and make sure the GHG projections were aligned with the Do-Nothing scenario of the TransformTO NZS (labeled BAU in the NZS). This scenario represents what would happen if the current energy and waste system is preserved until 2050.
2. **BAP-TTO**: A **Business-as-planned** scenario to assess the impact of the TransformTO NZS policies on GHG emissions (policy-based scenario). It is useful to assess the impact of the current policies on GHG emissions combined with the natural evolution of the system resulting from market competition between technologies and energy costs.
3. **NZ50-TTO**: A hybrid scenario, representing how the City may achieve net zero GHG by 2050 while considering the policies and targets of the TransformTO NZS.
4. **NZ50-OPT**: A target based or pure-optimal scenario, representing the cost-optimal pathway to reach net zero GHG by 2050.
5. **NZ40-TTO**: A hybrid scenario, representing how the City may achieve net zero GHG by 2040 while considering the policies and targets of the TransformTO NZS.
6. **NZ40-OPT**: A target based or pure-optimal scenario, representing the cost-optimal pathway to reach net zero GHG by 2040.

As explained earlier in this section, LENZ will generate cost optimal pathways for both types of net zero scenarios. However, the hybrid scenario (TTO) has policies imposed on it which translate into more constraints than the target-based scenario (OPT) and as result, the TTO scenario has less flexibility to explore cost optimal solutions. This will result in the TTO scenario having a less economical solution than the OPT scenario as illustrated in Figure 3.

Figure 3. Schematic cost-optimality representation of LENZ and TransformTO NZS scenarios



2.2. TEMOA-TO, a long-term planning model

TEMOA-TO is a capacity expansion model for long-term planning of energy, waste and GHG emitting systems based on the TEMOA open-source platform which is written using Python programming language. TEMOA-TO can be used to model policies included in the NZS and identify least-cost configurations of energy and waste systems under different socio-economic conditions. This section first outlines the scope and assumptions of TEMOA-TO, providing a comprehensive understanding of its structure and underlying construction principles. Subsequently, it presents examples of results obtained with TEMOA-TO.

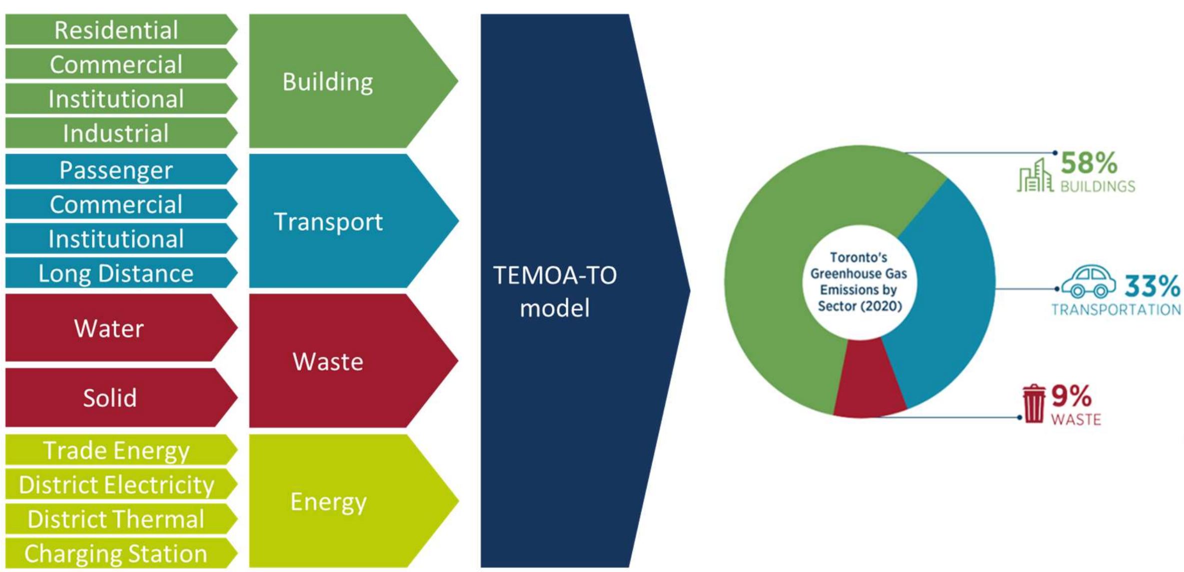
2.2.1. Scope & assumptions

TEMOA-TO projects the evolution of energy and waste systems, as well as GHG emissions at either annual level or with 5-years increment, on a long-term horizon (2016-2050) for the City of Toronto. The subsections below describes the definition of the energy and waste system modeled and the methodology applied to build it.

Scope of the model

TEMOA-TO focuses on long-term planning of the GHG emitting sectors (buildings, transportation, and waste) of the city. These sectors align with the GHG Protocol for Cities (GPC)[13], and the sector-based emissions inventory the City reports annually. Additionally, as local generation is expected to grow, it includes a module representing the energy sector, both distributed energy resources and energy imports. Figure 4 shows how the modelling scope relates to the sector-based GHG inventory from the City[14].

Figure 4. Modelling scope related to GHG emitting sectors



[13] Green House Gas Protocol for Cities https://ghgprotocol.org/ghg-protocol-cities
[14] City of Toronto (2022). 2020 Sector-Based Greenhouse Gas Emissions Inventory.

Reaching GHG net zero target requires a drastic change in both energy supply and demand. Increase of low-carbon transportation options, expansion of local renewable energy and storage, significant reduction of natural gas use, and building performance targets are the four key drivers for the deep decarbonization of the Toronto's economy.

TEMOA-TO is used to model the NZS policies and targets. It is calibrated with the energy figures reported in CityInsight and with data provided by the City. The model is finely calibrated by energy type and sector for the base year with a maximum four per cent difference in energy consumption and five per cent difference in GHG emissions (please refer to the technical documentation[15] for more information on the benchmarking process).

Building a comprehensive database

The development of a system model like TEMOA-TO involves first the development of comprehensive databases from a large amount and variety of specific data sources. This is a very important task that requires to be performed meticulously. Figure 5 describes the approach used to build the TEMOA-TO databases.

[15] ESMIA Consultants (2023). Local Emissions for Net Zero Modelling Suite – Toronto: Technical Documentation.

Figure 5. Steps to build a comprehensive database for TEMOA-TO

Step 1: Compile

Raw data are collected from multiple sources (see Table 2)

- City-owned datasets and SSG-owned processed datasets from the CityInsight model were used as the starting point.
- Those datasets were enhanced with open-source data from annual reports (e.g., Via Rail, Ports Toronto, TTC), other modelling initiatives (e.g., Google Environmental Insights) and private sector data.

Step 2: Format

Raw data are formatted, broken down and adapted for the adequate representation of the energy, waste and GHG systems of the city of Toronto

- For example, total energy consumption data (e.g., total electricity consumed in residential buildings) are further broken down into multiple end-use demands and technologies (e.g., electricity consumed by heat pumps to provide cooling) using multiple data sources including NATEM and NRCAN datasets.
- For example, Canadian and Ontario specific data are adapted to the Toronto context.

Step 3: Calibrate

Data are further refined to replicate the City's sector-based GHG inventory

- Adjustment to input data and model parameters such as efficiencies are done to be able to replicate energy consumption and GHG figures available in official publications such as the GHG Inventory.

Step 5: Project

Some data are projected to the 2050 modelling horizon and used as input in TEMOA-TO

- Techno-economic parameters such as performance and capital cost are projected for a wide range of new technologies available in the model database for future investments. These projections are based on an extensive literature review as well as from the NATEM model.
- Demands for energy services are projected using macroeconomic drivers specific to the city such as population and employment projections.

Step 6: Constraint

User constraints are built in the model to capture resource limitations, and/or to model specific targets or policies

- Constraints representing the technical feasibility of technology deployment (e.g., the maximum potential deployment for PV panel is 7350 MW in a given region).
- Constraints representing targets and policies from the TransformTO NZS (e.g., a ban on natural gas appliances by 2040).

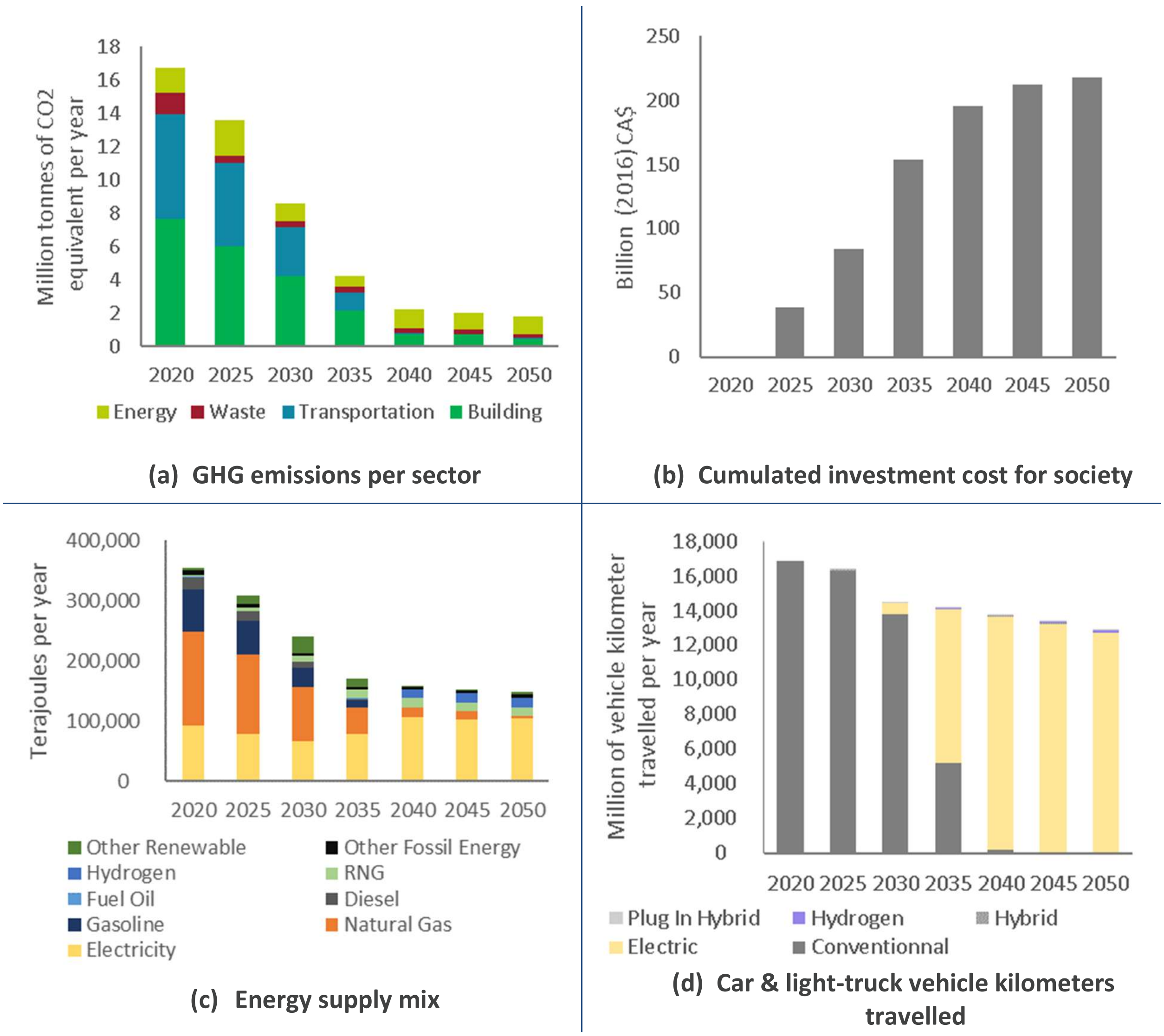
Table 2. List of data sources used to build the TEMOA-TO model

Type of data	Sources
Existing system per sector	NATEM, Google, PORTS TORONTO, Natural Resources Canada / Ressources naturelles Canada, Canada, TTC, VIA Rail Canada, CityInSight, TORONTO
Calibration data	TORONTO, CityInSight
New technology	NATEM
Demographic projection	TORONTO
Net zero strategy	TORONTO

2.2.2. Results interpretations

TEMOA-TO model can provide various insights including: GHG emissions, costs (investment and operational), energy mix supply, and capacity deployment. Figure 6 shows aggregated examples of these results. Note that since the model database is broken down at the technology level, higher granular results may be obtained.

Figure 6. Results of the NZ40-TTO scenario of the case study from TEMOA-TO



(a) GHG emissions per sector

(b) Cumulated investment cost for society

(c) Energy supply mix

(d) Car & light-truck vehicle kilometers travelled

A general advice for result interpretation is not to consider these results as forecasts or as the most likely outcomes, but rather as ideal outcomes to meet a certain target at the minimum cost and under specific conditions.

2.3. SILVER-TO & the Linking Tool, a short-term planning model

SILVER-TO is a production cost model for short-term planning of electricity systems based on the SILVER platform (OS) written using Python programming language. SILVER-TO can be used to identify least-cost operation strategies for the electricity system and to address power supply and demand balancing under variable operation conditions.

The Linking Tool ensures communication between TEMOA-TO and SILVER-TO models to maximize their complementarity and to reinforce the value for decision makers. The Linking Tool transforms possible operational risks into recommendations that the decision-maker may use for the consequent run of TEMOA-TO. Like the two other models, the Linking Tool is written using Python programming language.

The next sub-sections outline the scope and results interpretations of the two models presented above.

2.3.1. Scope & assumptions

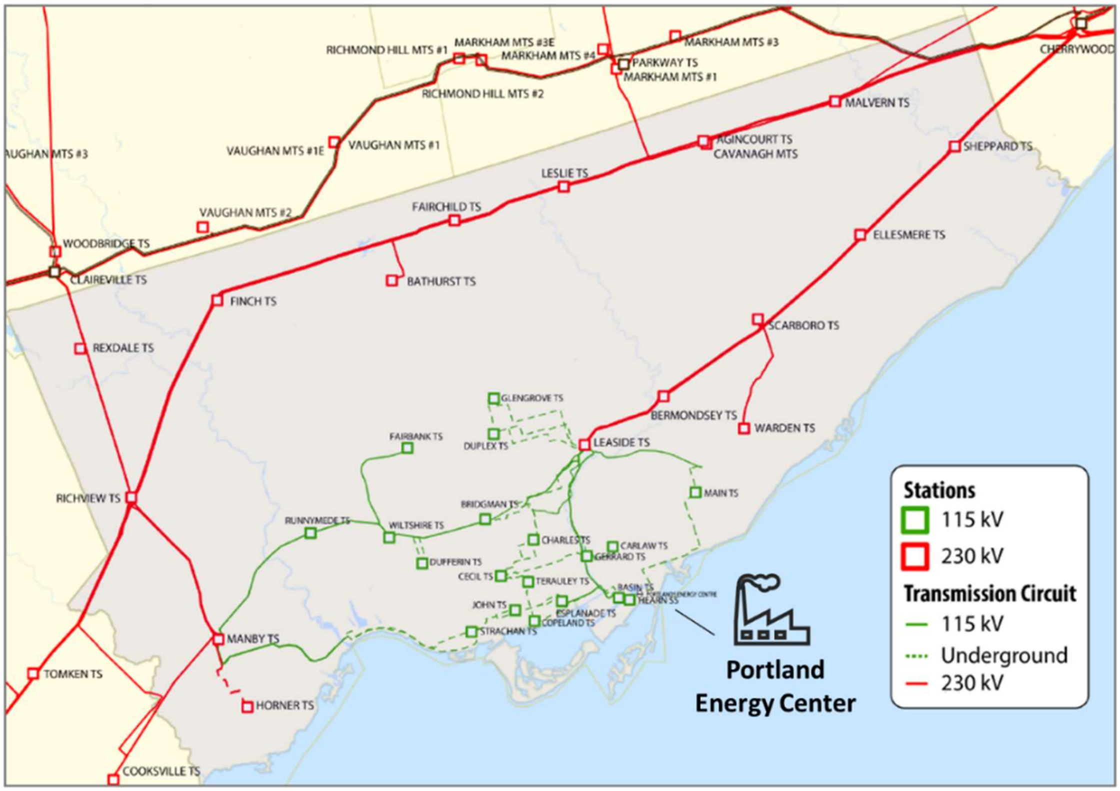
SILVER-TO focuses on grid-operator scale and is used to evaluate the impact of a Toronto energy transition (such as electrification of end-use appliances, deployment of renewable generation like PV and wind turbines etc.) on the transmission power system. It allows unit commitment and power flow calculation at an hourly level for critical years between 2016 and 2050. This transmission system supplying Toronto is described below.

The Linking Tool is a Python based tool built especially for LENZ and is used to link TEMOA-TO and SILVER-TO models. Linking both models is the key to identifying the least-cost pathway for GHG emitting sectors evolution in Toronto that is also operationally reliable and less costly. An overview of the methodology used in the Linking Tool is provided below.

The transmission system supplying Toronto

Power grid is composed of two grid levels that are distinguished mainly by their voltage levels. Electricity power is carried from the centralized conventional generators connected to the high voltage transmission grid down through the lower voltage transmission levels towards distribution grids to which most consumers are connected. Ontario transmission grid, operated by the Independent Electricity System Operator (IESO), is composed on the extra-high voltage (500 kV), high voltage (230 kV and 115 kV). Distribution low-voltage grid (less than 50 kV) is operated by distribution companies (Toronto Hydro for the city). Electricity power generators depending on their capacity may be connected to transmission and distribution grids. Transmission-connected generators are typically conventional generators, such as nuclear and gas plants, as well as renewable generators of large-capacity (e.g., wind and solar farms). Distribution-connected generation, also known as embedded generation, is small-scale generation located within local distribution companies' territories (e.g., rooftop solar). Most consumers are connected to the low-voltage distribution grid. In Toronto, only few large-scale consumers are directly connected to the transmission grid. Those large-scale consumers, such as steel arc furnaces, may be connected to the high-voltage level under contractual agreement.

Figure 7. The regional transmission system supplying Toronto[16]



The Toronto power grid includes a gas-fired power plant (Portland Energy Center) connected at the transmission level at Hearn switching station (Figure 7). This power plant is managed by IESO[17] within the Ontario generation portfolio to address provincial electricity power demand. Electric power generators connected to the transmission grid are large-scale generators, such as nuclear plants operated by the Ontario Power Generation (OPG) or renewable generators (including hydro power plants) operated by the Brookfield Renewable Partners. The amount and the schedule of power generation produced by these plants are defined via the electricity market where the electricity is sold by suppliers (i.e., generators) to distributors (that sell the electricity to end-use consumers). IESO predicts Ontario electric power demand 24-hour in advance and receives bids from generators indicating the amount the amount of electricity they can produce and at what price. The IESO reviews and accepts bids, starting from the lowest-cost options, until enough energy is secured to meet Ontario's demand[18]. Therefore, the amount of electricity at each time step (e.g., hour) produced by transmission-connected generators will be defined by the electricity demand of the entire province, as well as export commitments (if any). Toronto Hydro will purchase the electricity from the market to cover the city electricity demand from the grid.

[16] IESO - Independent Electricity System Operator (2019). Toronto Region: Integrated Regional Resource Plan.
[17] More details on Transmission-Connected Generation at https://www.ieso.ca/en/Power-Data/Supply-Overview/Transmission-Connected-Generation
[18] More details on the IESO electricity pricing at https://www.ieso.ca/en/Learn/Electricity-Pricing-Explained/The-Value-of-Electricity-Markets

Scope of SILVER-TO and the Linking Tool

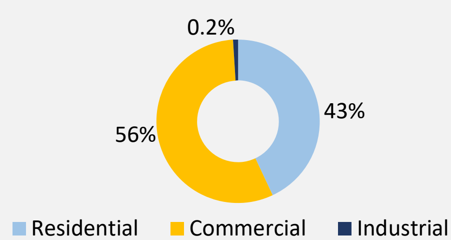
In SILVER-TO, the city is mainly supplied through power imports from the province at different 230 kV transmission stations, and from the Portland Energy Center gas-fired power plant at Hearn switching station. The electricity generated by renewables sources or battery discharging are considered consumed locally (at distribution level) and do not feed into the grid[19]. With SILVER-TO, the power system operation cost is optimized by minimizing power generation costs subject to meeting electricity demands and reliability requirements. The SILVER-TO model utilizes data from various sources, including the TEMOA-TO model, which provides outputs at the city level. However, the data must be broken down to the transmission level and at hourly resolution to be useful for SILVER-TO inputs. To accomplish this, various methods are used, such as population rates by areas or power generation potential.

The Linking Tool is an essential component to break down the data from TEMOA-TO for SILVER-TO, which is responsible for projecting geographically and hourly the total net load that must be met by the power grid. This projection considers several factors such as load profile, generation capacity, residential batteries, electric vehicles use, and grid constraints. By analyzing these factors, the Linking Tool ensures that the power grid can provide reliable and sufficient energy to meet the demand at any given time.

WHAT IS THE DIFFERENCE BETWEEN LOAD PROFILE AND TOTAL NET LOAD?

- **The load profile** is a representation of the variation in electrical power demand over a specific period. The shape of load profile in a transmission zone depends on the type of consumers and their consumption habits. The shape of load profile in a city where the majority of power consumers are households and small businesses will be different from the load profile shape of a large jurisdiction (e.g., a province or a country). Typically, provincial and country load profiles will be impacted by the large-scale consumers (e.g., industries) whose power demand will be more constant throughout the entire day. As a consequence, the shape of the provincial or country profile will be “flatter” than the shape of the load profile in the city. In 2020, Toronto Hydro distribution company supplied 697,000 residential consumers, 83,000 commercial consumers and 44 large-scale users.

Electric power consumers by category in Toronto

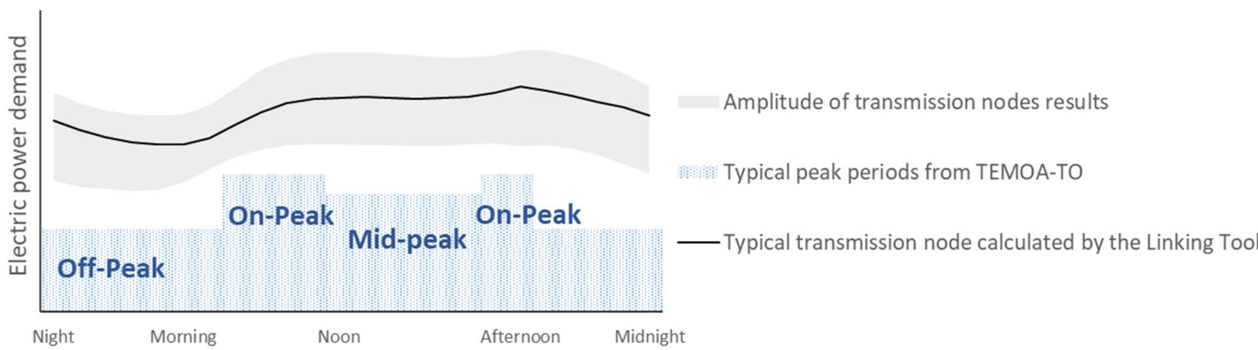


- **The total net load** refers to the actual power demand that must be met by the power grid after accounting for factors such as load profile, generation capacity, residential batteries and electric vehicles use, and grid constraints.

[19] Although SILVER-TO gives the possibility of integrating centralized renewable generation (as well as storage) at a grid, we observe that in reality there is not enough space in Toronto to deploy such high-capacity generators that would be directly connected to the transmission grid. Please refer to the technical documentation for further details.

In more concrete terms, part of the data used for the SILVER-TO model comes from the TEMOA-TO model, and the Linking Tool ensures the data conversion and transfer. The outputs of TEMOA-TO, reported at the city level for a season or a year, must be broken down spatially by transformer zone, and temporally by hour for SILVER-TO. Spatial break down is done based on the load in different transmission nodes. Temporal break down to generate representative patterns for energy consumption and production patterns is done using a dedicated approach for each type of TEMOA-TO data (e.g., load profile, PV, electric vehicles (EV) etc.) (see Figure 8 for an example of load profile break down). The final goal is to estimate a total net load at the level of each transformer zone in Toronto for a selected year. The total net load is defined as the electricity demand plus electricity used to charge batteries and EV, minus generation from variable renewable generation.

Figure 8. Example of load profile break down done by the Linking Tool for a winter day



2.3.2. Results interpretations

The total net load calculated by the Linking Tool will be strongly affected by electrification of end-use energy[20], distributed generation, storage, and electric vehicles, creating important ramp-up and ramp-down effects and accentuating peaks. The Linking Tool processed TEMOA-TO results to provide the different energy transition measures and calculated the total net load. Figure 9 illustrates the impacts of the different energy transition measures on the total net load. This total net load is then used as an input for SILVER-TO model.

The ramp-up and ramp-down effects and the accentuation of peaks in net load that needs to be supplied by the grid may lead to two major effects:

- **increase of the load level** that may require transmission lines to operate at more than 40 per cent of their maximum capacities, increasing resistive heating and generating higher energy losses; and
- **increase of load variation** of transmission lines that may result in additional equipment stress.

SILVER-TO tests the operational viability of a specific energy transition strategy from the power grid operational perspective for a certain time period (e.g., year, season). SILVER-TO model includes an excel-based dashboard of outputs with overview of key statistics for a user-selected operational time period. Those metrics are designed to quickly identify the risks for the transmissions system supplying Toronto. For example, the user can choose the threshold leading to the increase of heat losses on the line and the dashboard will automatically show a summary of the number of lines at risk.

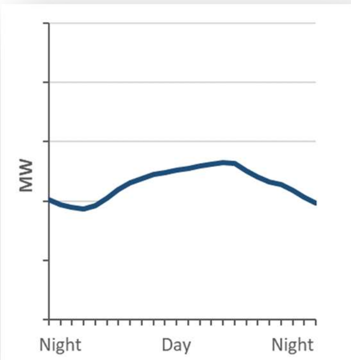
[20] The electrification of end-use energy refers to the transition from using traditional fossil fuels (e.g., natural gas) for various end-use applications, such as transportation, heating, and cooling, to using electricity as the primary energy source. The goal of electrification of end-use energy is to reduce greenhouse gas emissions and increase energy efficiency.

Figure 9. How electricity demand profile of the City may be reshaped in the future?

To be supplied from the grid | **Impact of different energy transition measures**

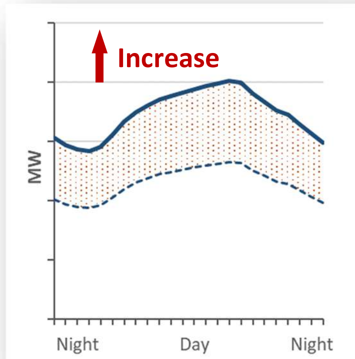
TODAY

- Day load is higher than night load



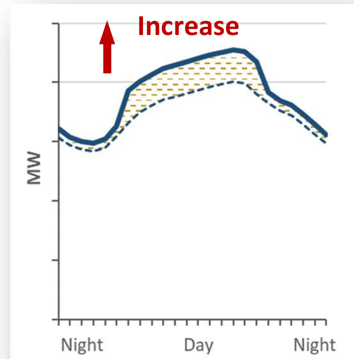
End-use electrification (gas phase-out):

- Overall demand increase



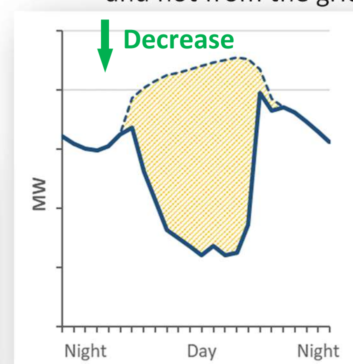
Transport options electrification (EV):

- Demand increase for transport charging at public station and at home



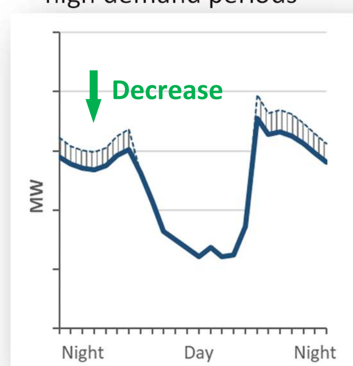
Increase of distributed PV generation:

- Demand decreases during periods when PV generation is available (electricity is consumed from the local source (PV) and not from the grid)



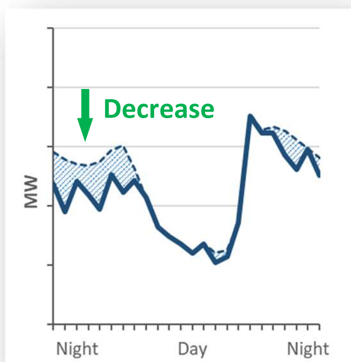
Use of battery storage:

- Discharging batteries during high demand periods



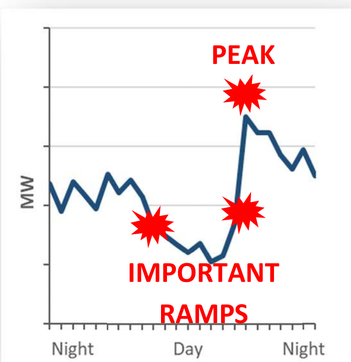
Increase of distributed wind generation:

- Demand decrease during periods when wind generation is available



TOMORROW

- High demand variability
- High and well pronounced demand peaks



SECTION 3

3. Typical use cases for LENZ

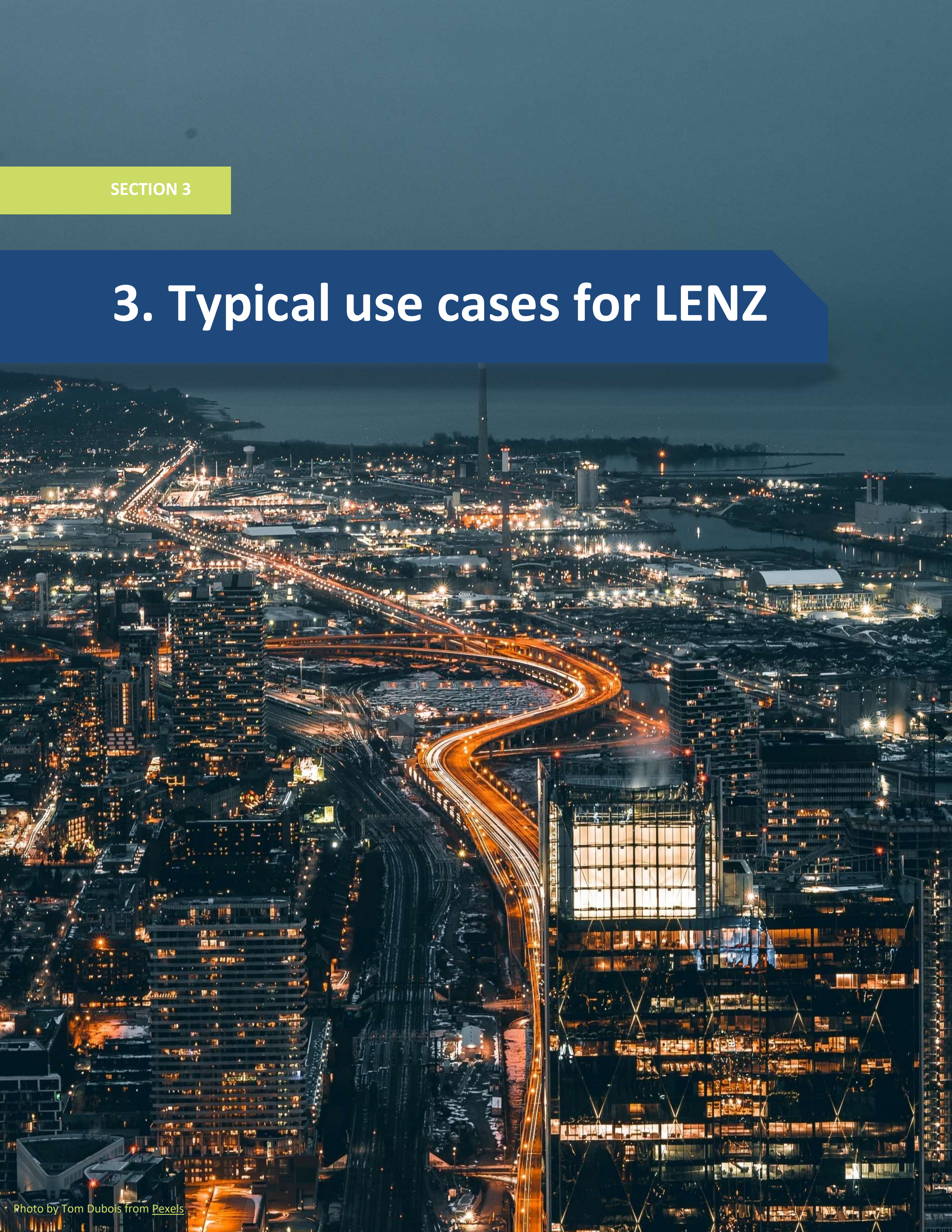


Photo by Tom Dubois from Pexels

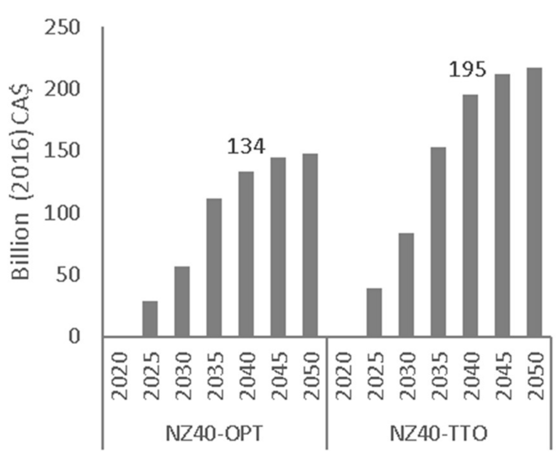
This section presents examples do demonstrate some of the use cases of LENZ and is by no means exhaustive. The examples are based on the scenarios developed in LENZ and discussed in detail in the Case Study. The examples focus on the five critical steps identified in the Net Zero Strategy, as well as resilience, energy affordability, employment, and social cost of inaction in the city of Toronto.

3.1. Carbon accountability through carbon budgets

The City will establish a carbon budget to track climate actions against annual emission limits to drive accountability.
LENZ can provide insights on the cumulative costs of scenarios to identify cost-effective solutions to reach GHG emissions targets.

<u>Insight from the Case Study as an example:</u> Toronto's net zero by 2040 pathway is achievable with different implementation paths, each with trade-offs (based on TEMOA-TO).

Figure 10. Cumulated investment costs



A comparison of the cumulated cost from the Case Study for example suggests that achieving net zero by 2040 with the NZ40-OPT scenario may imply 31 per cent less investment costs compared to the NZ40-TTO scenario (Figure 10).

The TransformTO NZS is built mostly on 'safe bets'[21], defined as existing technologies that are already commercially available and face no major constraints to widespread implementation which is reflected in the polices. Optimal NZ40 includes both 'safe bets' as well as emerging technologies with high impact. While the cost is less in the NZ40-OPT scenario than the NZ40-TTO scenario, there is more risk associated in the first due to the uncertainties inherent to the limited confidence in emerging technologies.

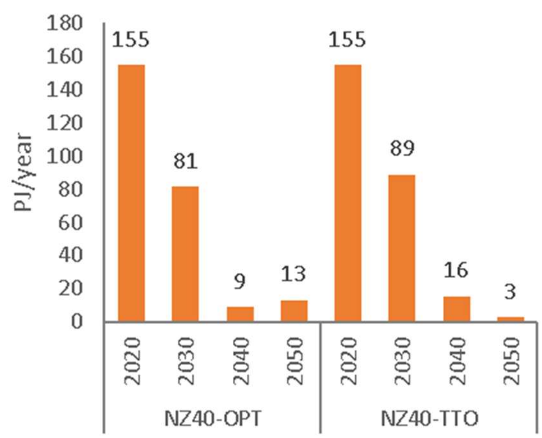
[21] "Safe bets" are solutions that show up no matter how Canada's transition plays out. They leverage existing technologies that face no major barriers to scaling. Canadian Climate Institute (2023). Online information. https://climateinstitute.ca/safe-bets-and-wild-cards/

3.2. Accelerate significant reduction of natural gas

To achieve the targets, the City of Toronto must limit dependence on natural gas.
LENZ can provide a forecast of natural gas consumption in the future for different scenarios to assess the trade-offs between different policies.

<u>Insight from the Case Study as an example:</u> Residual natural gas may be required as a resilience measure (based on TEMOA-TO).

Figure 11. Natural consumption in net-zero scenario



Natural gas phase out may be reasonable for carbon emission reduction in Toronto. Figure 11 shows natural gas consumption in net zero scenario, it suggests different level of consumption by 2050.

As suggested by the NZ40-OPT scenario, the option leading to only partial natural gas grid abandonment is highly recommended under net zero strategy. The use of natural gas as a backup will still result in a reduction of carbon emissions in the City while contributing to the resilience of energy supply.

3.3. Establish building performance targets

Toronto will establish emissions performance targets for buildings to reach Net Zero by 2040. LENZ can assess different the level of retrofits required in buildings to reduce energy usage and the technologies required to replace gas appliances.

<u>Insight from the Case Study as an example:</u> Upgrade building to high efficiency through deep-retrofit is not the cost-optimal path (based on TEMOA-TO).

Figure 12. Retrofitting level in existing buildings

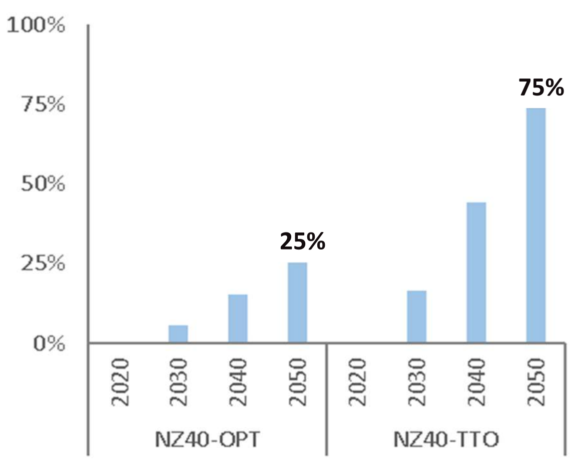


Figure 12 retrofit level refers to the thermal energy gains in buildings. The scenarios suggest different level of retrofit for existing buildings.

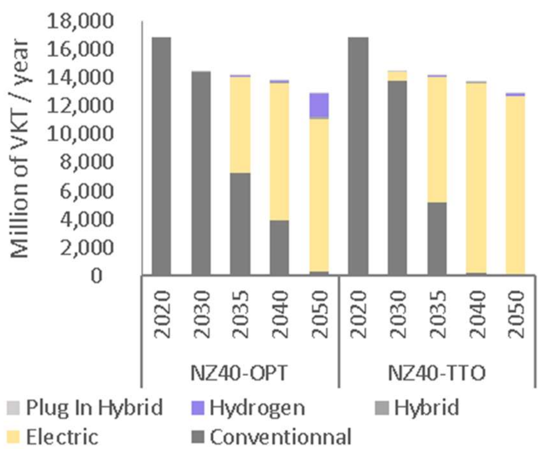
The NZ40-TTO scenario suggests deep retrofits with 75 per cent of thermal gains, for all existing buildings by 2050. The NZ40-OPT scenario suggests retrofit with 25 per cent of thermal gains. This gain is aligned with a standard retrofit, including energy assessment, recommissioning, and priority insulation improvements. The optimal level of retrofit depends in fact on various criteria (vintage, archetype, size, and use) and would need to be further assessed for each building type. However, to avoid extra costs, the target of the TransformTO NZS could be revised to a more flexible set of targets starting with the most cost-effective options.

3.4. Increase low carbon transportation options

In addition to increasing the active and public transportation, Toronto will advance options to incentivize electric vehicle adoption and disincentivize the use of carbon polluting gasoline and diesel vehicles.
LENZ can estimate the level of electrification of vehicles required and the role alternative renewable fuels can play in the transition based on different policies.

<u>Insight from the Case Study as an example:</u> Complete electrification of conventional vehicle stock is not resilient nor cost-effective (based on TEMOA-TO).

Figure 13. Car & Light-truck vehicle kilometres travelled



To achieve a resilient and sustainable transportation system, a multi-faceted approach is required to decarbonize transportation, as per Figure 13.

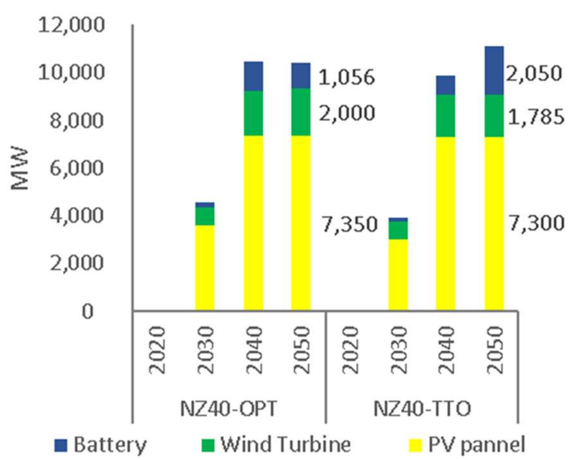
Behavioral change should be the priority. Encouraging people to use alternative transportation, such as public transportation (22 per cent of trips by 2040), biking (23 per cent of trips by 2040), and walking (22 per cent of trips by 2040). Finally, for residual vehicle trips especially for longer passenger transportation trips and commercial transportation trips, decreasing GHG emissions may include electrifying vehicles (75 per cent of light vehicles by 2040 in NZ40-OPT) supported by charging station deployment.

3.5. Increase local renewable energy & storage

By increasing opportunities for local renewable generation to be located within the City's boundary, Toronto will contribute to a decarbonized electricity supply.
LENZ can determine the capacity of renewable generation sources and electricity storage that needs to be deployed.

<u>Insight from the Case Study as an example:</u> **Increased local renewable energy & storage may supply a growing electricity demand (based on LENZ).**

Figure 14. Capacity deployment for local energy



To decrease electricity consumption from the grid, PV generation scale-up to 7,000 MW or greater, followed by expansion of onsite battery storage capacities that is suitable to go beyond 2,000 MW.

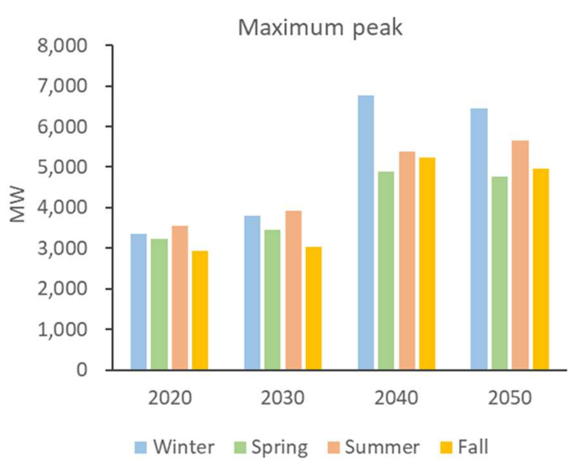
Scaling-up of wind power capacity should be done with caution and is estimated to reach 2,000 MW by 2050. Wind generation may create pronounced undesirable variations not only during the day (such as solar), but also during the night. Wind power generators deployment must be followed by an additional increase in battery storage and the deployment of additional technologies for continuous balancing of wind generation variability.

3.6. Resilience of electric power supply

The energy transition in Toronto is marked by the phase-out of conventional fuels (such as natural gas), massive electrification of end-uses, and expansion of distributed renewable capacity which will result in major changes to electricity generation and demand trends.
Using LENZ, the risks associated with the shifting trends can be evaluated and different mitigation strategy can be tested to design strategies that result in a resilient electric power supply.

<u>Insight from the Case Study as an example:</u> **Net zero pathways create considerable risk for resilience of electricity supply after 2030 (based on SILVER-TO).**

Figure 15. Impact on seasonal peak demand supplied from the electricity grid



Seasonal peak demand may increase over time with end-use electrification (Figure 15)

The City may adopt different actions to mitigate power demand peak increase by incentivising the expansion in battery storage capacity, incentivising particular user behaviours (e.g., coordinated EV changing during specific time periods), or reinforcing standards for building retrofits. If these measures are not sufficient, more advanced actions could be considered (e.g., the adoption of seasonal storage at the city level and grid upgrades at power grid level).

3.7. Energy affordability

Dependence on electricity where rates may be susceptible to increases that would add pressure on low-income households and push a larger fraction of the residents into energy poverty.
LENZ can evaluate the impact of policies on financially vulnerable residents and determine the subsidies and rebates that would provide energy security to residents at risk.

<u>Insight from the Case Study as an example:</u> 2.5 Million CA$ per year will be required to help 50,000 low-income households to pay their electricity bills (derived from TEMOA-TO).

Figure 16. Subsidies to be paid as bill rebates to decrease energy poverty in Toronto

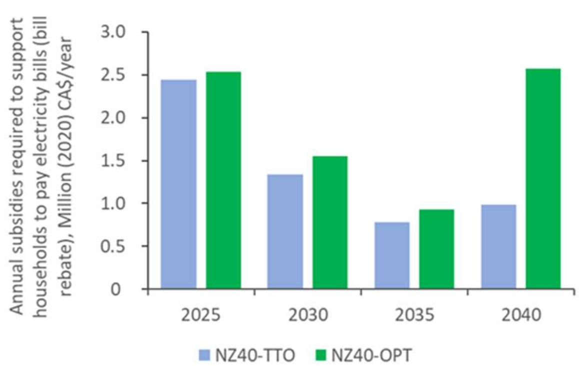


Figure 16 shows that under net-zero, electricity rates are susceptible to increase. This may drive the increase of electricity bills for Toronto consumers, likely creating the need to support low-income households with bill rebates to mitigate their energy poverty[22]. The Case Study modelling indicates that up to 2.5 Million CA$ may be needed annually for electricity bill rebates to keep energy poverty in the city under the six per cent threshold. In addition, other support actions will be required to ensure a just energy transition in the city, such as subsidies for low-income households for investment in renewable generation and residential storage, and support for low- and medium-income households to implement building retrofit measures.

[22] Energy burden defined as the percentage of household income spent on energy (electricity, natural gas, central heating etc.).

3.8. Employment

The adoption of net zero strategies in different jurisdictions will increase competition to attract workers holding key qualifications able to implement and deliver the change needed.
LENZ can assess the job market requirements and estimate the size of qualified labor power required to avoid labour shortage that would compromise the set targets.

<u>Insight from the Case Study as an example:</u> The City may face an important shortage of qualified labour after 2030 (derived from TEMOA-TO)

Figure 17. Net person-year of employment required and the projected annual labour force in Toronto

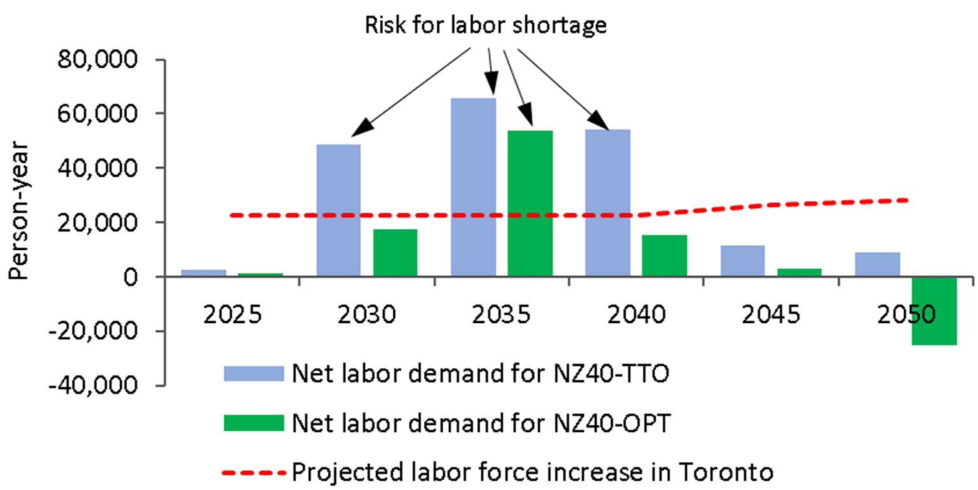


Figure 17 compares the pace of net person-years of employment required for net-zero by 2040 scenarios with the projected annual labour force increase in Toronto. Negative values indicate that conventional jobs elimination outpaces clean jobs creation, which may increase unemployment.

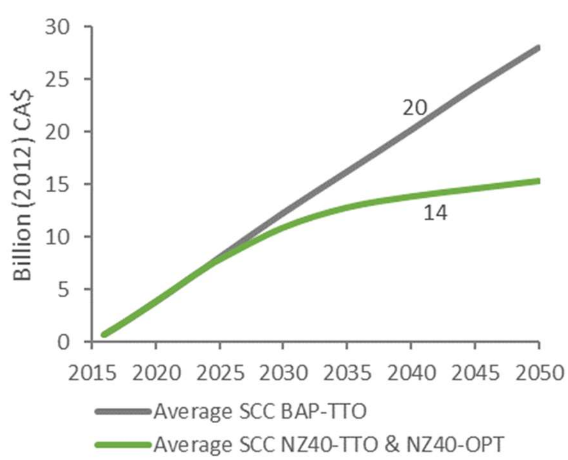
The adoption of net zero strategies in different jurisdictions will increase competition to attract workers holding key qualifications. In net zero by 2040 scenarios, Toronto may require a considerable net person-year addition after 2030. Attracting workers from other sectors and new qualified labour may not be sufficient to address the labour needed to implement the net zero strategy. This creates a risk of labour shortage. The City will be required to implement particular programs, such as relocation support and different social benefits, to attract a large enough qualified labour force.

3.9. Social cost of inaction

Social cost of inaction refers to the economic, social, and environmental costs that are incurred when action is not taken to address a particular issue or problem. It is the cost that society as a whole pays when no action is taken to prevent or mitigate negative outcomes.
LENZ can estimate the cost society will incur under different scenarios and can be used to evaluate the return on investment of implementing different solutions from those scenarios and the economic gains Toronto can benefit from.

Insight from the Case Study as an example: Failure to act can result in considerable costs for society (derived from TEMOA-TO)

Figure 18. Cumulative Social cost of carbon



Social cost of inaction refers to the economic, social, and environmental costs that are incurred when action is not taken to address a particular issue or problem. It is the cost that society as a whole pays when no action is taken to prevent or mitigate negative outcomes. To measure the cost of inaction for the climate crisis, the social cost of carbon is most often used as per Figure 18.

Under current policies, the City is engaged on the Business-As-Planned scenario GHG trajectory, the cumulative cost of the BAP-TTO scenario between 2016 and 2040 may be around 20 Billion (2016) CA$ in the average case[23]. Addressing the climate crisis globally by reaching net zero by 2040 would imply a significant economic gain for the city of Toronto with an average estimate of 6 Billion (2012) CA$ in the average case.

[23] A wide range of social cost of carbon are used, the average case represents an average with a 3 per cent Discount Rate.