Modeling emissions reductions pathways in the Northwest Territories

Report prepared for the Government of Northwest Territories Department of Infrastructure

SUBMITTED TO

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About Us

Navius Research Inc. is an independent and non-partisan consultancy based in Vancouver. We operate proprietary energy-economy modeling software designed to quantify the impacts of climate change mitigation policy on greenhouse gas emissions and the economy. We have been active in this field since 2008 and have become one of Canada's leading experts in modeling the impacts of energy and climate policy. Our analytical framework is used by clients across the country to inform energy and greenhouse gas abatement strategy.

We are proud to have worked with the following clients:

Provincial, territorial, and municipal governments: Alberta, British Columbia, Manitoba, New Brunswick, Newfoundland and Labrador, Northwest Territories, Nova Scotia, Nunavut, Ontario, Saskatchewan, Surrey, Prince Edward Island, Vancouver, Yukon

Federal government: Environment and Climate Change Canada, Natural Resources Canada, Office of the Auditor General of Canada, Transport Canada

Utilities and the energy sector: Advanced Biofuels Canada, BC Hydro, Canadian Association of Petroleum Producers, Canadian Energy Centre, Canadian Gas Association, Kinder Morgan Canada, National Energy Board, Ontario Energy Board, Power Workers' Union, Spectra Energy, Western Canada Biodiesel Association

Non-profit and research: Alberta Innovates, Canadian Climate Choices Institute, Carbon Management Canada, Clean Energy Canada, Climate Action Network Canada, David Suzuki Foundation, Ecofiscal Commission, Electric Mobility Canada, Electric Power Research Institute, Emissions Reduction Alberta, Environmental Defense Fund, Equiterre, International Council on Clean Transportation, International Institute for Sustainable Development, National Roundtable on the Environment and the Economy, Pembina Institute, Pacific Institute for Climate Solutions, World Animal Protection

Executive summary

Project overview

The Government of Northwest Territories (GNWT) Department of Infrastructure is reviewing territorial energy and climate change strategies. This project will inform this process by answering the following two questions:

- What is the gap between where greenhouse gas emissions are headed in response to existing policies and emission reduction targets in the NWT?
- What are the most economically efficient technologies, fuels and actions that could close the gap to the NWT's 2030 target of 1,094 ktCO_2e (a 30% reduction below 2005 levels)[1] and net zero emissions[2] in 2050?

Approach

To help answer these questions, Navius developed customized versions of two models to characterize the NWT's energy-economy, each with unique strengths:

- **gTech** provides a comprehensive representation of all economic activity, energy use and greenhouse gas emissions in the NWT and rest of North America.
- **IESD** provides additional insights into the optimal way of supplying electricity within the NWT's isolated communities, capturing both (1) short-term dynamics of hourly supply and demand and (2) long-term improvements to technologies like wind, solar and storage.

We simulated four policy scenarios in this analysis:

1. **Current policies:** The current policy forecast describes how the NWT's energy-economy is likely to evolve in the absence of new policies. This scenario captures substantive policies and projects on the books as of March 2022 (e.g., carbon pricing increasing to \$170/tCO_2e by 2030, energy efficiency regulations, territorial subsidies). It excludes potential projects being

[1] Government of Northwest Territories. *2030 NWT Climate Change Strategic Framework.* Available from: https://www.enr.gov.nt.ca/sites/enr/files/resources/128-climate_change_strategic_framework_web.pdf

[2] Defined as a virtual elimination of all energy-related emissions tracked by the National Inventory Report (NIR).

considered by the GNWT that are not yet finalized (e.g., the transmission line from Providence and Kakisa, liquified natural gas projects in Fort Simpson and Tuktoyaktuk, and the Taltson Hydro Expansion Project). In other words, additional transmission lines between grids and new and expanded hydro were not modeled in this analysis. Similarly, small modular nuclear reactors (SMnRs) were excluded as they are as much a political decision as an economic one.

2. **NWT target pathway:** The NWT achieves its existing 2030 target (30% below 2005 levels) and net zero emissions in 2050. Net zero is defined as a virtual elimination of all energy-related greenhouse gas emissions.
3. **NWT target excuding industry pathway:** The NWT achieves its 2030 target and net zero emissions in 2050 excluding the mining and oil and gas sectors.
4. **Federal target pathway:** The NWT achieves the federal 2030 target (simulated at 45% below 2005 levels) and net zero emissions by 2050.

Simulating developments in the NWT's economy out to 2050 is fundamentally uncertain. To quantify key elements of this uncertainty, we conducted a sensitivity analysis that considered changes to mining activity, the cost of emerging low-carbon technologies and the level of climate mitigation policy in the rest of North America.

A detailed explanation of the approach, including an introduction to the gTech and IESD models, can be found in section 2, and frequently asked modelling questions are answered in the next section.

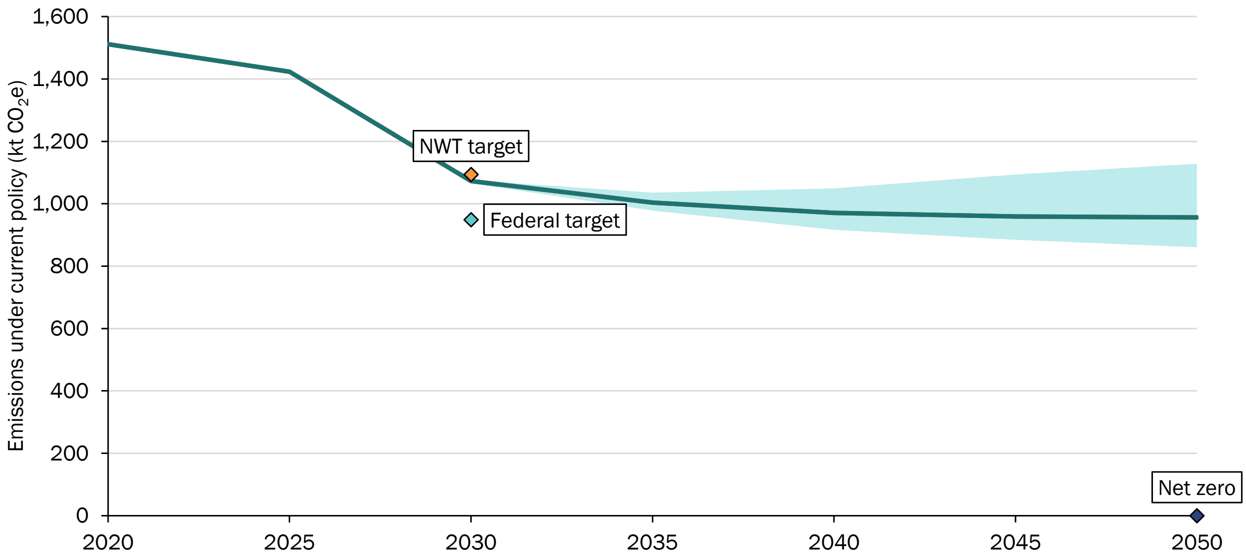
Key findings

Key findings from this analysis include:

1. **The NWT is on track to achieving its 2030 emissions target, but achieving a 45% decline relative to 2005 levels (in line with federal commitments) would require additional emissions reduction efforts.** In response to current policies, GHG emissions decline from 1,511 ktCO_2e in 2020 to 1,073 ktCO_2e in 2030 (see Figure 1). Much of this decline is due to an expected reduction in mining activity during the 2020s.

   This analysis shows that the NWT is on track to achieving its target of 1,094 ktCO_2e in 2030. However, additional emissions reductions (124 ktCO_2e) would be required to achieve reductions in line with federal commitments of 45% by 2030 (949 ktCO_2e).

Figure 1: Territorial emissions to 2050



Source: Navius analysis using gTech-IESD. Scenarios shown: Current policy; shaded area represents range observed under all simulated sensitivities.

2. **The gap to net zero in 2050 is large and would require strong policy to close.** The NWT's emissions start to flatline after 2030 as existing policies run their course. By 2050, emissions reach between 860 and 1,128 ktCO_2e. The implication is that strong and compulsory policies will be required to close this gap, requiring an effective carbon price of between \$300 and \$700 per tonne (i.e., a carbon price of that level or a comparable suite of regulatory policies that achieve the same effect).

3. **This analysis suggests that policymakers seeking to achieve substantial greenhouse gas reductions in the NWT should focus on four technological pathways:**

   a. Maximizing the use of **biomass** for building heat. Biomass heating with wood stoves and pellet furnaces is an important emissions reduction option across all net zero scenarios. Consumption of biomass increases by 24-69% relative to current levels in a net zero future.

   b. **Electrifying** end-uses where possible, with a particular emphasis on light and medium-duty vehicles. These types of vehicles are particularly amenable to going electric thanks to improvements in battery performance and cost. Plug-in electric vehicles account for 11-71% of all light-duty vehicles on the road by 2050 in a net zero future. Heat pumps could also play an important role in the NWT, accounting for 28-49% of space heat load by 2050 under net zero.

c. Boosting **low carbon electricity supply** from wind and solar photovoltaic (PV) coupled with battery storage. Under net zero, utility electricity demand increases by 57-131% relative to current levels. This analysis finds that the most cost-effective way to meet this demand is by higher capacity utilization of existing hydro assets coupled with deployment of wind, solar and batteries. The adoption of renewables is accelerated by declining technology costs, the high cost of importing fossil fuels and the flexibility offered by battery storage.

d. Blending **biofuels** into the diesel pool used for transport, heat, and electricity. Biofuels like renewable diesel can be manufactured with cold-weather operating characteristics similar to conventional diesel and can be used in existing equipment without modification. Under the scenarios in which the NWT achieves net zero, biofuels start being blended into the diesel and gasoline pools between 2030 and 2040 depending on the pathway scenario, and by 2050 biofuels account for virtually all of the diesel pool in the territory.

4. This analysis focuses on reducing emissions in the NWT. Policymakers in the NWT could also investigate options for **carbon dioxide removals** (CDR) to remove carbon from the atmosphere and store it in geological, terrestrial, or ocean reservoirs. To achieve net zero, CDR is necessary to counterbalance any residual emissions (e.g., from hard to decarbonize sources). The impact of CDR on the cost of achieving net zero emissions in the NWT is discussed in section 5.2.

Opportunities for future research

This study provides a preliminary assessment of options for achieving substantial greenhouse gas reductions in the NWT. Future work could:

- **Explore additional technological pathways to emissions reductions.** There are multiple ways to reach net zero emissions. While this analysis explored many emissions reduction options in the NWT, additional research could:
    - Assess emissions reduction opportunities at specific mines or types of mines. This analysis was economy-wide and relied on generalized information to characterize the mining sector. Future research could explore, to a greater extent, how specific mines use energy and their options available for decarbonizing their energy supply and use.

  - Investigate the potential for additional electricity and heat supply options, including new/expanded hydro facilities and the deployment of small modular nuclear reactors in the territories.
  - Examine the impact of grid connections within the NWT and/or to other jurisdictions. This analysis simulated eight grids in the NWT, where each grid is treated as an isolated, self-sufficient unit. Grid connections within the NWT, or grid connections between the NWT and Alberta, could make greenhouse gas reductions less costly to achieve.
  - Further explore the implications of land use, land use change and forestry emissions for achieving net zero in the NWT, including the potential to sequester CO_2 via nature-based solutions.

- **Identify policies to achieve territorial emissions targets and other objectives.** This analysis identified promising technologies, fuels and actions that could be targeted by climate policy to help the NWT achieve its targets. However, it is not an analysis of policy options. For example, to further expand biomass use in buildings, the NWT could implement any number of policies with a range of different impacts (from subsidies to carbon pricing to regulations). As a starting point, section 6 of this report provides an overview of the types of policies that could be used or expanded to achieve substantial greenhouse gas reductions in the territory. The GNWT may have other objectives related to economic development, equity and other factors that may influence its ideal policy mix.

- **Update the current policy forecast.** Determining whether the NWT is on track to meeting its targets requires updating projections to reflect changes to current policies (either territorial or federal, such as the *Emissions Reduction Plan*), revised historical energy and emissions data, and expectations for the cost of emerging low carbon technologies.

- **Further explore the costs and benefits of substantial emissions reductions in the territory.** Future analyses could quantify investments in low carbon technologies and actions, as well as identify the direct growth in jobs and GDP from the development of the NWT's low carbon economy.

Sommaire

Aperçu du projet

Le ministère de l'Infrastructure du gouvernement des Territoires du Nord-Ouest (GTNO) revoit actuellement les stratégies énergétiques et climatiques territoriales. Le présent projet éclairera ce processus en répondant à deux questions :

- Comment la trajectoire des émissions de gaz à effet de serre (GES) selon les politiques actuelles se compare-t-elle aux cibles de réduction des émissions aux TNO?
- Quels sont les combustibles, technologies et mesures les plus rentables qui permettraient aux TNO d'atteindre leur cible de 1 094 kt éq. CO2 pour 2030 (30 % sous le niveau de 2005)[3] et la carboneutralité[4] en 2050?

Approche

Pour y arriver, Navius a adapté deux modèles pour caractériser l'économie énergétique des TNO, chacun ayant ses forces particulières :

- Le modèle **gTech** offre une représentation exhaustive de l'ensemble de l'activité économique, de la consommation d'énergie et des émissions de GES aux TNO et dans le reste de l'Amérique du Nord.
- Le modèle **IESD** fournit d'autres perspectives sur les meilleures formes d'approvisionnement en électricité dans les collectivités isolées des TNO, à la fois sur 1) la dynamique horaire à court terme de l'offre et de la demande et 2) l'amélioration à long terme des technologies comme l'éolien, le solaire et le stockage.

Notre analyse a consisté en une simulation de quatre scénarios de politiques :

1. **Politiques actuelles :** Ce scénario décrit l'évolution probable de l'économie énergétique des TNO en l'absence de nouvelles politiques. Il tient compte des politiques et projets importants prévus en mars 2022 (p. ex. tarification du

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[3] Gouvernement des Territoires du Nord-Ouest Cadre stratégique sur le changement climatique des TNO pour 2030 : https://www.enr.gov.nt.ca/sites/enr/files/resources/128-climate_change_strategic_framework_web.pdf

[4] Élimination presque complète de toutes les émissions liées à l'énergie suivies par le Rapport d'inventaire national (RIN).

carbone passant à 170 $/t. éq. CO_2 d'ici 2030, réglementation sur l'efficacité énergétique, subventions territoriales), mais exclut les projets envisagés par le GTNO qui ne sont pas encore au point (p ex. ligne de transport vers Fort Providence et Kakisa, projets de gaz naturel liquéfié de Fort Simpson et Tuktoyaktuk, projet d'agrandissement de la centrale hydroélectrique Taltson). Autrement dit, les projets de lignes de transport supplémentaires entre les réseaux et de construction ou d'agrandissement de centrales hydroélectriques n'ont pas été modélisés dans cette analyse. De la même manière, les petits réacteurs nucléaires modulaires ont été exclus, car ils relèvent d'un choix politique autant qu'économique

2. **Trajectoire vers la cible des TNO :** Les TNO atteignent leur cible pour 2030 (30 % sous le niveau de 2005) et la carboneutralité en 2050. On définit la carboneutralité comme l'élimination presque complète de toutes les émissions liées à l'énergie.

3. **Trajectoire vers la cible des TNO à l'exclusion de l'industrie :** Les TNO atteignent leur cible pour 2030 et la carboneutralité en 2050, à l'exclusion des secteurs minier, pétrolier et gazier.

4. **Trajectoire vers la cible fédérale :** Les TNO atteignent la cible fédérale pour 2030 (simulée à 45 % sous le niveau de 2005) et la carboneutralité en 2050.

La simulation de l'évolution de l'économie des TNO jusqu'en 2050 est empreinte d'incertitude. Pour quantifier les principales composantes de cette incertitude, nous avons mené une analyse de sensibilité tenant compte de l'évolution de l'activité minière, du coût des nouvelles technologies sobres en carbone et de la nature des politiques climatiques adoptées dans le reste de l'Amérique du Nord.

On trouvera à la section 2 une explication détaillée de l'approche (dont une présentation des modèles gTech et IESD) et à la prochaine section, les réponses aux questions les plus fréquentes sur la modélisation.

Principales constatations

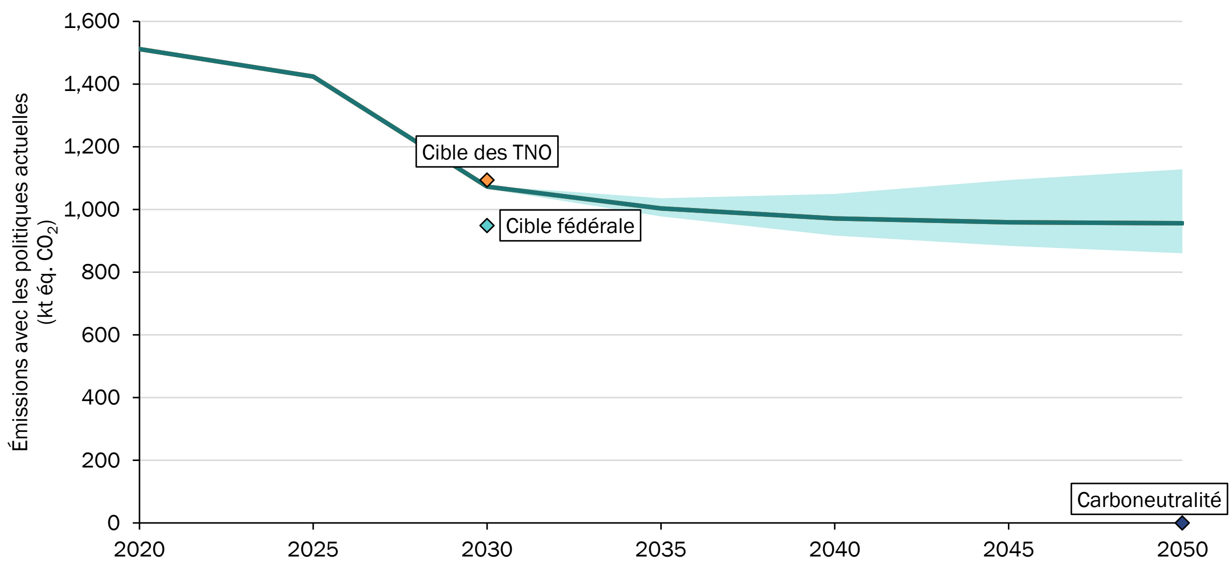
Voici les principales conclusions de cette analyse :

1. **Les TNO sont sur la bonne voie pour atteindre leur cible d'émissions en 2030, mais une diminution de 45 % par rapport à 2005 (conformément aux engagements fédéraux) exigerait des efforts supplémentaires.** Avec les politiques actuelles, les émissions de GES passent de 1 511 kt éq. CO_2 en

2020 à 1 073 kt éq. CO_2 en 2030 (voir figure 1). Cette diminution est due en grande partie à un ralentissement attendu des activités d'exploitation minière dans les années 2020.

L'analyse montre que les TNO sont en voie d'atteindre leur cible de 1 094 kt éq. CO_2 en 2030. Cependant, il faudrait des réductions supplémentaires (de 124 kt éq. CO_2) pour respecter les engagements fédéraux (45 % d'ici 2030, soit 949 kt éq. CO_2)

Figure 2: Émissions territoriales d'ici 2050 aux TNO



Source : Analyse de Navius avec gTech-IESD. Scénarios montrés: politiques actuelles; la zone ombrée représente la fourchette pour toutes les sensibilités simulées.

2. **L'écart par rapport à la carboneutralité en 2050 est grand, et il faudrait des politiques fortes pour le combler.** Les émissions des TNO commencent à se stabiliser après 2030, les politiques actuelles ayant eu l'effet escompté. D'ici 2050, les émissions atteignent 860 à 1 128 kt éq. CO_2. On peut en déduire qu'il faudra des politiques rigoureuses et obligatoires pour combler l'écart, imposant un prix effectif du carbone de 300 \$ à 700 \$ la tonne (sous la forme d'une tarification du carbone ou d'une série de politiques réglementaires ayant le même effet).

3. **L'analyse laisse croire que les décideurs souhaitant une réduction importante des GES aux TNO devraient se concentrer sur quatre trajectoires technologiques :**

a. Maximiser l'utilisation de la **biomasse** pour le chauffage des bâtiments. L'utilisation de poêles à bois et de chaudières à granules pour le chauffage à biomasse est un important moyen de réduire les émissions dans tous les scénarios de carboneutralité. La consommation de biomasse augmente de 24 à 69 % par rapport au niveau actuel dans un avenir carboneutre.
b. **Électrifier** les utilisations finales lorsque c'est possible, surtout les véhicules légers et moyens. Ces derniers sont particulièrement adaptés à cette fin étant donné l'efficacité croissante des batteries, de moins en moins chères. Dans un avenir carboneutre, les véhicules branchables comptent pour 11 à 17 % de tous les véhicules légers en service en 2050. Dans une perspective de carboneutralité, les thermopompes pourraient aussi jouer un rôle important aux TNO, fournissant 28 à 49 % du chauffage d'ici 2050.
c. Augmenter **l'approvisionnement en électricité sobre en carbone** d'origine éolienne et solaire, de même que le stockage d'énergie. Dans une trajectoire de carboneutralité, la demande en services publics d'électricité augmente de 57 à 131 % par rapport au niveau actuel. Selon cette analyse, la façon la plus efficace économiquement de répondre à cette demande est d'optimiser la capacité de production des installations hydroélectriques actuelles tout en développant l'éolien, le solaire et le stockage. L'adoption des énergies renouvelables est facilitée par la diminution des coûts de la technologie, le coût élevé de l'importation de combustibles fossiles et la souplesse apportée par le stockage sur batterie.
d. Intégrer des **biocarburants** dans le diesel utilisé pour le transport, le chauffage et l'électricité. Il est possible de donner aux biocarburants comme le diesel renouvelable des caractéristiques de fonctionnement par temps froid similaires à celles du diesel classique pour pouvoir s'en servir dans l'équipement actuel sans modifier ce dernier. Dans les scénarios où les TNO arrivent à la carboneutralité, les biocarburants commencent à s'ajouter au diesel et à l'essence entre 2030 et 2040 selon la trajectoire, et d'ici 2050, ils composent la presque totalité de tout le diesel du territoire.

4. Cette analyse porte sur la réduction des émissions aux TNO. Les décideurs du territoire pourraient aussi étudier des solutions **d'élimination du dioxyde de carbone** pour retirer ce dernier de l'atmosphère et le stocker dans des réservoirs géologiques, terrestres ou océaniques. Pour atteindre la carboneutralité, ces solutions sont nécessaires pour compenser toute émission

résiduelle (p. ex. de sources difficiles à décarboner). L'effet de l'élimination du dioxyde de carbone sur l'atteinte de la carboneutralité aux TNO est analysé à la section 5.2.

Avenues de recherche

La présente étude constitue une analyse préliminaire des options de réduction substantielle des GES aux TNO. Des travaux subséquents pourraient approfondir les points suivants :

- **Explorer d'autres trajectoires technologiques de réduction des émissions.** Il y a plus d'une façon d'atteindre la carboneutralité. Si la présente analyse a exploré de nombreuses options de réduction des émissions aux TNO, voici sur quoi pourraient porter les autres études :
  - Évaluer les possibilités de réduction des émissions dans certaines mines ou catégories de mines. La présente analyse portait sur l'ensemble de l'économie et reposait sur des données générales pour caractériser le secteur minier. D'autres études pourraient explorer plus avant la façon dont des mines données consomment l'énergie ainsi que leurs options de décarbonation.
  - Explorer le potentiel de nouvelles options pour l'électricité et le chauffage, comme la construction ou l'agrandissement de centrales hydroélectriques et le déploiement de petits réacteurs nucléaires modulaires aux TNO.
  - Analyser les répercussions des connexions entre les réseaux des TNO ou avec ceux d'autres territoires. La présente analyse a simulé huit réseaux aux TNO, chacun pris isolément et traité comme une unité autosuffisante. Les connexions entre les réseaux aux TNO ou entre ceux des TNO et de l'Alberta pourraient diminuer les coûts de la réduction des GES.
  - Explorer plus avant le rôle de l'utilisation des terres, de l'évolution de cette utilisation et des émissions forestières dans la carboneutralité aux TNO, notamment le potentiel de séquestration du CO_2 par des solutions naturelles.
- **Définir des politiques pour atteindre les cibles d'émissions territoriales et d'autres objectifs.** La présente étude a identifié des technologies, des mesures et des combustibles prometteurs que pourraient cibler les TNO dans leurs politiques climatiques. Elle ne constitue cependant pas une analyse des différentes politiques possibles. Par exemple, pour développer l'utilisation de la biomasse dans les bâtiments, les TNO pourraient adopter plusieurs politiques aux répercussions diverses (des subventions à la tarification du carbone en passant par la réglementation). La section 6 du présent rapport peut servir de point de départ :

elle survole les types de politiques dont l'adoption ou l'expansion pourraient contribuer à une réduction importante des GES. Le GTNO pourrait avoir d'autres objectifs pour les facteurs comme le développement économique et l'équité susceptibles d'influer sur son bouquet de politiques idéal.

- **Mettre à jour les prévisions en fonction des politiques.** Pour savoir si les TNO sont sur la bonne voie pour atteindre leur cible, il faut actualiser les projections pour refléter les nouvelles politiques (territoriales ou fédérales, comme le Plan de réduction des émissions), les données historiques révisées sur l'énergie et les émissions, ainsi que les coûts projetés des nouvelles technologies sobres en carbone.
- **Approfondir l'exploration des coûts et des avantages d'une réduction importante des GES dans le territoire.** De futures analyses pourraient quantifier les investissements dans les technologies et les mesures sobres en carbone, et préciser la croissance directe de l'emploi et du PIB qui résulterait d'une économie verte.

Frequently asked modeling questions

1. **Why do NWT's GHG emissions for 2020 in the modelling slightly differ from the National Inventory Report?**
   Simulated emissions differ from the NIR for two reasons. First, building GHGs were aligned with the NWT Fuel Tax Data rather than the NIR as requested by the GNWT. Second, gTech is designed to capture medium and long-term trends. As such, it doesn't capture short-term shocks like those induced by pandemic lockdowns in 2020.
2. **Why are some energy infrastructure projects such as the Taltson Hydro Expansion not included in the modeling?** Some projects that the GNWT is currently advancing were intentionally not included in this analysis. For example, the transmission line to Fort Providence and Kakisa, liquified natural gas projects in Fort Simpson and Tuktoyaktuk, and the Taltson Hydro Expansion Project. This analysis only considers projects where there is certainty that they will advance and where we have a good estimate of the project cost (i.e., there is limited uncertainty around the project).
3. **Why were geothermal resources not considered in the analysis?**
   We did not have data available to characterize the potential for geothermal resources in the NWT.
4. **Why is biomass energy deemed not contributing to climate change?**
   Biomass heating through wood stoves or pellet furnaces is generally considered a low or zero carbon heating option, depending on its source and the way in which it is harvested. Biogenic CO_2 is treated as carbon neutral in this analysis, aligned with methodology established by UNFCCC.[5]
5. **How are emissions from liquid biofuels accounted for in the modeling?**
   Biogenic CO_2 is treated as carbon neutral in this analysis. Emissions from the production of liquid biofuels are accounted for in the modeling, though note that production occurs outside the NWT.
6. **Why are SMnRs not included in the modeling?**
   The decision to pursue small modular reactors (SMnRs) is as much a political

[5] UNFCC. *Annex 18 Definition of Renewable Biomass.* Available from: https://cdm.unfccc.int/EB/023/eb23_repan18.pdf

decision as an economic one. Future analysis could assess the potential of this emerging technology to provide heat and power for communities and mines.

7. **Why is the modelling seeing very limited development of hydrogen-based technologies?**
While we see some adoption of hydrogen in the transportation sector, results suggest electrification and biofuels remain more competitive options for decarbonization in the NWT. The primary option for producing hydrogen in the NWT is from renewable electricity, so it generally makes more economic sense to use the electricity directly. Results from this analysis indicate that the cost of hydrogen production via electrolysis is over $100/GJ by 2050 in many scenarios, which impacts its attractiveness as a fuel. Hydrogen adoption is outlined in detail in section 4.5.

8. **Are nature-based solutions included in the modeling?**
Nature-based solutions are discussed in section 4.6.1. Because limited information on its potential in the NWT is available, it was not included in the pathways scenarios (this presents an opportunity for future research). However, we do discuss a scenario with carbon dioxide removals available (including nature-based solutions) nationally to capture its potential impacts on GDP, investment, and jobs in the NWT (see section 5.2).

9. **Are costs associated with upgrades to transmission, distribution systems, and customer facilities related to increased electrification of end-uses (e.g. electric vehicles) included in the modeling?**
These costs are accounted for.

10. **What are direct air capture technologies and are these included in the modeling?**
Direct air capture (DAC) uses chemical reactions to pull CO_2 out of air. When air moves over these chemicals, they react with and trap CO_2. Once CO_2 is captured from the atmosphere, heat is typically applied to release it from the solvent or sorbent. Direct air capture technologies are described in more detail in section 4.6.2. While DAC is not included in the pathways scenarios, we do discuss a scenario with carbon dioxide removals available (including DAC) nationally to capture its potential impacts on GDP, investment, and jobs in the NWT (see section 5.2).

11. **What are the technologies included under battery energy storage system?**
Lithium-ion batteries. See section 2.3.3 for additional details.

12. **Can heat pumps really work in the North? What are the assumptions/findings about heat pumps? Does the model assume that heat pumps are used for AC in summer?**

Heat pumps in the NWT were informed by a feasibility study conducted in the Yukon.[6] This study highlights that heat pumps are feasible in the North, and informs the efficiency used in this analysis. Despite the very low efficiency in the North, the analysis finds that heat pumps are a promising option in the NWT (see section 4.3.1). We do not assume heat pumps can be used for AC in the summer. Due to the few heating degree days compared to cooling degree days in Yellowknife, cooling load would be a very small portion of overall electric load and would have a marginal impact on the results.

13. **Are the EV power requirements adjusted for NWT specific circumstances, including winter conditions?**
    Battery electric vehicles lose range and require additional power in cooler temperatures.[7] For this analysis we did not adjust the efficiency for NWT-specific conditions, but this is an area that could be examined in the future. The implication is that electricity consumption for transport may be higher in the net zero scenarios than reported.
14. **What are the assumptions in terms of energy efficiency and conservation improvements over time, if any?**
    Energy efficiency is a result of the modeling, not an input assumption. gTech solves for energy use endogenously based on various parameters like the fuel cost, technology cost, policy constraints (i.e., flexible regulations like carbon pricing or mandates like building codes) and consumer preferences.
15. **What is the potential for CCUS in the NWT?**
    Carbon capture and storage (CCS) was not included in this analysis because it benefits from economies of scale that would likely be inappropriate for potential demand for the technology in the NWT.
16. **Why do the net zero scenarios result in liquid biofuels being adopted in later years of the projections?**
    Liquid biofuels are a costly abatement option compared to others adopted in the net zero scenarios. Therefore, we only see this technology adopted in the territory in the pathways scenarios when emissions are reduced close to net-zero by mid-century. When the NWT achieves net zero emissions, the shadow carbon price reaches between \$300/tCO_2e and \$700/tCO_2e, meaning that any

[6] Government of Yukon. (2021). *Air Source Heat Pump Pilot Project Technical Report.* Available from: https://yukon.ca/sites/yukon.ca/files/emr/emr-air-source-heat-pump-pilot-project-technical-report.pdf

[7] CBC. (2023). *Electric vehicles lose up to 30% range when temperatures dip below freezing, study finds.* Available from: https://www.cbc.ca/news/canada/sudbury/electric-vehicle-cold-range-1.6738892

abatement option cheaper than this gets adopted. In this scenario, biofuels become economic.

Contents

1. Introduction

Understanding the cost of greenhouse gas abatement options is an important step in developing climate policy because it enables decision makers to direct policy efforts towards areas that reduce emissions at the lowest cost.

The Government of Northwest Territories (GNWT) Department of Infrastructure is in the process of reviewing their territorial energy and climate strategies.

This project aims to inform this process by answering the following two questions:

- First, what is the gap between where greenhouse gas emissions are headed in response to existing policies and emission reduction targets in the Northwest Territories (NWT)?
- Second, what are the most economically efficient technologies, fuels and actions that could help close the gap to the NWT's 2030 target and net zero emissions in 2050?

Navius developed customized versions of two models to characterize the Northwest Territories' (NWT) energy-economy, each with unique strengths:

- **gTech** provides a comprehensive representation of all economic activity, energy consumption and greenhouse gas emissions.
- **IESD** provides additional insights into the optimal way of supplying electricity, capturing both (1) short-term dynamics of hourly supply and demand and (2) long-term improvements to technologies like wind, solar and storage.

In this report, we describe how we applied these models to explore how the NWT's energy-economy could evolve in response to existing policies, as well as potential pathways to deep emissions reductions. The report is structured as follows:

- Section 2 outlines the approach of the analysis.
- Sections 3-5 present results, including emissions trajectories in response to current policies and pathways to deep emissions reductions.
- Section 6 provides a qualitative overview of policy options that could be employed to achieve territorial objectives.

2. Approach

This section outlines the approach taken for this analysis, covering an introduction to Navius' modeling toolkit, key gTech and IESD assumptions, and an overview of scenarios simulated.

2.1. Introduction to our modeling toolkit

Navius has developed customized versions of two models to characterize the NWT's energy-economy, each with unique strengths:

- **gTech** provides a comprehensive representation of all economic activity, energy consumption and greenhouse gas emissions.
- **IESD** provides additional insights into the optimal way of supplying electricity, capturing both (1) short-term dynamics of hourly supply and demand and (2) long-term improvements to technologies like wind, solar and storage.

Sections 2.1.1 and 2.1.2 introduces the gTech and IESD models.

2.1.1. Introduction to gTech

Canada's energy-economy is complex. Energy consumption, which is the main driver of anthropogenic greenhouse gas emissions, results from the decisions made by millions of Canadians. For example, households must choose what type of vehicles they will buy and how to heat their homes; industry must decide whether to install technologies that might cost more but consume less energy; municipalities must determine whether to expand transit service; and investors need to decide whether to invest their money in Canada or somewhere else.

All levels of government in Canada have implemented policies designed to encourage or require firms and consumers to take actions to reduce their emissions. Achieving provincial, territorial, and national targets will likely require strengthening existing policies and/or implementing new policies that result in additional emission reduction activities.

Existing policies and those required to achieve targets will have effects throughout the economy and interact with each other. For example, the federal vehicle emission standard and carbon pricing efforts seek to reduce greenhouse gas emissions from passenger vehicles, as do a variety of provincial and territorial policies (such as BC's low carbon fuel standard, the federal clean fuel regulations and zero-emission vehicle mandates in Québec and proposed in BC). The interactive effects among such policies can be complex. The economic effects of all federal, territorial and provincial climate initiatives implemented together are even more complex.

Estimating the regional, sectoral, technological and economic impacts of achieving emissions and energy targets therefore requires a modeling framework that captures the complexity of this energy-economic system.

gTech provides a comprehensive representation of all economic activity, energy consumption and greenhouse gas emissions in Canada. gTech is unique among energy-economy models because it combines features that are typically only found in separate models:

- A realistic representation of how households and firms select technologies and processes that affect their energy consumption and greenhouse gas emissions;
- An exhaustive accounting of the economy at large, including how provinces and territories interact with each other and the rest of the world; and
- A detailed representation of energy supply, including liquid fuel (crude oil and biofuel), gaseous fuel (natural gas and renewable natural gas), hydrogen and electricity.

Simulating technological choice

Technological choice is one of the most critical decisions that influence greenhouse gas emissions in Canada. For example, if a household chooses to purchase an electric vehicle over a gasoline car, that decision will reduce their emissions. Similarly, if a mining facility chooses to electrify its operations, that decision reduces its emissions.

gTech provides a detailed accounting of the types of energy-related technologies available to households and businesses. In total, gTech includes over 300 technologies across more than 50 end-uses (e.g., light-duty vehicle travel, residential space heating, industrial process heat, management of agricultural manure).

Naturally, technological choice is influenced by many factors. Table 1 summarizes key factors that influence technological choice and the extent to which these factors are included in gTech.

Table 1: Technological choice dynamics captured by gTech

Criteria	Description
Purchasing (capital) costs	Purchasing costs are simply the upfront cost of purchasing a technology. Every technology in gTech has a unique capital cost that is based on research conducted by Navius. Everything else being equal (which is rarely the case), households and firms prefer technologies with a lower purchasing cost.
Energy costs	Energy costs are a function of two factors: (1) the price for energy (e.g., cents per litre of gasoline) and (2) the energy requirements of an individual technology (e.g., a vehicle's fuel economy, measured in litres per 100 km). In gTech, the energy requirements for a given technology are fixed, but the price for energy is determined by the model. The method of "solving" for energy prices is discussed in more detail below.
Time preference of capital	Most technologies have both a purchasing cost as well as an energy cost. Households and businesses must generally incur a technology's purchasing cost before they incur the energy costs. In other words, a household will buy a vehicle before it needs to be fueled. As such, there is a tradeoff between near-term capital costs and long-term energy costs. gTech represents this tradeoff using a "discount rate". Discount rates are analogous to the interest rate used for a loan. The question then becomes: is a household willing to incur greater upfront costs to enable energy or emissions savings in the future? Many energy modelers use a "financial" discount rate (commonly between 5% and 10%). However, given the objective of forecasting how households and firms are likely to respond to climate policy, gTech employs behaviourally realistic discount rates of between 8% and 25% to simulate technological choice. Research consistently shows that households and firms do not make decisions using a financial discount rate, but rather use significantly higher rates[8]. The implication is that using a financial discount rate would overvalue future savings relative to revealed behaviour and provide a poor forecast of household and firm decisions.
Technology specific preferences	In addition to preferences around near-term and long-term costs, households (and even firms) exhibit "preferences" towards certain types of technologies. These preferences are often so strong that they can overwhelm most other factors (including financial ones). For example, buyers of passenger vehicles can be concerned about the driving range and available charging infrastructure of vehicles, some may worry about the risk of buying new technology, and some may see the vehicle as a "status symbol" that they value[9]. gTech quantifies these technology-specific preferences as "non-financial" costs, which are added to the technology choice algorithm.

[8] For example, see: Rivers, N., & Jaccard, M. (2006). Useful models for simulating policies to induce technological change. *Energy policy*, *34*(15), 2038-2047; Axsen, J., Mountain, D.C., Jaccard, M., 2009. Combining stated and revealed choice research to simulate the neighbor effect: The case of hybrid-electric vehicles. Resource and Energy Economics 31, 221-238.

[9] Kormos, C., Axsen, J., Long, Z., Goldberg, S., 2019. Latent demand for zero-emissions vehicles in Canada (Part 2): Insights from a stated choice experiment. Transportation Research Part D: Transport and Environment 67, 685-702.

Criteria	Description
The diverse nature of Canadians	Canadians are not a homogenous group. Individuals are unique and will weigh factors differently when choosing what type of technology to purchase. For example, one household may purchase a Toyota Prius while their neighbour purchases an SUV and another takes transit. gTech uses a “market share” equation in which technologies with the lowest net costs (including all the cost dynamics described above) achieve the greatest market share, but technologies with higher net costs may still capture some market share[10]. As a technology becomes increasingly costly relative to its alternatives, that technology earns less market share.
Changing costs over time	Costs for technologies are not fixed over time. For example, the cost of electric vehicles has come down significantly over the past few years, and costs are expected to continue declining in the future[11]. Similarly, costs for many other energy efficient devices and emissions-reducing technologies have declined and are expected to continue declining. gTech accounts for whether and how costs for technologies are projected to decline over time and/or in response to cumulative production of that technology.
Policy	One of the most important drivers of technological choice is government policy. Current federal, provincial and territorial initiatives in Canada are already altering the technological choices households and firms make through various policies: (1) incentive programs, which pay for a portion of the purchasing cost of a given technology; (2) regulations, which either require a group of technologies to be purchased or prevent another group of technologies from being purchased; (3) carbon pricing, which increases fuel costs in proportion to their carbon content; (4) variations in other tax policy (e.g., whether or not to charge GST on a given technology); and (5) flexible regulations, like the federal clean fuel regulation which will create a market for compliance credits. gTech simulates the combined effects of all these policies implemented together.

[10] Rivers, N., & Jaccard, M. (2006). Useful models for simulating policies to induce technological change. *Energy policy*, *34*(15), 2038-2047.
[11] Nykvist, B., Sprei, F., & Nilsson, M. (2019). Assessing the progress toward lower priced long range battery electric vehicles. *Energy Policy*, 124, 144-155.

Understanding the macroeconomic impacts of policy

As a full macroeconomic model (specifically, a "general equilibrium model"), gTech provides insight about how policies affect the economy at large. The key macroeconomic dynamics captured by gTech are summarised in Table 2.

Table 2: Macroeconomic dynamics captured by gTech

Dynamic	Description
Comprehensive coverage of economic activity	gTech accounts for all economic activity in Canada as measured by Statistics Canada national accounts[12]. Specifically, it captures all sector activity, all gross domestic product, all trade of goods and services and the transactions that occur between households, firms and government. As such, the model provides a forecast of how government policy affects many different economic indicators, including gross domestic product, investment, household income and jobs.
Full equilibrium dynamics	gTech ensures that all markets in the model return to equilibrium (i.e., that the supply for a good or service is equal to its demand). This means that a decision made in one sector is likely to have ripple effects throughout the entire economy. For example, greater demand for electricity requires greater electricity production. In turn, greater production necessitates greater investment and demand for goods and services from the electricity sector, increasing demand for labor in construction services and ultimately leading to higher wages. The model also accounts for price effects. For example, the electricity sector can pass policy compliance costs on to households, who may alter their demand for electricity and other goods and services (e.g., by switching to technologies that consume other fuels and/or reducing consumption of other goods and services).
Sector detail	gTech provides a detailed accounting of sectors in Canada. In total, gTech simulates how policies affect over 80 sectors of the economy. Each of these sectors produces a unique good or service (e.g., the mining sector produces ore, while the trucking sector produces transport services) and requires specific inputs into production.
Labor and capital markets	Labor and capital markets must also achieve equilibrium in the model. The availability of labor can change with the "real" wage rate (i.e., the wage rate relative to the consumption level). If the real wage increases, the availability of labor increases. The model also accounts for "equilibrium unemployment".

[12] Statistics Canada. Supply and Use Tables. Available from: www150.statcan.gc.ca/n1/en/catalogue/15-602-X

Dynamic	Description
Interactions between regions	Economic activity in Canada is highly influenced by interactions among provinces/territories, with the United States and with the rest of the world. Each province and territory in the model interact with other regions via (1) the trade of goods and services, (2) capital movements, (3) government taxation and (4) various types of "transfers" between regions (e.g., the federal government provides transfers to provincial and territorial governments). The version of gTech used for this project accounts for the 10 Canadian provinces, the 3 Canadian territories, and the United States. The model simulates each of the interactions described above, and how interactions may change in response to policy.
Households	On one hand, households earn income from the economy at large. On the other, households use this income to consume different goods and services. gTech accounts for each of these dynamics, and how either change with policy.

Understanding energy supply markets

gTech accounts for all major energy supply markets, such as electricity, refined petroleum products and natural gas (though the latter is less important for the NWT). Each market is characterized by resource availability and production costs by province and territory, as well as costs and constraints (e.g., pipeline capacity) of transporting energy between regions.

Low carbon energy sources can be introduced within each fuel stream in response to policy, including renewable electricity, bioenergy and hydrogen. The model accounts for the availability and cost of bioenergy feedstocks, allowing it to provide insight about the economic effects of emission reduction policy, biofuels policy and the approval of pipelines.

gTech: The benefits of merging macroeconomics with technological detail

By merging the three features described above (technological detail, macroeconomic dynamics, and energy supply dynamics), gTech can provide extensive insight into the effects of climate and energy policy.

First, gTech can provide insights related to technological change by answering questions such as:

- How do policies affect technological adoption (e.g., how many electric vehicles are likely to be on the road in 2030)?
- How does technological adoption affect greenhouse gas emissions and energy consumption?

Second, gTech can provide insights related to macroeconomics by answering questions such as:

- How do policies affect individual sectors of the economy?
- Are households affected by the policy?
- Does the policy affect energy prices or any other price in the model (e.g., food prices)?

Third, gTech answers questions related to its energy supply modules:

- Will a policy generate more supply of renewable fuels?
- Does policy affect the cost of transporting refined petroleum products, and therefore the price of gasoline in Canada?

Finally, gTech expands our insights into areas where there is overlap between its various features:

- What is the effect of investing carbon revenue into low- and zero-carbon technologies? This question can only be answered with a model like gTech.
- What are the macroeconomic impacts of technology-focused policies (e.g., how might a zero-emissions vehicle standard impact GDP)?
- Do biofuels-focused policies affect (1) technological choice and (2) the macroeconomy?

2.1.2. Introduction to IESD

IESD estimates the impact of government policies and economic conditions on electricity demand, supply, and prices by simulating how utilities meet electric load by adding new capacity and by dispatching new and existing units on an hourly basis, including electricity storage.

The electricity supply module of IESD includes a detailed representation of the different units available to generate or store electricity in each region, including their unique costs and generation constraints. The electricity supply simulation determines new generation and storage capacity additions, hourly dispatch of each unit to meet electric load over the course of the year, GHG emissions from the electricity sector and the wholesale price for electricity.

IESD's electricity supply module is a linear programming model that simulates how the electricity sector makes capacity and dispatch decisions based on the hourly load profile, energy prices and the cost of installing and operating different units. The electricity supply module endogenously adds and dispatches electricity units such that the total costs of the electricity system are minimized, system revenues are maximized, and load in each hour is met.

Each type of electricity generation resource is characterized by its cost profile, heat rate, and maximum capacity utilization. The value provided by storage technologies and their possible revenue streams are reflected by the extent to which they can minimize system costs relative to other generation technologies. The model can simulate specific policy decisions that may promote or constrain the use of a given technology (i.e., a portfolio standard that requires renewable energy).

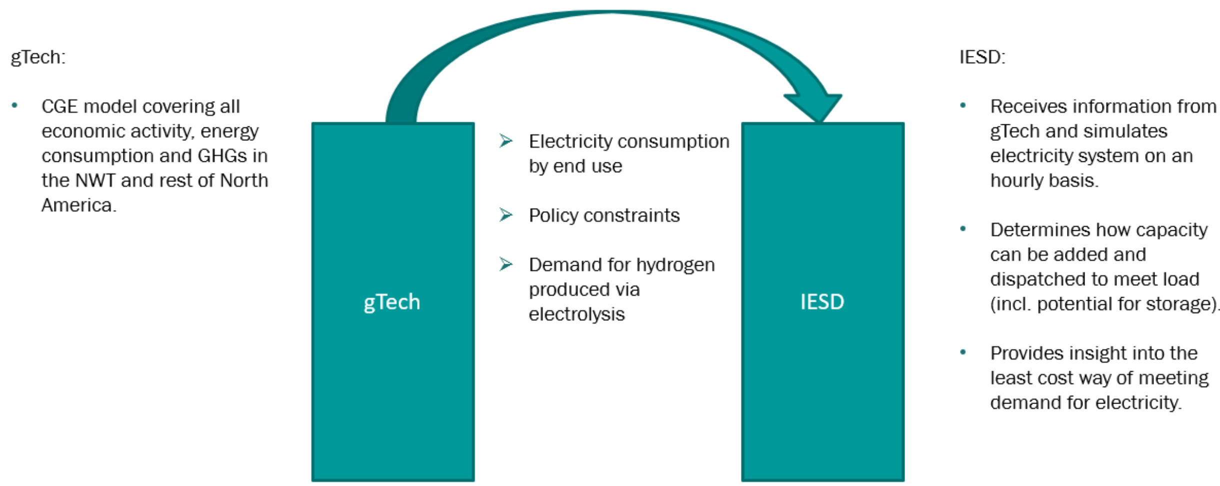
IESD supplements gTech by representing electricity system dynamics such as:

- **Hourly electricity consumption.** Electricity markets are unique from perhaps any other market in that the supply of electricity must be perfectly timed to match demand in every hour of the day and in every day of the year. This poses a challenge because electricity consumption is not consistent throughout the day or year. In IESD, each region within the NWT must have enough electricity to meet demand in any one hour.
- **Hourly generation profiles.** Some generation units can be made available upon demand, but others cannot. For example, generation from wind resources is available when the wind is blowing. Likewise, generation from solar photovoltaics is only available when the sun is up. These sources of power may or may not be available to meet demand in any given moment.
- **Identifying the potential for emerging technologies.** Because IESD represents short and long-term dynamics important to the electricity system, it can identify the potential for variable renewable electricity (VRE) sources, like wind and solar, and determine opportunities for energy storage technologies to better integrate VREs into grids. Storage technologies will become increasingly relevant as their costs decline and if more wind and solar plants are deployed. IESD can also simulate the potential for hydrogen production via electrolysis, either as a dispatchable electricity storage technology or for use in other sectors, such as transport.

- **Load shifting.** An alternative way for meeting peak load to is shift demand to off peak hours. IESD can simulate various options for load shifting, such as utility-controlled charging for electric vehicles.

Figure 3 below summarizes how IESD is linked to gTech and the inputs that are sent from gTech to IESD.

Figure 3: The gTech-IESD model



2.2. Key gTech assumptions

This section summarizes data sources and assumptions used to develop the energy-economic projections in the NWT. It begins with an overview of the various data sources which are used to calibrate gTech, followed by assumptions regarding future economic growth, energy prices, and activity in the oil, natural gas, and mining sectors.

2.2.1. Calibration sources

To characterize the NWT's energy-economy and that of the rest of Canada and the United States, gTech is calibrated to a large variety of historical data sources. Key calibration data sources for the NWT are listed below:

- Historical emissions are calibrated to Environment and Climate Change Canada's National Inventory Report (2022)[13] except for buildings (calibrated to NWT fuel tax data[14])
- Statistics Canada's Supply-Use Tables[15]
- Natural Resources Canada's Comprehensive Energy Use Database[16].
- Statistics Canada's Annual Industrial Consumption of Energy Survey[17]
- Statistics Canada's Report on Energy Supply and Demand[18]
- Navius' technology database
- GDP growth forecast provided by NWT Bureau of Statistics
- Canada's Energy Future (2021)[19]
- Various sources for future activity in the mining sector (see section 2.2.3)

Each data source is generated using different methods, so the data sources are therefore not necessarily consistent with one another. For example, expenditures on gasoline by households in Statistics Canada's Supply-Use tables may not be consistent with fuel consumption reported by Natural Resources Canada's Comprehensive Energy Use Database. Further, energy expenditures are a function of consumption and prices, so if prices vary over the course of the year, it is difficult to perfectly align consumption and expenditures.

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[13] Environment and Climate Change Canada. National Inventory Report. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html

[14] Shared by GNWT.

[15] Statistics Canada. Supply and Use Tables. Available from: www150.statcan.gc.ca/n1/en/catalogue/15-602-X

[16] Natural Resources Canada. Comprehensive Energy Use Database. Available from: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm

[17] Statistics Canada. Annual Industrial Consumption of Energy Survey. Available from: www.statcan.gc.ca

[18] Statistics Canada. Report on Energy Supply and Demand in Canada. Available from: https://www150.statcan.gc.ca/n1/en/catalogue/57-003-X

[19] Canada Energy Regulator. (2021). *Canada's Energy Future 2021.* Available from: www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/index.html

gTech's calibration routine places greater emphasis on some data sources relative to others. This approach means that gTech achieves near perfect alignment with data sources receiving the highest priority weight, but alignment starts to diverge from data sources that receive a lower weight.

For this project, the datasets that receive the highest weights are:

- Environment and Climate Change Canada's National Inventory Report except for buildings (NWT fuel tax data).
- Natural Resources Canada's Comprehensive Energy Use Database.
- Navius' technology database.
- Input from GWNT staff.

2.2.2. Economic activity

The NWT's economy is calibrated to a GDP forecast prepared by the NWT Bureau of Statistics in June 2022 (please see Table 3). gTech is designed to examine long-term trends (i.e., when the economy is in equilibrium) and not short-term business or economic cycles such as the those that occurred in response to the COVID-19 pandemic. We therefore smooth out GDP growth as shown in Table 3 below. Therefore, we align with overall historical growth rates but smooth out the economic dip of 2020. After 2030 we use an average annual growth rate of 0.9% based on conversations with GNWT.

GDP by sector is largely determined by this rate of growth and the relative capital and labour productivity of each sector (i.e., the value of goods and services produced for a given amount of capital and labour inputs). In other words, the overall economic growth is "allocated" amongst sectors based on historical data regarding the structure of the economy in Canada and the United States, and changes brought on by policy and other factors.

Table 3: GDP average annual growth rate

	2015-2020	2020-2025	2025-2030	2030-2050
GNWT forecast	-3.1%	1.1%	-2.5%	0.9%
gTech	-1.1%	-0.9%	-2.4%	0.9%

2.2.3. Mining activity

The mining sector is calibrated to a variety of data sources, including average yearly expected emissions by facility (before the implementation of additional abatement policies) and facility lifetime.

There were four active mines in the NWT between 2015 and 2020: Ekati, Diavik, Snap Lake, and Gahcho Kue. Table 4 outlines historical emissions that gTech is calibrated to from the mining sector in the NWT based on the 2022 National Inventory Report (NIR).[20]

Table 4: Historical mining emissions (kt CO_2e)

Source	2015	2016	2017	2018	2019	2020
NIR by Economic Sector	326	308	297	301	268	278

Four new soon to be active mines are also included in the current policy forecast: NICO, Prairie Creek, Pine Point, and Nechalacho. No centralized body for the collection of mining related GHGs and production information exists for the NWT.[21] We therefore rely on a variety of data sources to build up a plausible picture of future activity and emissions from new and existing mines in the NWT:

- The Mackenzie Valley Environmental Review Board, which has responsibility for approving mining operations and assessing their environmental impact.[22] Importantly, this was the source of detailed environmental impact assessment (EIA)

[20] Environment and Climate Change Canada. National Inventory Report. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html

[21] Bauer. (2017). *Northwest Territories Mineral Sector Review and Benchmarking.* Available from: https://www.ntassembly.ca/sites/assembly/files/td_27-183.pdf

[22] https://reviewboard.ca/

documents for the NICO mine[23], the Prairie Creek mine[24], the Nechalacho mine[25], and the Pine Point mine based on conversations with GNWT.

- The corporate websites of the mine owner/operators. These include the websites of Fortune Minerals (operators of NICO)[26], Nonzinc (operators of the Prairie Creek mine)[27], Osisko Metals (owners of the Pine Point mine)[28], and Vital Metals (operators of Nechalacho)[29].
- Mining Works North, a corporate body for the mining sector in the NWT.[30]
- Greenhouse Gas Reporting Program (GHGRP) – Facility Greenhouse Gas (GHG) Data[31] for existing mining emissions in the NWT adjusted down to align with the 2022 National Inventory Report (NIR) as the Facility GHG Data emissions are significantly greater.[32]

Cross-referencing these sources of data, we report starting and ending dates and the average GHG emissions of all active and soon to be active mines in the NWT in Table 5 below.

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[23] Golder Associates. (2011). *Appendix 10.II Regional Air Emission Sources.* Available from: https://reviewboard.ca/upload/project_document/EA0809-004_Appendix_10_II_Regional_Air_Emissions_Sources.PDF

[24] Canadian Zinc Corporation. (2015) *Developer's Assessment Report All Season Road Project Prairie Creek Mine.* Available form: https://reviewboard.ca/upload/project_document/EA1415-01_EA141501_Developer_s_Assessment_Report.PDF

[25] Avalon Rare Metals Inc. (2011). *Environmental Assessment.* Available from: https://reviewboard.ca/upload/project_document/EA1011001_06_Thor_Lake_Project_DAR_Environmental_Assessment__623-655_.PDF

[26] https://www.fortuneminerals.com/

[27] https://norzinc.com/

[28] https://www.osiskometals.com/

[29] https://vitalmetals.com.au/portfolio/nechalacho-project/

[30] https://miningnorthworks.com/

[31] Government of Canada. (n.d.). *Greenhouse Gas Reporting Program (GHGRP) – Facility Greenhouse Gas (GHG) Data.* Available from: https://open.canada.ca/data/en/dataset/a8ba14b7-7f23-462a-bdbb-83b0ef629823

[32] Environment and Climate Change Canada. National Inventory Report. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html

Table 5: Mining facility overview

Mine	Start year	End year	GHG emissions (kt CO_2e/year)
Ekati		2030	134
Diavik[33]		2025	116
Snap Lake		2017	76
Gacho Kue		2030	75
NICO[34]	2027	2046	97.6
Prairie Creek	2025	2046	32.6
Pine Point	2025	2036	65
Nechalacho	2029		48.5

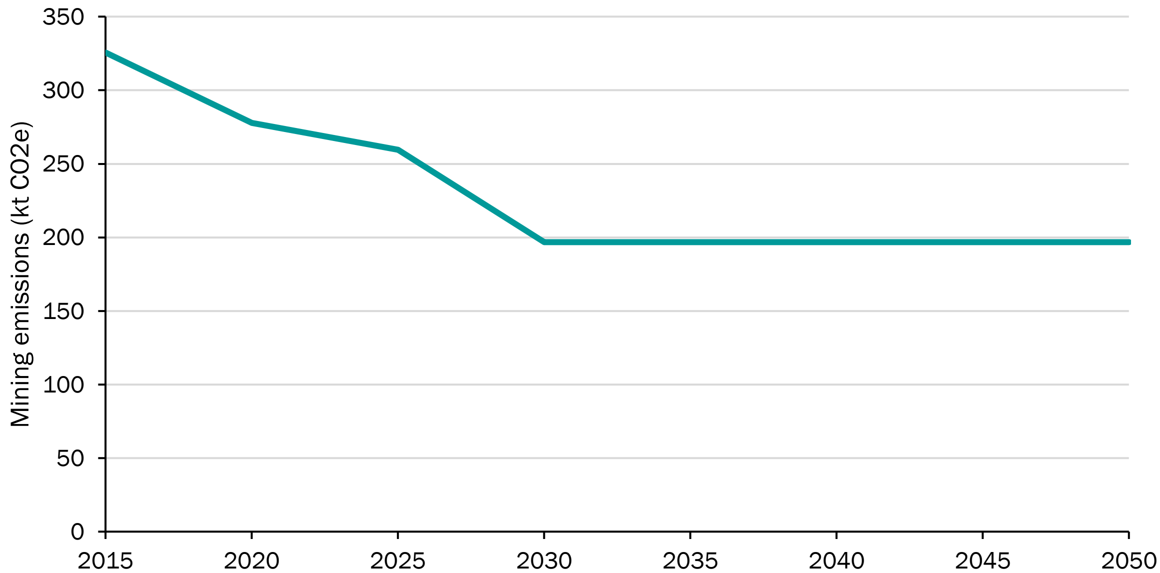
Figure 4 shows how total mining emissions would change over time in response to the facility information identified above. Due to the potential for new mines to be developed that are not yet in advanced planning phases, activity is held constant after 2030.

To account for uncertainty in future mining activity, we conduct a sensitivity analysis to explore the impact of alternative growth rates after 2030 described in section 2.4.2.

[33] For Diavik, this is a consolidated average for three separate mines.

[34] For NICO, Prairie Creek, Pine Point and Nechalacho mines: the information was obtained from a variety of sources and includes some unavoidable uncertainties. See the discussion in the bullet points for an illustration of this.

Figure 4: Mining emissions in the absence of new policy



It is important to note that our characterization of the mines above rely on several assumptions:

- We assume that the only mine that connects to the electricity grid is Pine Point.
- A direct estimate of the GHG emissions from the Pine Point mine was unavailable. To estimate annual GHG emissions from Pine Point we use quantitative information identified of the amount of electricity the mine would consume (119.5 GWh per year of which approximately half would come from Taltson)[35] and an assumption that electricity generation would normally have accounted for 80% of the emissions associated with mining operations.[36] Using these two pieces of information, we infer emissions from Pine Point would be approximately 65 kt annually.
- Emissions from the NICO mine are based on the "maximum daily emissions during winter operation" as outlined in NICO's EIA.[37]

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[35] Estimate provided to us by GNWT.

[36] Alternatives North. (2020). *Climate Emergency: Getting the NWT off Diesel.* Available from: https://www.ntassembly.ca/sites/assembly/files/td_103-192.pdf

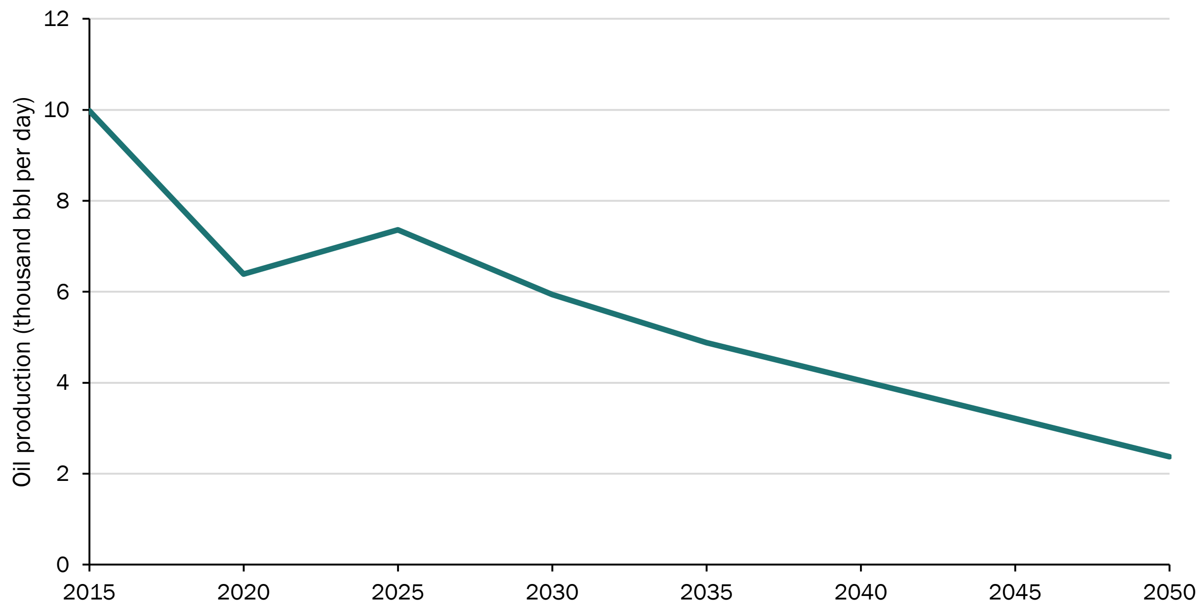
[37] Golder Associates. (2011). *Appendix 10.II Regional Air Emission Sources.* Available from: https://reviewboard.ca/upload/project_document/EA0809-004_Appendix_10_II_Regional_Air_Emissions_Sources.PDF

- We consider the average annual emissions over the operational lifetime of each mine. Mine startup and closure could be associated with additional (short-lived) emissions.

2.2.4. Oil and gas activity

Oil production in the NWT is calibrated to Canada's Energy Future 2021 (see Figure 5).[38]

Figure 5: Reference oil activity in the NWT



Natural gas production is negligible, aligning with projections from Canada's Energy Future.[39] These projections are based on an understanding that production in Cameron Hills has been suspended and Ikhil only produces back-up natural gas (for imported liquified natural gas).[40]

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[38] Canada Energy Regulator. (2021). *Canada's Energy Future 2021.* Available from: https://apps.cer-rec.gc.ca/ftrppndc/dflt.aspx?GoCTemplateCulture=en-CA

[39] Ibid.

[40] Canada Energy Regulator. (n.d.). *Provincial and Territorial Energy Profiles – Northwest Territorie*s. Available from: https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-northwest-territories.html

2.2.5. Energy prices

The price for oil is an exogenous[41] input to the model (i.e., based on an assumed global price). The reference price reflects Canada Energy Regulator projections as shown in Table 6. The reference projection stays constant at $66 USD per barrel.

Table 6: Oil price forecast (2020 USD per barrel)[42]

	2025	2030	2035	2040	2045	2050
Reference	66	66	66	66	66	66

The price for other energy commodities is determined by the model based on demand and the cost of production. For example, the price of electricity in the NWT depends on a variety of factors that are accounted for by the modeling, such as:

- The cost of generating electricity while meeting any policy constraints.
- The cost of maintaining the transmission and distribution network.
- Any taxes on or subsidies to the sector

2.3. Key IESD assumptions

This section outlines modeling assumptions specific to the NWT IESD model, covering generation technologies, storage technologies, commodity prices and calibration sources.

Modeled regions include Snare[43], Taltson[44], Sachs Harbour, Paulatuk, Fort McPherson, Wrigley, Ulukhaktok and Inuvik, accounting for approximately 76% of utility generation in the NWT. The choice of communities was based on the availability of data from the Northwest Territories Power Corporation (NTPC). All eight grids modeled in IESD are operated by NTPC. Each of the eight communities is treated as an isolated, self-

41 An exogenous input refers to an input that it is not solved for by gTech but is instead set from an external source.

42 Canada Energy Regulator. (2021). *Canada's Energy Future 2021.* Available from: www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/index.html

43 Main grid in North Slave.

44 Main grid in South Slave.

sufficient unit where all electricity consumed must come from within the boundaries of the region itself.

2.3.1. Calibration Sources

To accurately characterize the NWT's electricity system, we ensure the model aligns with historical data. To do this we calibrate the IESD model to the following data sources:

- Total historical electricity generation from NTPC.
- Historical generation by type in Snare and Taltson from Power Advisory.[45]
- Data on installed solar capacity from GNWT.
- Data on installed diesel capacity from "A Vision for the NWT Power System Plan".[46]
- Hydro data from NTPC.
- Historical LNG and diesel generation in Inuvik from two GNWT sources[47,48], and a constraint on future LNG generation at 18.2 GWh provided by the GNWT to account for the size of storage tanks.
- Articles to inform the addition of a 3.5 MW wind turbine[49] in Inuvik by model year 2025.
- Based on conversations with GNWT we assume diesel generation in Snare and Taltson equal to their 2020 value in 2025 to account for short-term constraints on the electricity grid.

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[45] Power Advisory. (2021). *Assessment of Incremental Utility Revenues for Northwest Territories.* Available from: https://www.inf.gov.nt.ca/sites/inf/files/resources/incremental_utility_revenue_study_-_load_growth_-_power_advisory_0.pdf

[46] NT Energy. (2013). *A VISION for the NWT Power System Plan.* Available from: https://www.inf.gov.nt.ca/sites/inf/files/a_vision_for_the_nwt_power_system_plan_-_december_2013.pdf

[47] Government of Northwest Territories. *Energy Conservation Initiatives Report 2015-2016.* Available from: https://www.inf.gov.nt.ca/sites/inf/files/pws_energy_conservation_initiatives_report_2015-2016.pdf

[48] Government of Northwest Territories. *Energy Initiatives Report 2016-2017.* Available from: http://library.assembly.gov.nt.ca/2018/INF/a379246_td_92-183_Energy_Initiatives_Report_2016-2017.pdf

[49] Government of Northwest Territories. *Milestone achieved as wind turbine arrives in Inuvik.* Available from: https://www.gov.nt.ca/en/newsroom/milestone-achieved-wind-turbine-arrives-inuvik

Historical load data for modeled communities was provided by NTPC and in the case of Inuvik the GNWT. This informs electricity demand in the model's base year (2015). Electricity demand in future years is informed by gTech.

For all thermal communities, we faced a challenge of inconsistent data for the hourly loads. Specifically, in many instances there were missing hours or even entire days. In some cases, we were able to "smooth" missing load data by averaging the load in the preceding hour and the following hour where possible. In other cases, we relied on creating a "typical" hour which took an average of the load while taking into account the month, day of the week, and time of day.

2.3.2. Generation technologies

To meet the electricity demand (from Navius' gTech model), IESD may choose to generate via a range of technologies depending on their costs, including diesel, liquefied natural gas (LNG)[50], hydro[51], solar and wind. This section outlines the assumed cost for each generation type. Additional details on how renewable resources (hydro, wind and solar) are parameterized are provided in Appendix A.

Table 7 summarizes the cost of new generation capacity of hydro, LNG and diesel. Costs are based on the 2013 "A Vision for the NWT Power System Plan".[52] Diesel facilities are assumed to have generator efficiencies (electrical) of 31%.[53] LNG is available for generation in Inuvik, with an assumed generator efficiency (electrical) of 32.5% based on input from the GNWT.

Table 7: Generation cost assumptions

Generation type	Capital cost ($2021/kW)	Fixed operating cost ($2021/kW)	Variable operating cost ($2021/MWh)
Hydro	7,030	6	
Diesel	3,378	16	10
LNG	1,172	12	11

[50] In Inuvik only.

[51] In Snare and Taltson only.

[52] NT Energy. (2013). *A VISION for the NWT Power System Plan.* Available from: https://www.inf.gov.nt.ca/sites/inf/files/a_vision_for_the_nwt_power_system_plan_-_december_2013.pdf

[53] Based on data received from GNWT.

Table 8 summarizes capital costs for wind and solar. A range of costs are considered to account for uncertainty in the cost of installing renewable systems in the North today as well as how these costs could change in the future. Costs for wind are based on the 2013 "A Vision for the NWT Power System Plan"[54], while alternative sources are used to characterize a range of potential current costs for solar PV. A pessimistic solar PV cost assumption is based on historical solar PV installations in the NWT since 2016[55], as well as the 2013 "A Vision for the NWT Power System Plan".[56] An optimistic cost assumption is based on more recent experience with solar PV in the Yukon[57] which better reflects declines in the cost of this technology over the past decade.

Moving forward, the costs of both solar and wind are expected to continue decreasing (in real terms) due to technological improvements and learning. The rate of decline is based on the National Renewable Energy Laboratory's Annual Technology Baseline, using a CAD-USD exchange rate of 1.3.[58]

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[54] NT Energy. (2013). *A VISION for the NWT Power System Plan.* Available from: https://www.inf.gov.nt.ca/sites/inf/files/a_vision_for_the_nwt_power_system_plan_-_december_2013.pdf

[55] Data provided by the GNWT.

[56] NT Energy. (2013). *A VISION for the NWT Power System Plan.* Available from: https://www.inf.gov.nt.ca/sites/inf/files/a_vision_for_the_nwt_power_system_plan_-_december_2013.pdf

[57] Yukon Energy Corporation. (2020). *10-year Renewable Electricity Plan Technical Report.* Available from: https://yukonenergy.ca/media/site_documents/YEN20093rpt_Technical_web2_compressed.pdf

[58] Please note that the rate of decline for solar PV corresponds to the moderate decline scenario in NREL. The two wind cost trajectories are based on the moderate and conservative decline scenarios.

Table 8: Solar and wind capital cost ($2021/kW)

Generation type	2020	2030	2040	2050
Solar historic	6,085			
Solar forecast (pessimistic)		3,363	3,063	2,763
Solar forecast (optimistic)		980	893	822
Wind historic	5,272			
Wind forecast (pessimistic)		3,629	3,447	3,266
Wind forecast (optimistic)		3,447	3,103	2,758

2.3.3. Storage technologies

Optimistic and pessimistic cost projections are considered to account for uncertainty in battery storage costs in the NWT. The cost optimistic scenario is based on the National Renewable Energy Laboratory (NREL)[59] and increased by 20% to consider regional challenges for infrastructure that are unique to the NWT. The cost pessimistic scenario is based on a report prepared for the Government of Northwest Territories.[60] In both cases, capital costs are assumed to decline in the future at a similar rate defined by NREL.[61] Roundtrip efficiency is assumed to be 85% for lithium-ion batteries.

[59] National Renewable Energy Laboratory. (2020). *Cost Projections for Utility-Scale Battery Storage: 2020 Update.* https://www.nrel.gov/docs/fy20osti/75385.pdf

[60] Government of Northwest Territories. (2021). *Microgrid Stability with Intermittent Renewables.* https://www.inf.gov.nt.ca/sites/inf/files/resources/s13291a_renewable_energy_penetration_analysis_-_gnwt.pdf

[61] Aligns with NREL's moderate decline scenario.

Table 9: Historical cost of lithium-ion batteries

CAPEX type	2020
Storage capital cost ($2021/kWh)	3,803
Power capital cost ($2021/kW)	1,544

Table 10: Forecast optimistic cost of lithium-ion batteries

CAPEX type	2030	2040	2050
Storage capital cost ($2021/kWh)	314	275	235
Power capital cost ($2021/kW)	449	393	338

Table 11: Forecast pessimistic cost of lithium-ion batteries

CAPEX type	2030	2040	2050
Storage capital cost ($2021/kWh)	1,802	1,577	1,352
Power capital cost ($2021/kW)	1,874	1,642	1,409

2.3.4. Commodity prices

Diesel

Diesel prices are determined exogenously in the IESD model in all years (though policy could change these prices). Table 12 shows prices for diesel in IESD in the regions modeled in the NWT. Historical prices are based on data from NTPC, and prices are extrapolated to future years based on Canada's Energy Future 2021.[62] Due to lack of data for the Snare and Taltson grids, we used the difference between retail diesel prices in Wrigley and Snare/Taltson and applied this to the Wrigley price from NTPC as a proxy.

62 Canada Energy Regulator. (2021). *Canada's Energy Future 2021.* https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/index.html

We could not find a definitive source for the cost of diesel in Inuvik, and instead relied on a government published report which related the cost of diesel in Inuvik to what it was in Yellowknife[63], and applied this difference to estimate Inuvik's price.

Table 12: Diesel prices (2021$/GJ)

Region	2020	2025	2030	2035	2040	2045	2050
Wrigley	28	34	36	35	34	33	33
Fort McPherson	31	38	41	39	38	38	37
Paulatuk	38	46	49	47	46	45	44
Sachs Harbour	34	41	44	43	42	41	40
Ulukhaktok	38	46	49	47	46	45	44
Snare Grid	23	28	30	29	29	28	28
Taltson Grid	23	28	30	29	29	28	28
Inuvik	29	35	37	36	35	34	33

Liquefied natural gas

Liquefied natural gas (LNG) is available as a generation option in Inuvik. To quantify the cost of natural gas used for electricity generation, we relied on a 2016 estimate from the GNWT which set the cost of LNG in that community to be 85% of the cost of diesel.[64] We extrapolated the cost to future years based on natural gas price projections in the NWT in Canada's Energy Future 2021.[65]

Table 13: Natural gas prices ($2021/GJ)

Region	2020	2025	2030	2035	2040	2045	2050
Inuvik	32	33	35	36	37	39	40

[63] Government of Northwest Territories. *NWT Economic Trends*. Available from: http://library.assembly.gov.nt.ca/2006/ITI/02-0023889Issue9.pdf

[64] See, "Energy Prices and Costs in the NWT, May 2016," https://www.inf.gov.nt.ca/sites/inf/files/resources/energy_prices_and_costs_in_the_nwt.pdf

[65] Canada Energy Regulator. (2021). *Canada's Energy Future 2021.* https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/index.html

2.4. Scenario design

This section outlines policy scenarios simulated in the analysis, and summarises sensitivities explored in the sensitivity analysis.

2.4.1. Policy scenarios

We simulated four policy scenarios in this analysis.

1. **Current policies:** The current policy forecast (aka "reference case" or "business as usual" describes how the NWT's energy-economy is likely to evolve in the absence of new policies and in response to baseline assumptions. This scenario is intended to capture all policies and projects on the books as of March 2022. For example, this scenario includes the carbon price rising to \$170/tCO_2e by 2030 in nominal terms. Current policies are described in more detail below.
2. **NWT target pathway:** In this scenario the NWT achieves its 2030 target and net zero emissions in 2050. This is modeled as an economy-wide emissions cap at 1,094 ktCO_2e in 2030[66], declining to net zero in 2050. Net zero is defined as a virtual elimination of all energy-related emissions tracked by the National Inventory Report (NIR).
3. **NWT target excl. industry pathway:** In this scenario the NWT achieves its 2030 target and net zero emissions in 2050 excluding the mining and oil and gas sectors. This is modeled as an economy-wide emissions cap at 1,094 ktCO_2e 2030[67], declining to net zero in 2050. Mining and oil production is excluded from the emissions cap in this scenario.
4. **Federal target pathway:** In this scenario the NWT achieves the federal 2030 target and net zero emissions by 2050. This is modeled as an economy-wide emissions cap at 45% below 2005 levels in 2030[68], declining to net zero in 2050.

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[66] Government of Northwest Territories. *2030 NWT Climate Change Strategic Framework.* Available from: https://www.enr.gov.nt.ca/sites/enr/files/resources/128-climate_change_strategic_framework_web.pdf

[67] Ibid.

[68] Government of Canada. (2021). *Government of Canada confirms ambitious new greenhouse gas emissions reduction target.* Available from: https://www.canada.ca/en/environment-climate-change/news/2021/07/government-of-canada-confirms-ambitious-new-greenhouse-gas-emissions-reduction-target.html

Net zero is defined as a virtual elimination of all energy-related greenhouse gas emissions. Emissions reductions associated with nature-based solutions are beyond the scope of this analysis.

Current policies

Current policies implemented by the federal, provincial, and territorial governments are influencing the NWT's greenhouse gas emissions now and will continue to do so moving forward. This excludes federal policies that have been announced but not yet implemented (like policies announced in the federal *Emissions Reduction Plan*).

The current policy forecast includes the federal fuel charge and output-based performance standard applied to the NWT from the model year 2025 with the price rising to \$170/tCO_2e by 2030 in nominal terms. Table 14 below outlines more details on which policies are included in the current policy forecast.

Table 14: Federal policies included in the current policy forecast

Policy	Description
Carbon Pollution Pricing Backstop[69],[70]	This policy includes two components: (1) a carbon levy applied to fossil fuels that reaches \$ \$170/tCO2e in 2030 and stays constant at that level thereafter in nominal terms, and (2) an output-based pricing system for industrial facilities emitting more than 50 ktCO_2e annually increasing at the same level as the carbon levy. Revenue raised by this policy is returned to households in each respective province/territory.
Territorial subsidies and incentives	We account for various subsidy programs and incentives already in place in the NWT through calibration to historical data.
Energy efficiency regulations[71]	Federal standards exist for space conditioning equipment, water heaters, household appliances, and lighting products.

[69] Government of Canada. (n.d.). *The Federal Carbon Pollution Pricing Benchmark*. Available from: https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/carbon-pollution-pricing-federal-benchmark-information.html

[70] Environment and Climate Change Canada. (2021). *Review of the OBPS Regulations.* https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/output-based-pricing-system/2022-review-consultation.html

[71] Natural Resources Canada. (n.d.). Canada's Energy Efficiency Act and Energy Efficiency Regulations. Available from: www.nrcan.gc.ca/energy/regulations-codes-standards/6861

Policy	Description
Green Freight Assessment Program[72]	Four-year funding program launched in 2018 with a budget of $3.4 million available for medium and heavy-duty fleet performance reviews, implementing operational best practices, installing fuel saving technologies, and purchasing alternative fuel vehicles.
Hydrofluorocarbon Controls[73]	The Canadian government was one of the signatories of the 2016 Montreal Protocol-amending Kigali Agreement on ozone-depleting substances. Canada has pledged to reduce its HFC-related GHG emissions by 15% by 2036 relative to 2011/2013 levels by revising the Regulations Amending the Ozone-depleting Substances and Halocarbon Alternatives Regulations.
Light-Duty ZEV Subsidy[74]	Light-duty vehicle subsidy available at $2,500 for short-range plug-in hybrids and $5,000 for long-range plug-in hybrids, hydrogen vehicles, and battery electric vehicles until 2025.
Regulations Amending the Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations[75]	The federal government has proposed amending the Heavy-Duty Vehicle Emissions Standard to increase the vehicle emission stringency for vehicles manufactured in model years 2018 to 2027.

[72] Government of Canada. (2020). Green Freight Assessment Program. Available from: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/greening-freight-programs/green-freight-assessment-program/20893.

[73] Government of Canada. (2018). Canada agrees to control hydrofluorocarbons under the Montreal Protocol. www.canada.ca/en/environment-climate-change/services/sustainable-development/strategic-environmental-assessment/public-statements/canada-agree-control-hydrofluorocarbons.html

[74] Government of Canada. (n.d.) Zero-emission vehicles. Available from: https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles

[75] Government of Canada. (2018). Regulations Amending the Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations and Other Regulations Made Under the Canadian Environmental Protection Act, 1999: SOR/2018-98. http://gazette.gc.ca/rp-pr/p2/2018/2018-05-30/html/sor-dors98-eng.html

Policy	Description
Regulations Amending the Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations[76]	New passenger vehicles and light-commercial vehicles/light trucks sold in Canada must meet fleet-wide GHG emission standards between 2012 and 2016, and between 2017 and 2025. Fleet targets for passenger cars are aligned with U.S. regulation.
Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds[77]	Oil and gas facilities must adopt methane control technologies and practices.
Tax Write-Off[78]	Businesses that purchase light-, medium-, or heavy-duty zero emission vehicles (including plug-in hybrids with a battery capacity of at least 7kWh, fully electric vehicles, and hydrogen vehicles) are eligible for a 100% tax write-off. Vehicles that qualify for the federal Incentive for Zero-Emission Vehicles Program are ineligible for the tax write-off.
Zero Emission Vehicle Infrastructure Program[79]	Federal funding available (total budget of $130 million over five years from 2019 to 2024) to partially pay for various types of charging and re-fueling stations, including medium- and heavy-duty vehicle charging and re-fueling stations.

2.4.2. Sensitivity analysis

Simulating developments in the NWT's economy out to 2050 is fundamentally uncertain. To quantify key elements of this uncertainty, we conducted a sensitivity analysis that considered changes to:

[76] Government of Canada. (2018). Regulations Amending the Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations. http://www.gazette.gc.ca/rp-pr/p2/2014/2014-10-08/html/sor-dors207-eng.html

[77] Government of Canada. (2020). Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas Sector): SOR/2018-66. Available from: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2018-66/index.htm

[78] Government of Canada. (2020). Zero Emission Vehicles. Tax Write-Off. Available from: https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles

[79] Government of Canada. (2020). Zero Emission Vehicle Infrastructure Program. Available from: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/zero-emission-vehicle-infrastructure-program/21876

- **Mining activity.** We explore three trajectories of the growth of the mining sector after 2030. While activity stays constant at 2030 levels in the reference case (as described in section 2.2.3), under the low activity sensitivity, activity begins to decline in 2035 until a 75% lower than 2020 activity level is achieved by 2050. In the high activity sensitivity, activity begins to grow in 2035 until a 75% higher than 2020 activity level is achieved by 2050.

- **Cost of emerging low-carbon transport technologies and fuels.** We simulate three sensitivities on the rate at which capital costs for battery electric vehicles, fuel cell electric vehicles, second-generation biofuels, and hydrogen production come down over time.

- **Cost of emerging low-carbon electricity technologies.** We simulate a pessimistic and optimistic scenario for the cost of renewables and batteries. This is described in more detail in sections 2.3.2 and 2.3.3.

- **Level of policy in the rest of Canada and the U.S.** For each net zero scenario we run a sensitivity on the level of greenhouse gas abatement effort in the rest of Canada and the U.S. The baseline level of effort reflects that embedded in current policies, such as the carbon price rising to \$170/tCO_2e by 2030 in nominal terms. A more stringent scenario reflects one in which Canada and the U.S. achieve deep decarbonization consistent with net zero by 2050.

3. Where are emissions headed in response to current policies?

3.1. Overview

The NWT's emissions decline from 1,511 ktCO_2e in 2020 to 1,073 ktCO_2e in 2030 under current policies (Figure 6). Emissions decline due to natural turnover of technological stock (i.e., replacement of existing technologies with more efficient ones), implementation of current policy (e.g., $170/t$CO_2$e carbon price and vehicle fuel efficiency standards), and projected decreases to GDP and mining activity (as outlined in sections 2.2.2 and 2.2.3).

Based on this projection, the NWT meets its 2030 target of 1,094 ktCO_2e.[80] On the other hand, a gap of 124 ktCO_2e remains to reach a 45% reduction in 2030 (in line with the federal target)[81], indicating that stronger policy would be required to reduce emissions to this level.

After 2030, the decline in emissions slows. By 2050, emissions range from 860-1,128 ktCO_2e (956 ktCO_2e in the reference sensitivity). The NWT is not on track towards deep decarbonization required of achieving net zero emissions, implying that significantly stronger policies would be required to achieve this objective.

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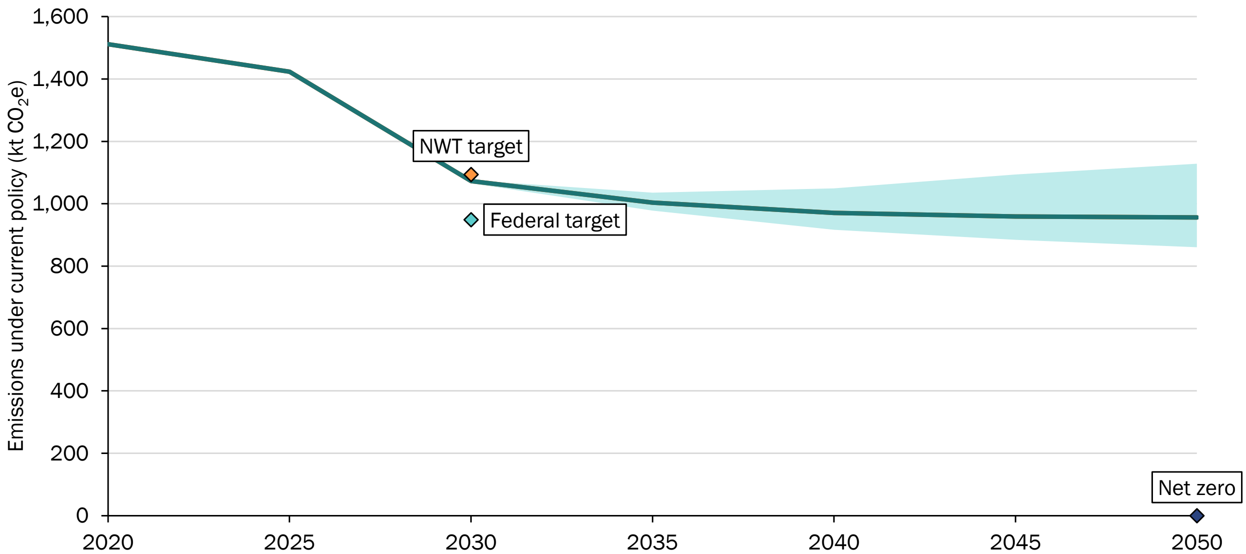
80 Government of Northwest Territories. (2018). *2030 Energy Strategy*. Available from: https://www.inf.gov.nt.ca/sites/inf/files/resources/gnwt_inf_7272_energy_strategy_web-eng.pdf

81 Environment and Climate Change Canada. (2022). *2030 Emissions Reduction Plan.* Available from: https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf

Figure 6: Territorial emissions to 2050



3.2. Trends by sector

Figure 7 below shows trends in emissions by sector under current policy. Emissions are provided as a range across all simulated sensitivities.

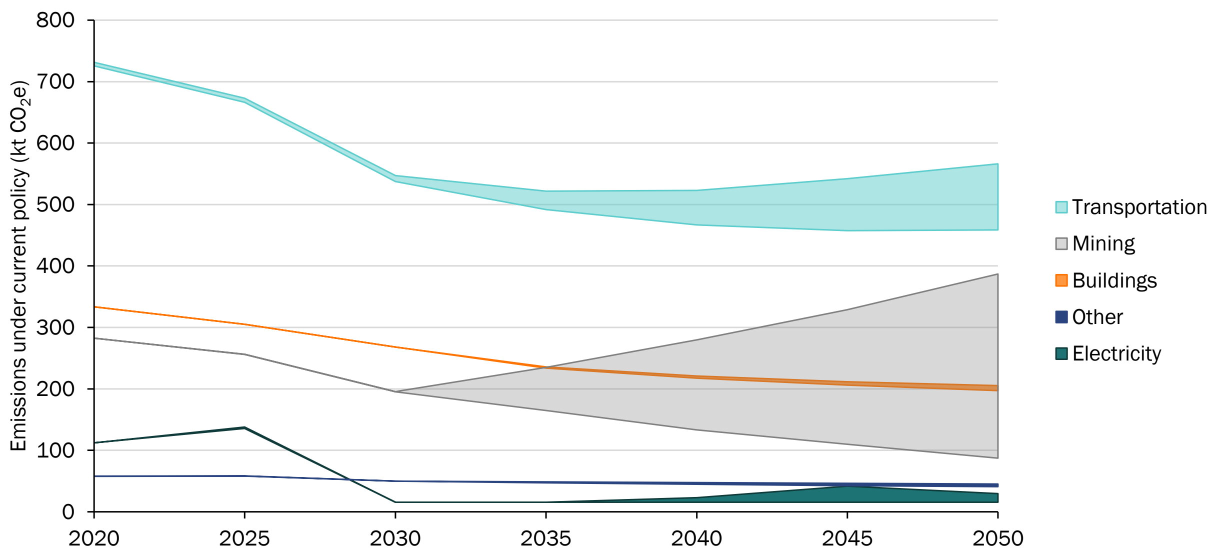
Most of the NWT's emissions come from the transportation sector. Emissions in this sector decline from 740 ktCO_2e in 2020 to 537-547 ktCO_2e in 2030 (544 ktCO_2e in the reference sensitivity) in response to current policies, the declining GDP forecast (see section 2.2.2), and natural turnover of technology stock. In other words, as vehicles reach the end of their life, they are replaced with more efficient internal combustion engine (ICE) vehicles or in some cases zero-emission vehicles (ZEVs). By 2050, emissions range from 459-566 ktCO_2e (503 ktCO_2e in the reference sensitivity). The range in emissions is driven by the extent to which the capital cost of emerging low carbon transportation technologies and fuels like electric vehicles, hydrogen production, and second-generation biofuels declines over time. Adoption of ZEVs is discussed in more detail in sections 4.3.2 and 4.5.

Emissions decline in the NWT's buildings under current policies across all sensitivities simulated, from 289 ktCO_2e in 2020, to 289 ktCO_2e in 2030, and 197-205 ktCO_2e in 2050 (201 ktCO_2e in the reference sensitivity). The range is narrow as the sensitivities examined (mining growth and technology cost) have little impact on NWT's buildings. This narrow range is likely misleading due to uncertainty in efficiency improvements and fuel switching trends. Nevertheless, current policy (e.g., \$170/tCO_2e) combined with natural turnover of technological stock, ensure simulated emissions continue to decline over time. Building electrification is discussed in more detail in section 4.3.1 and adoption of biomass is discussed in more detail in section 4.2.1.

There is also a decline in electricity emissions from utilities as variable renewables are adopted. As the capital cost of solar and wind declines, these technologies become more attractive over time (see section 4.4).

The largest uncertainty in the NWT's future emissions is due to the mining sector. As discussed in section 2.2.3, mining activity is assumed to decline through 2030, causing emissions to change from 282 ktCO_2e in 2020 to 195 ktCO_2e in 2030 in this sector. To account for uncertainty in the development of future mines, three sensitivities on mining activity is explored after 2030. In scenarios in which mining activity stays constant at 2030 levels until 2050, mining emissions are around 193 ktCO_2e in 2050 (reference sensitivity). On the other hand, if mining activity grows to 75% larger than 2020 levels by 2050 emissions could reach 387 ktCO_2e, and if it shrinks to 75% less than 2020 levels they could be as low as 87 ktCO_2e.

Figure 7: The NWT's emissions by sector under current policies (range across sensitivities)



4. What are promising options for achieving deep emissions reductions in the NWT?

This section outlines the most promising options for reducing the NWT's greenhouse gas emissions, as observed across the range of simulated scenarios.

As outlined in section 2.4.1, we explored the following emissions reduction pathways:

- First, a pathway where emissions are capped in 2030 at the NWT's emissions target and at net zero emissions in 2050 (**NWT target pathway**).
- Second, a version of the previous scenario, where emissions are capped in 2030 at the NWT's emissions target and at net zero emissions in 2050, but the mining and oil sectors are excluded from this emissions target (**NWT target excl. industry pathway**).
- Third, a pathway where emissions are capped at 45% below 2005 levels in 2030 in line with federal commitments, and at net zero emissions in 2050 (**federal target pathway**).

4.1. Overview

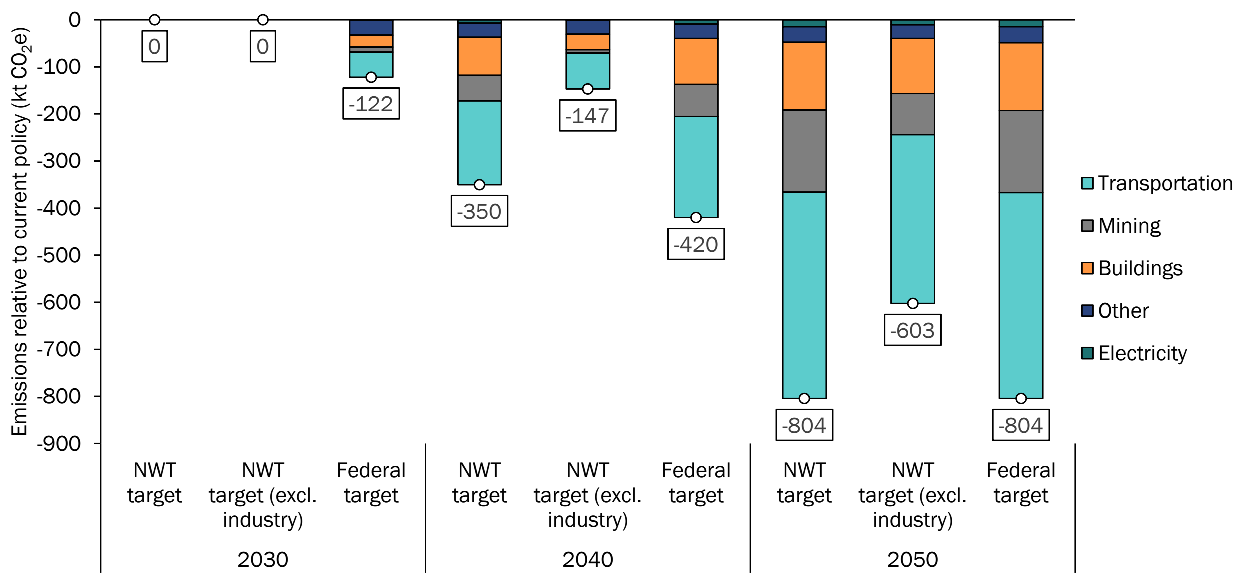
Figure 8 shows the reduction in territorial emissions under each pathway, measured relative to the current policy scenario. It shows that achieving net zero emissions by 2050 requires a significant reduction in the NWT's emissions across all sectors of the economy.

The most promising options for achieving net zero emissions are discussed in the remainder of this section and include:

- Blending biofuels into the diesel pool used for transport, space heat, industrial process heat and electricity (section 4.2.1).
- Replacing diesel consumed for space heating with solid biomass where possible (section 4.2.2).
- Electrifying space and water heating in buildings (section 4.3.1).

- Electrifying vehicles where possible (section 4.3.2).
- Boosting renewable electricity supply from hydro, solar and wind (section 4.4).
- Adopting hydrogen fuel cell vehicles for select heavy-duty applications (section 4.5).
- Exploring the potential for carbon dioxide removals (i.e., removing carbon from the atmosphere and storing it) (section 4.6).

Figure 8: Change to the NWT's emissions under pathways scenarios relative to current policies (reference sensitivity)



4.2. Bioenergy

4.2.1. Biofuels

Biofuels are a promising abatement option in the NWT as an alternative to gasoline and diesel, and could be used in buildings, vehicles, and for industrial process heat. Emissions from the production of liquid biofuels are captured in the modeling, though we note that production occurs outside the NWT. Emissions from organic materials (i.e., biogenic CO_2) are treated as carbon neutral in this analysis.

While conventional biofuels like ethanol and biodiesel are widely produced today, using them in their pure (i.e., non-blended) form requires significant modifications to existing engines and results in poor cold weather performance that is inadequate for cold winters in the Arctic.

A more attractive option for decarbonizing liquid fuels is drop-in fuels like hydrogenation derived renewable diesel (HDRD), as this fuel is interchangeable with petroleum-derived products. This means that these fuels require no change to the design of fuel transport and distribution, nor of internal combustion engines and turbines. Other benefits of HDRD include that it is an already commercialized fuel, and that it can be manufactured with cold-weather operating characteristics similar to conventional diesel.

Figure 9, below, contains the 2.5 percentile low-end design temperatures for diesel fuel for Yellowknife, the approach specified in CAN/CGSB-3.517-2020, the Canadian engineering standard for diesel fuel. While Arctic grades of renewable diesel would be needed to achieve a 100% blend rate year-round, high blend rates would be achievable for most of the year with currently commercially available renewable diesel. For example, -34°C, the cloud point which Neste communicated to GNWT is currently available and is higher than the CGSB-specified design temperature for Yellowknife for 70% of the calendar year. This would not be applicable to remote communities with one fuel delivery per year, but nonetheless demonstrates that the operating characteristics of commercially available renewable diesel would be adequate for much of the year, in much of the NWT. During periods of colder temperatures, commercially available grades of renewable diesel could be blended with lower cloud point petroleum fuels.[82]

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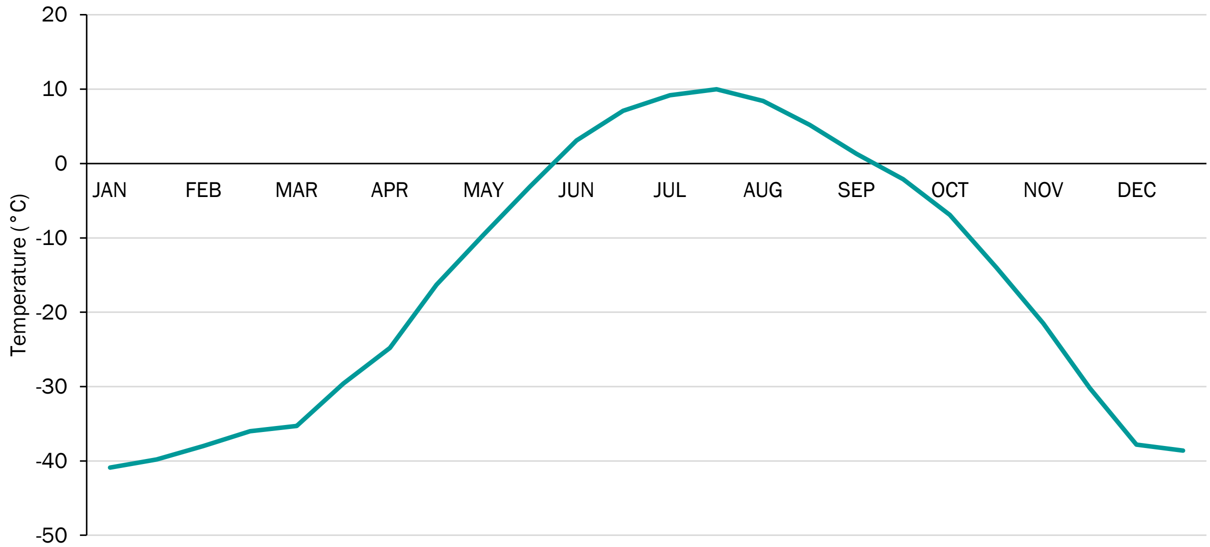
[82] Saskatchewan Research Council (2021). Assessing the Use of Liquid Biofuels in the Northwest Territories (p. 18). Available at: https://www.inf.gov.nt.ca/sites/inf/files/resources/src_nwt_biofuels_final_report.pdf

Figure 9: 2.5% low-end design temperature for diesel, Yellowknife Airport



Second-generation renewable gasoline and diesel that are produced via thermochemical processes (pyrolysis or gasification) offer the potential to boost supply while being less constrained by feedstock availability. The feedstocks used for these production pathways include lignocellulosic biomass (e.g. agricultural and forestry residues), algae, wastewater, and dedicated energy crops like switchgrass. The second-generation biofuel feedstocks represented in this analysis are agricultural and forestry harvest residues that can be sustainably extracted without harming soil fertility.

Figure 10 shows that biofuel consumption increases significantly across all pathways scenarios between 2030 and 2050. Biofuels aren't consumed to any extent in the current policy forecast because of their cost relative to gasoline and diesel. On the other hand, biofuels become increasingly competitive with conventional gasoline and diesel under net zero in the territory.

In scenarios where the NWT achieves net zero emissions, a significant portion of fossil fuel equipment remains installed (e.g., 82-94% of heavy-duty vehicles are internal combustion engine vehicles). To be consistent with net zero, this equipment must run on biofuels. As a result, demand for biofuels reaches 5,590-11,013 TJ when the NWT achieves net zero emissions in 2050 (8,369 TJ in the reference federal target pathway scenario). This means that the NWT's diesel and gasoline supply consists of a large portion of biofuels when the territory achieves net zero emissions.

Figure 10: Biofuel demand in the NWT (range across sensitivities)

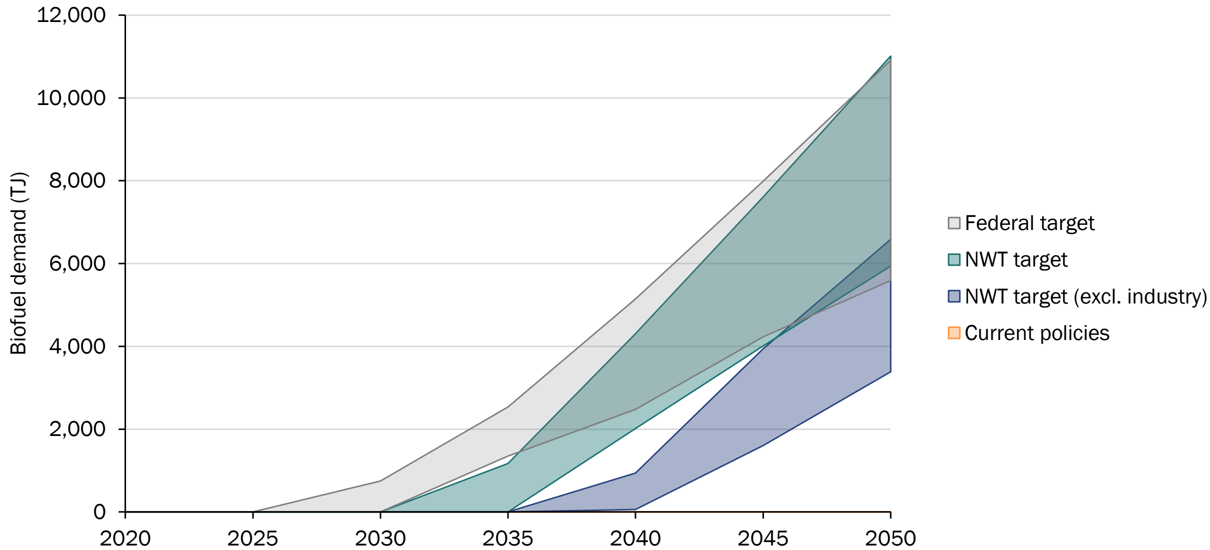
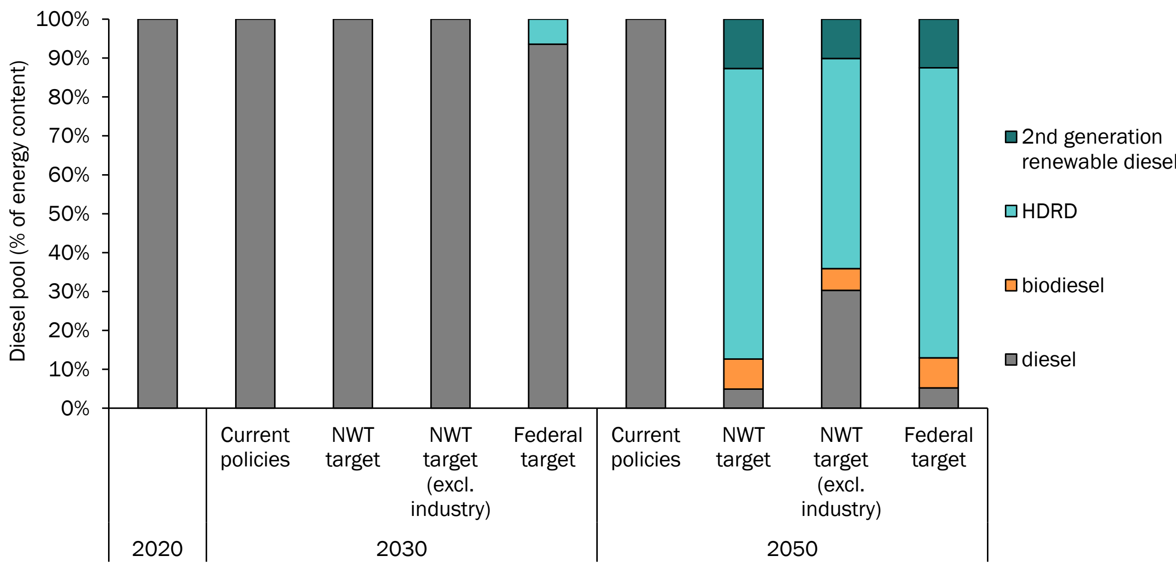


Figure 11 shows the NWT's diesel supply by fuel type. In the federal pathway scenario, 95% of the diesel pool consists of biofuels in the reference sensitivity. Results suggest HDRD is the most promising option for decarbonizing the NWT's diesel pool.

Figure 11: The NWT's diesel supply by fuel type (reference sensitivity)



Demand for biofuels is greatest in scenarios where the growth of the mining sector is high. The mining sector is a large source of biofuel demand both for use in stationary combustion and for mining vehicles. Adoption in the mining sector accounts for 14-

43% of total biofuel demand depending on the growth of the mining sector. The growth of the mining sector also impacts the total economic growth in the territory, which increases the activity both in other transportation and in the NWT's buildings, causing demand in these sectors to increase as well.

Biofuel adoption is lowest in scenarios in which the rest of Canada and the U.S. also pursues deep decarbonization consistent with net zero emissions. Action on climate change in other jurisdictions increases the demand for biofuels across the continent, which drives up the price of agricultural commodities (e.g. soy) used as biofuel feedstocks.

4.2.2. Biomass

Biomass heating through wood stoves or pellet furnaces is generally considered a low or zero carbon heating option, depending on its source and the way in which it is harvested. It is treated as carbon neutral in this analysis, aligned with methodology established by UNFCCC.[83] Despite limited availability of cordwood and wood pellets in certain NWT communities, it is an important abatement option in the NWT's building sector, and its adoption remains high across all scenarios simulated for this analysis.

Figure 12 shows biomass demand in the NWT as a range across the sensitivity scenarios simulated. Under current policies, its adoption increases from 1,329 TJ in 2020 to 1,419-1,420 TJ in 2030 (1,419 TJ in the reference sensitivity), and 1,583-1,643 TJ by 2050 (1,603 TJ in the reference sensitivity). Biomass meets 28% of space heat load by mid-century under current policies.

Biomass becomes increasingly important in a net zero future. In the federal target pathway to net zero, biomass demand ranges from 1,386-1,444 TJ in 2030 (1,444 TJ in the reference sensitivity), and 1,644-2,232 TJ by 2050 (1,699 TJ in the reference sensitivity). 31-44% of space heat demand is met by biomass by mid-century in the federal target pathway to net zero.

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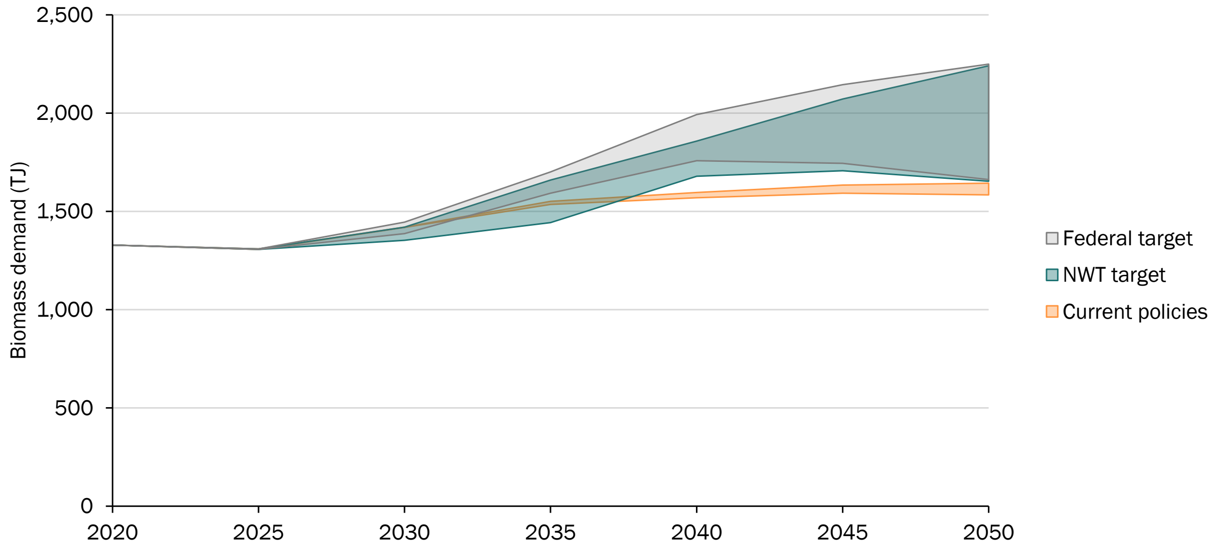
[83] UNFCC. *Annex 18 Definition of Renewable Biomass.* Available from: https://cdm.unfccc.int/EB/023/eb23_repan18.pdf

Figure 12: Biomass demand in the NWT (range across sensitivities)



Biomass adoption is greatest when the rest of Canada and the U.S. pursues deep decarbonization consistent with net zero. As described in section 4.2.1, climate action in other jurisdictions increases the competition for biofuels, increasing its price and making this a less attractive abatement option for buildings in the NWT. As a result, other forms of space heat are adopted, such as biomass. Biomass adoption is lowest across all scenarios when the growth of the mining sector is low, as economic activity across the territory is lower in this scenario affecting the total number of buildings in the territory as a result.

It is important to note that while biomass may be cost competitive with other heating options, its use is determined in large part by preference rather than cost (unless it was regulated). For example, some households readily prefer wood stoves due to the intangible benefit they derive from them. Conversely, other households would much prefer to avoid the hassle of chopping wood or re-stocking pellet supplies.

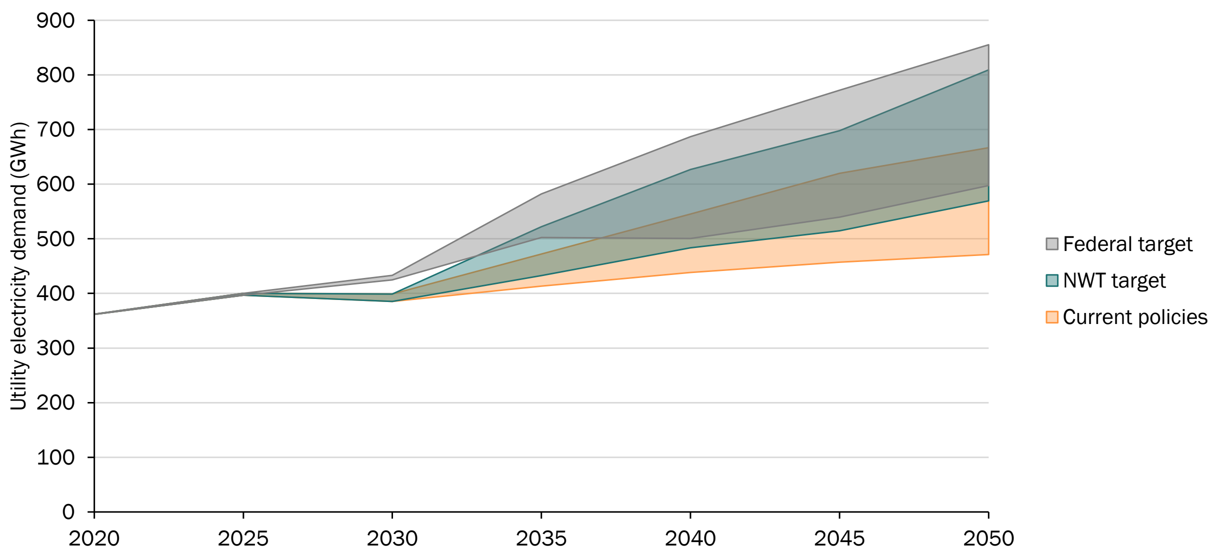
4.3. Electrification

Electrification could be important for achieving deep emissions reductions in the NWT. Figure 13 below shows utility electricity demand (i.e., excluding mining own-generation) in the NWT as a range across the sensitivity scenarios simulated. Electricity demand increases by 30-84% between 2020 and 2050 in the current policy scenario (59% in the reference sensitivity) due to growth in the building stock, adoption of battery electric vehicles (BEVs), and the Pine Point mine connecting to the electricity grid (see section 2.2.3 for details).

Achieving a 45% reduction in emissions by 2030 increases electricity demand by 28-40 GWh in 2030 relative to current policies (40 GWh in the reference sensitivity), and achieving net zero emissions increases electricity demand by 98-130 GWh by 2050 relative to current policies (126 GWh in the reference sensitivity).

By 2050, electricity demand is greatest under the federal target pathway to net zero, ranging from 579-837 GWh (701 GWh in the reference sensitivity). It is greater in this scenario than in the NWT target pathway as electrification occurs earlier in response to a more stringent 2030 target.

Figure 13: Utility electricity demand (i.e., excluding mining own-generation) in the NWT (range across sensitivities)



Under the pathways scenarios, electrification is highest when the rest of Canada and the U.S. also implements stringent climate policy. Implementation of climate policy in other jurisdictions influences electricity demand in two ways. First, the capital cost for BEVs decline faster over time due to greater adoption across the continent, making this technology more attractive in the NWT. Second, there is greater competition for biofuels across Canada and the U.S., driving up the cost of the fuels, which also makes electrification more attractive.

Electricity demand is lowest when technology costs for emerging low carbon transportation technologies are high, as BEVs are more expensive, making this a less attractive option for reducing emissions in the territory.

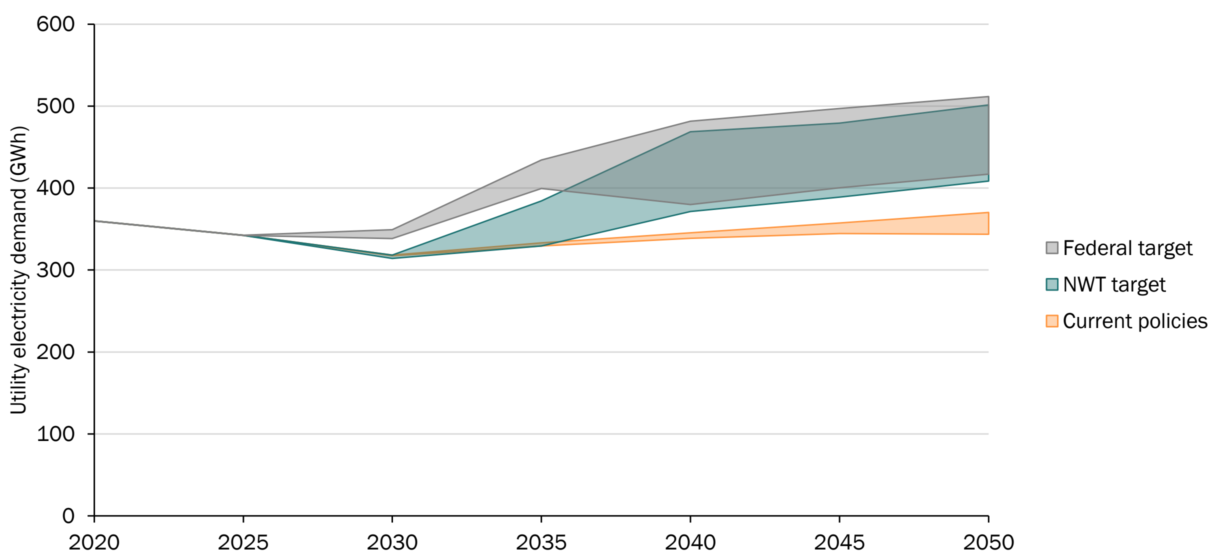
Electricity demand increases across all sectors under net zero. Below, we discuss two particularly important sources of electrification: buildings and transport.

4.3.1. Electrification of buildings

While there is some electricity demand in the NWT's buildings in response to current policies, it is significantly greater in a net zero future (Figure 14). It stays relatively constant in the current policy forecast, changing from 360 GWh in 2020 to 344-370 GWh in 2050 (363 GWh in the reference sensitivity) as electricity remains expensive in the territory leaving other sources of building heat like biomass or propane competitive options.

In response to net zero, electricity demand increases to reach 409-508 GWh by mid-century as more buildings are electrified to comply with climate policy (431 GWh in the reference federal target pathway). The high cost of electricity in the NWT limits additional uptake of electricity in NWT's buildings.

Figure 14: Utility electricity demand from buildings (range across sensitivities)



A significant portion of electricity demand in the NWT's buildings comes from space heat, and adoption of electric baseboards and heat pumps is a potential option for reducing the NWT's building emissions. Heat pumps play an important role in meeting space heat load, despite lower efficiency in colder temperatures resulting in a lower average efficiency in the NWT compared to the rest of Canada. Modern cold-climate air-source heat pumps can operate down to -25°C, at which point a backup heat source in the form of electric resistance, or a conventional furnace is required.

In the current policy scenario, 1% of space heat load is met by electric baseboards, and 18-20% by heat pumps by mid-century. The share of space heat load in the NWT's buildings met with electricity is significantly greater in the pathways scenarios. In a net zero future, electric baseboards meet 2-5%, and heat pumps meet 28-49% of space heat load in 2050.

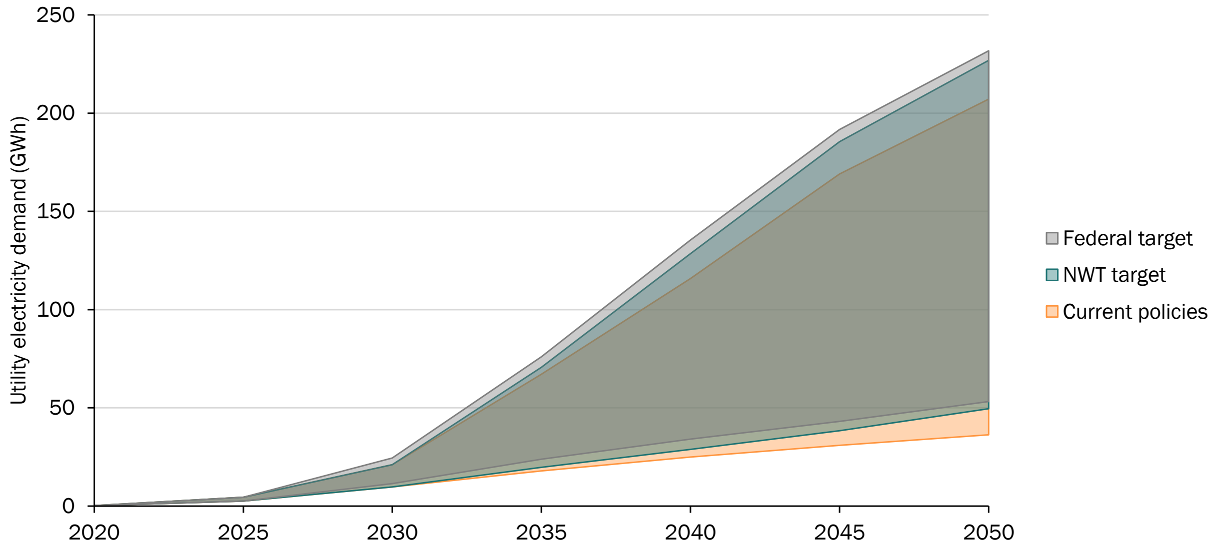
Electricity demand in the NWT's buildings is dependent on whether the rest of Canada and the U.S. pursues deep decarbonization. If other jurisdictions pursue deep decarbonization, this increases the cost for biofuels, making this a less attractive abatement option in NWT's buildings and in turn makes electrification of buildings more competitive in a net zero future.

Due to high electricity prices, other sources of building heat like biomass and biofuels remain competitive (see section 4.2). While improvements to energy efficiency in the built environment reduces the emissions intensity of buildings and the energy costs for households, improving building efficiency is not identified as a key option for deep emissions reductions in the NWT. It is an action that remains economic regardless of climate policy, and the type of heating system installed in the building has a more significant impact on emissions from the sector overall.

4.3.2. Electrification of vehicles

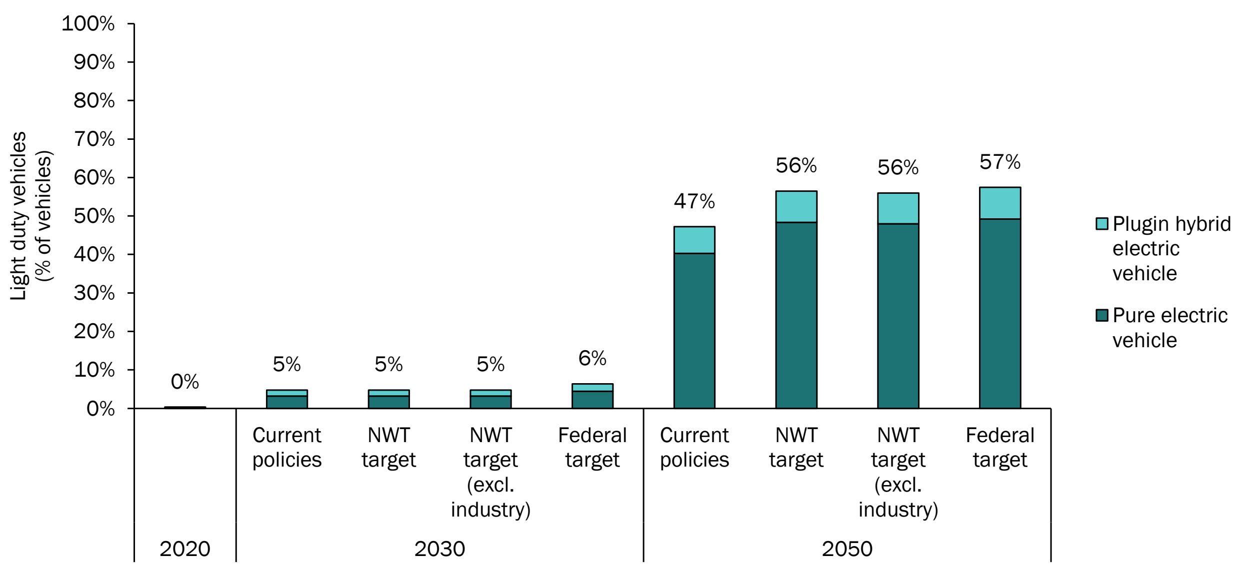
Electrification of vehicles is a key abatement option in the NWT, and the electricity demand form the transportation sector increases significantly over time across all scenarios as illustrated in Figure 15 below. Electricity demand ranges from 36-207 GWh by 2050 under current policies (134 GWh in the reference sensitivity), 50-227 GWh under the NWT target pathway to net zero (164 GWh in the reference sensitivity), and 51-230 GWh under the federal target pathway to net zero (168 GWh in the reference sensitivity).

Figure 15: Utility electricity demand from transportation (range across sensitivities)



The greatest potential for electrification is in light-duty vehicles, with BEVs accounting for 47% of light-duty vehicles on the road under current policies, and 57% under the federal target pathway to net zero in the reference sensitivity (Figure 16).

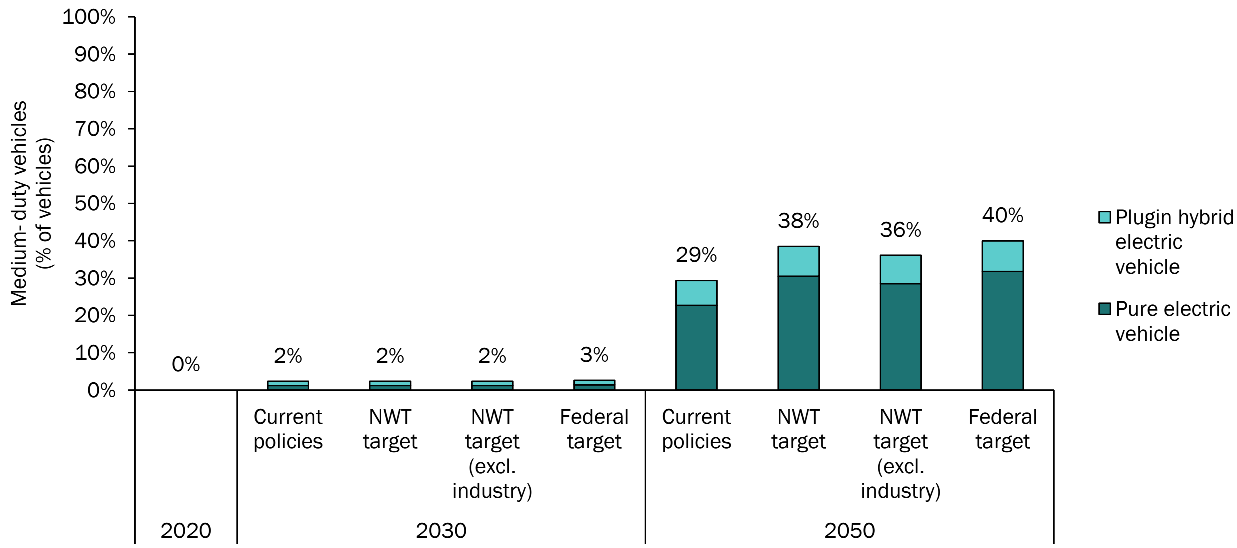
Figure 16: Light-duty vehicles in the NWT (reference sensitivity)



BEVs could also be conductive in many medium-duty vocations, such as delivery vehicles. In the reference sensitivity, BEVs account for 29% of medium-duty vehicles on the road under current policies and 40% under the federal target pathway (Figure

17). To be consistent with net zero, remaining vehicles must run on low carbon fuels like biofuels or hydrogen, discussed in more detail in sections 4.2.1 and 4.5 respectively.

Figure 17: Medium-duty vehicles in the NWT (reference sensitivity)



The level of electrification of transportation in the NWT is dependent on the extent to which the capital cost for low carbon transportation technologies declines over time. If the decline is more significant, BEVs are more cost competitive, making them a more attractive option for achieving net zero emissions in the territory. In a net zero future with low BEV costs, BEVs could account for 71% of light-duty vehicles, and up to 51% of medium-duty vehicles.

4.4. Renewables and batteries

To meet the increases in electricity demand described in the previous section, the NWT's electricity system must increase its generation capacity in response. Addressing emissions from electricity is important because in addition to decarbonizing the utility sector, it enables electrification as an abatement pathway in vehicles and buildings.

The NWT can meet increasing electricity demand (while keeping emissions low) via higher capacity utilization of existing hydro assets, as well as capacity additions of wind and solar. Battery storage can be adopted to facilitate the integration of variable renewables as it helps ensure that electricity supply can match electricity demand at all times of the day.

The rest of this section presents results for the hydro zone and thermal zone including future generation mix and the adoption of electricity storage. Appendix B provides detailed IESD results for each community modeled: Snare[84], Taltson[85], Inuvik, Sachs Harbour, Paulatuk, Fort McPherson, Wrigley, and Ulukhaktok.

4.4.1. Hydro zone

The most cost-effective way to meet increasing electricity demand in the hydro zone is with renewables, including higher capacity utilization of existing hydro assets and installation of wind generation capacity. In many scenarios this is also coupled with installation of batteries. Battery storage is a promising option for integrating variable renewables like wind into the electricity system because it helps ensure that electricity supply can match electricity demand at all times of the day. In other words, electricity storage makes variable renewables more attractive and reduces the need for back-up capacity.

Figure 18 and Figure 19 below show electricity generation by technology type in the hydro zone under two sensitivities on the cost for renewables and batteries. Because the hydro assets in Snare and Taltson (particularly in Taltson) are generating less than their hydrological potential (hydro assets are underutilized)[86], a higher capacity utilization of these assets is a cost-effective way of meeting growing electricity demand in the hydro zone across scenarios simulated.[87] In the current policy scenario, hydro generation increases by 46-48% between 2020 and 2050, while in the federal target pathway it increases by 59-69%.

Due to the high cost of imported diesel, and that the cost of variable renewables is expected to decline over time with technological innovation (see section 2.3.2), wind offers potential to meet new electricity demand in the hydro zone. By 2050, wind makes up 12-13% of generation in the hydro zone under current policies. In the

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[84] Main grid in North Slave.

[85] Main grid in South Slave.

[86] Taltson hydro spills a large amount of water every year due to low demand. For example, in 2015, Taltson had a capacity factor of about 35%, with high enough inflows and storage capacity upstream to sustain a higher utilization if demand were higher (~80% of river's flow is spilled).

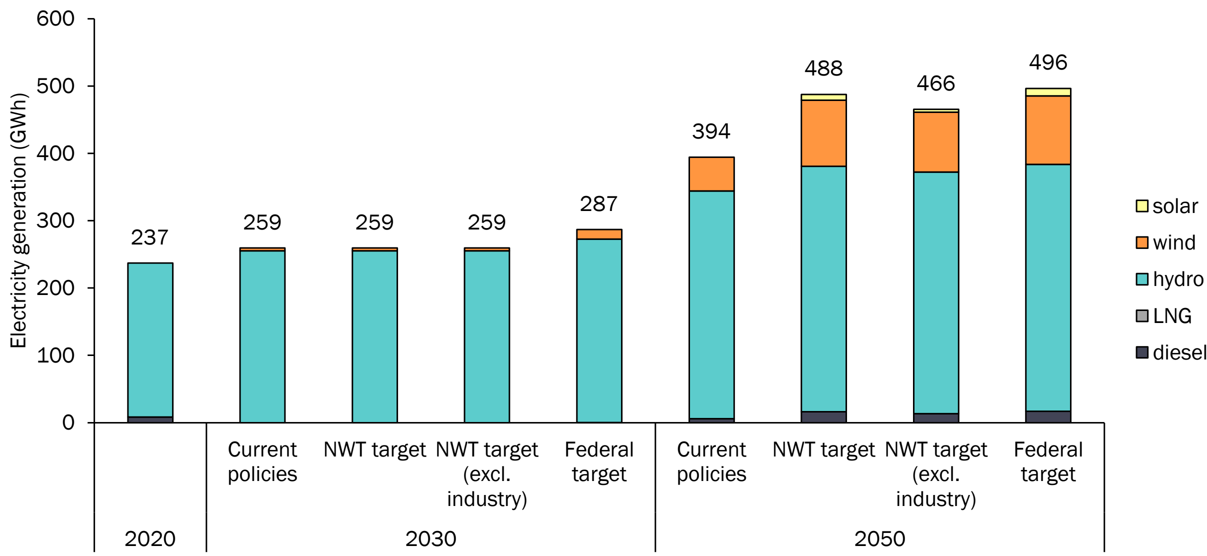
[87] See Appendix A for a detailed description on how hydro assets are modeled in IESD.

federal target pathway to net zero, wind makes up 20-27% of total generation. Most installations occur on the Snare grid, as Taltson has more underutilized hydro assets.

The adoption of solar is more limited, with no adoption occurring under current policies. In a net zero future, solar accounts for a maximum of 7% of total generation under the federal target pathway with all adoption occurring on the Snare grid.

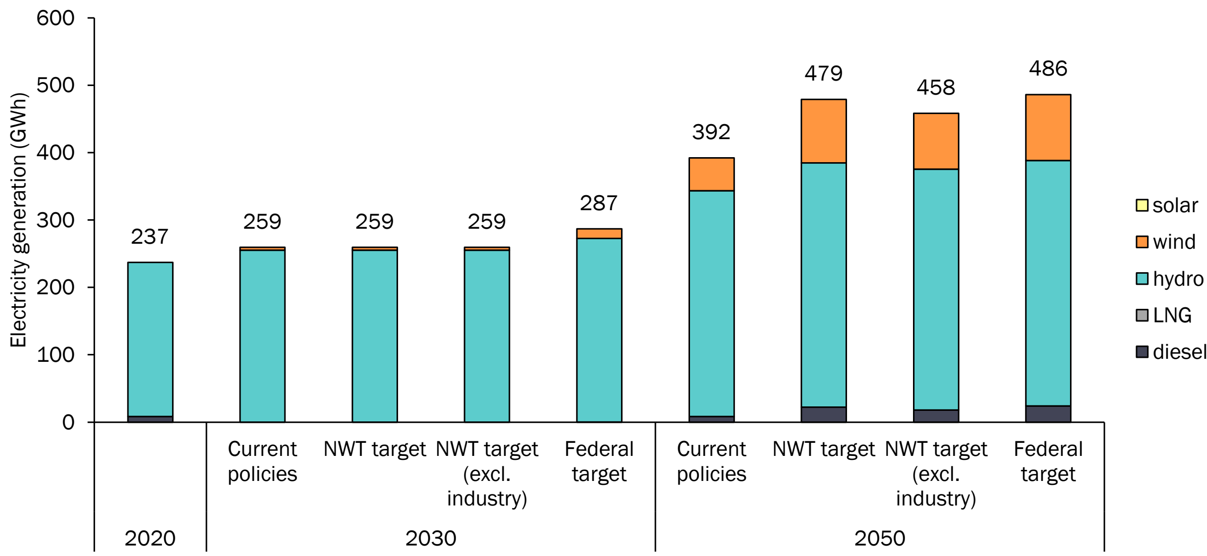
Diesel capacity is maintained to meet system reliability requirements across all scenarios simulated, but is operated at low capacity factors.

Figure 18: Utility electricity generation in the hydro zone (optimistic renewable/battery cost) [88]



88 Reference emerging low-carbon transportation technology costs and no additional climate action in the rest of Canada and the U.S.

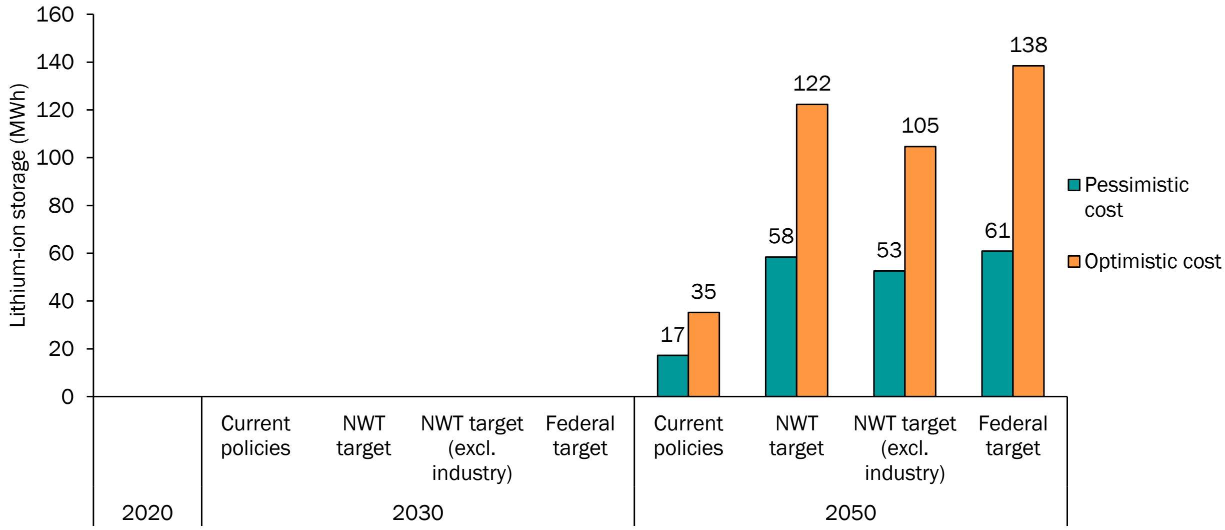
Figure 19: Utility electricity generation in the hydro zone (pessimistic renewable/battery cost)[89]



By 2050, there is significant adoption of batteries in the hydro zone to facilitate integration of variable renewables (Figure 20). Adoption of batteries in the hydro zone ranges from 17-35 MWh under current policies, and from 61-138 MWh under the federal target pathway to net zero. The majority of adoption is occurring in Snare to facilitate installations of wind capacity.

89 Reference emerging low-carbon transportation technology costs and no additional climate action in the rest of Canada and the U.S.

Figure 20: Utility adoption of batteries in the hydro zone[90]



As shown in the figures above, the cost of renewables and batteries impacts the rate of adoption of these technologies; the lower the cost, the greater the adoption. However, the level of climate action in the rest of Canada and the U.S. has the largest impact on the electricity system in the NWT, because of its impact on electricity demand (see section 4.3). When electricity demand is greater, there is greater capacity utilization of hydro assets, more installation of wind, and greater adoption of batteries in the hydro zone.

4.4.2. Thermal zone

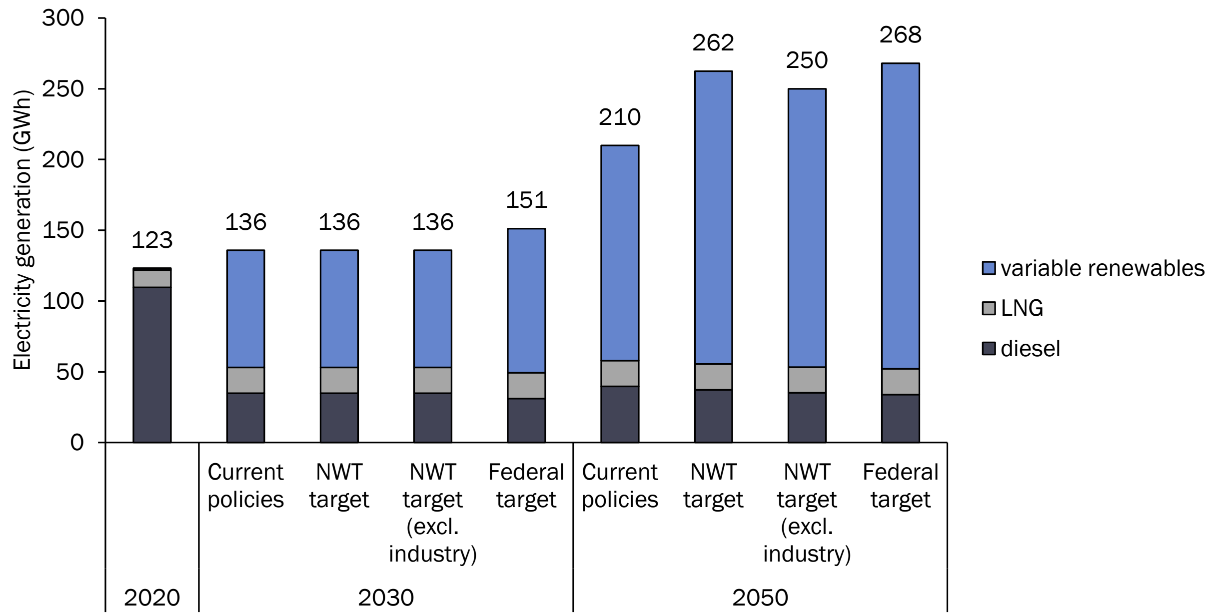
This section reports electricity and battery storage results for NWT's thermal zone. NWT's thermal zone consists of communities that primarily use fossil fuels (i.e., diesel or LNG) for their electricity generation. While six thermal communities were explicitly modeled for this analysis (Sachs Harbour, Paulatuk, Fort McPherson, Wrigley, Ulukhaktok, and Inuvik), covering approximately 76% of the NWT's utility electricity grid, results were extrapolated to report results for all of the NWT's grids. Detailed results for each modeled community are presented in Appendix B.

The most cost-effective way to meet increasing electricity demand in the thermal zone is with capacity additions of variable renewables like wind and solar (Figure 21 and Figure 22). The high cost of imported diesel and liquified natural gas (LNG) coupled with declining costs of variable renewables over time (see section 2.3.2) make solar

[90] Reference emerging low-carbon transportation technology costs and no additional climate action in the rest of Canada and the U.S.

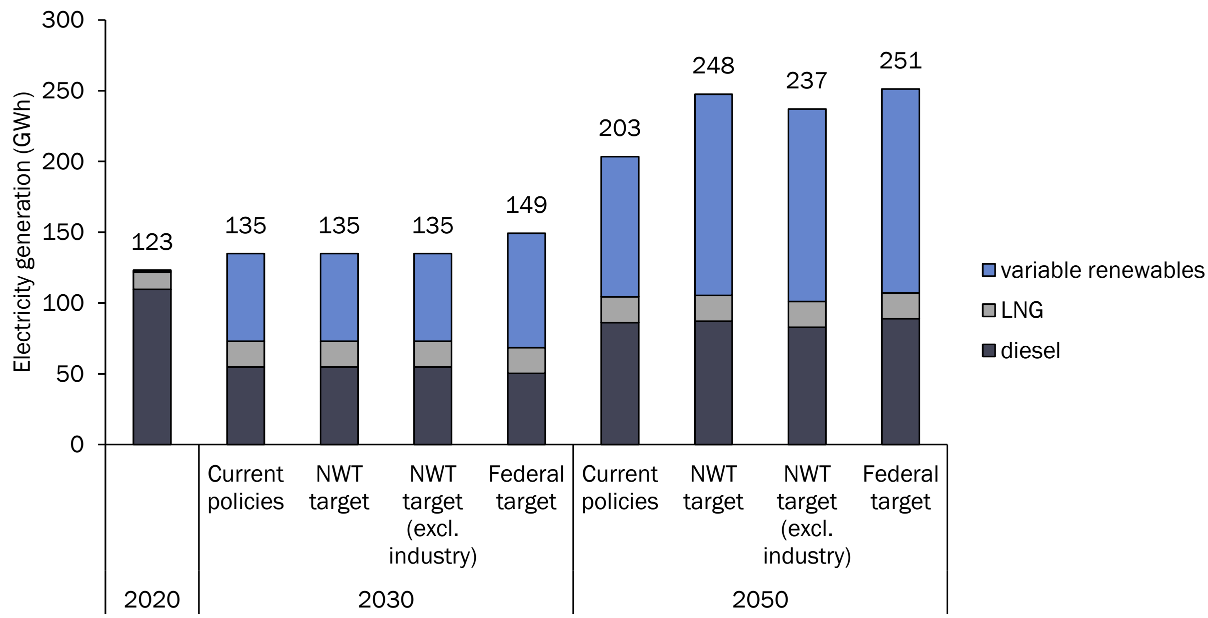
and wind competitive options for supplying electricity in the thermal zone. This is true even under current policy, where wind and solar account for 49-72% of total generation by 2050. Under the federal target pathway to net zero, wind and solar account for an even greater portion of total generation, ranging from 57-84%. The relative competitiveness of wind compared to solar is community specific. See Appendix B for detailed results by modeled community.

Figure 21: Utility electricity generation in the thermal zone (optimistic renewable/battery cost)[91]



91 Reference emerging low-carbon transportation technology costs and no additional climate action in the rest of Canada and the U.S.

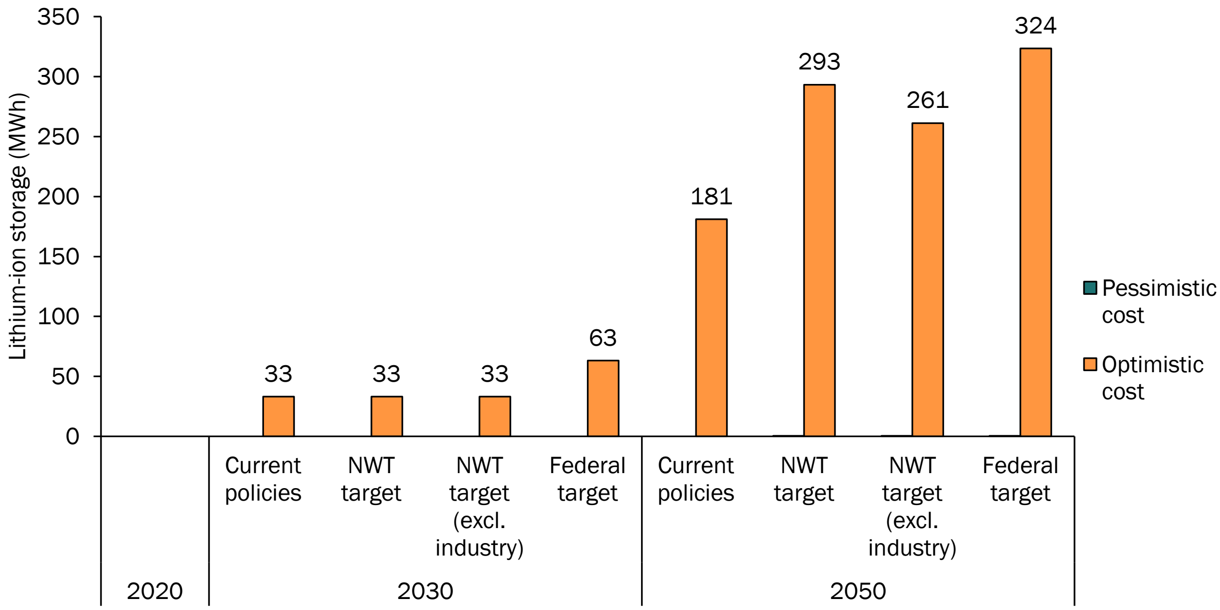
Figure 22: Utility electricity generation in the thermal zone (pessimistic renewable/battery cost)[92]



To maintain system reliability, thermal capacity is preserved across all scenarios simulated but is operated at low capacity factors (e.g., around 10% in most communities). Additionally, there is significant adoption of battery storage in the thermal zone in the optimistic technology cost sensitivity (Figure 23). Batteries facilitate the integration of wind and solar by ensuring that electricity supply can match electricity demand at all times of the day, reducing the need for back-up thermal capacity.

[92] Reference emerging low-carbon transportation technology costs and no additional climate action in the rest of Canada and the U.S.

Figure 23: Utility adoption of batteries in the thermal zone[93]



As shown in the figures above, the cost of renewables and batteries impacts the rate of adoption of solar, wind, and batteries in the thermal zone. However, the level of climate action in the rest of Canada and the U.S. has the largest impact on the electricity system in the NWT, because of its impact on electricity demand (see section 4.3). When electricity demand is greater, there are more installations of wind, solar, and batteries.

Another source of uncertainty which could impact the results shown above, is whether biofuels could be blended into the diesel pool for electricity generation. Depending on the cost of biofuels there will be a crossover point at which it is cheaper to use renewable diesel in an existing thermal generation, than to reduce emissions with adoption of wind and solar. This depends on the cost of biofuels, as well as the capital costs of wind, solar, and battery storage.

4.5. Hydrogen

Hydrogen is a potential abatement option in the NWT if produced using low carbon means. Because transporting hydrogen from other jurisdictions to the NWT is expensive, low carbon hydrogen must be produced in the NWT via electrolysis.

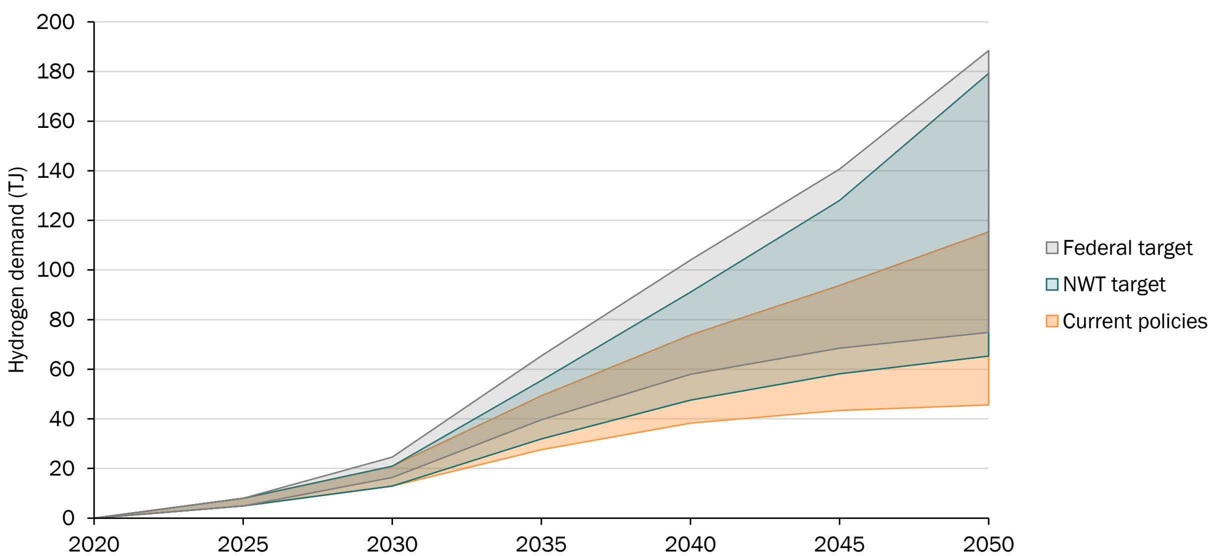
93 Reference emerging low-carbon transportation technology costs and no additional climate action in the rest of Canada and the U.S.

Electrolysis involves using electricity to separate water molecules into hydrogen and oxygen. The carbon intensity can be close to zero if electricity from renewable energy sources is used.

Low carbon hydrogen production via electrolysis relies on renewable electricity capacity. As discussed in section 4.4 there is an increase in renewable capacity across the NWT's electricity grids over time. A high penetration of variable renewables results in times when there is surplus electricity available at very low costs. Using this electricity reduces the energy cost of hydrogen produced via electrolysis.

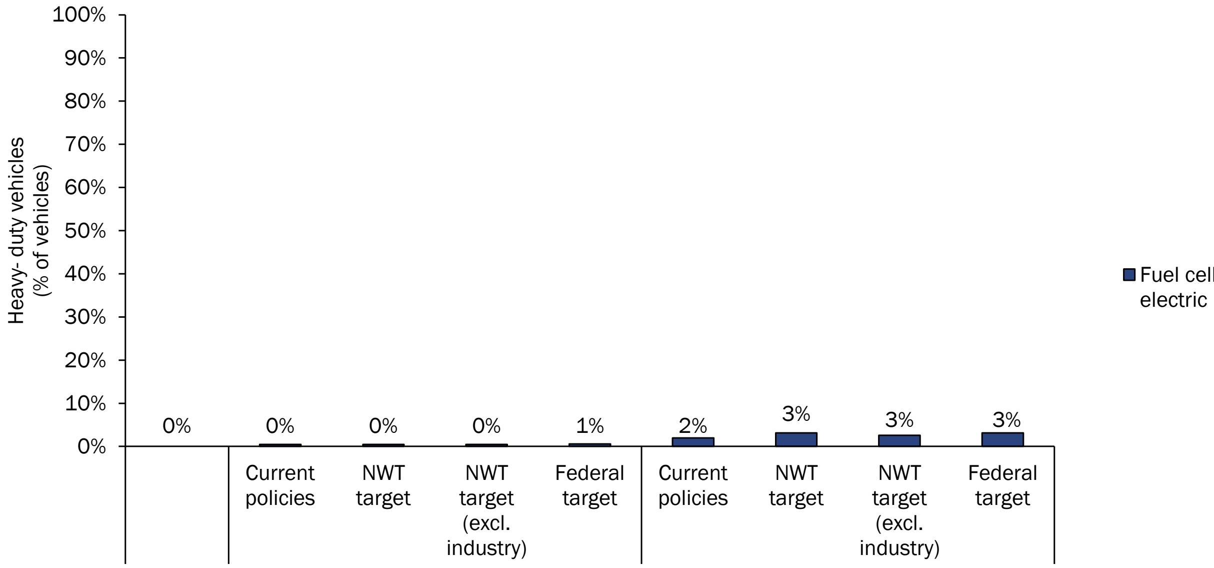
Adoption of hydrogen ranges from 46-115 TJ under current policies (56 TJ in the reference sensitivity), and 65-178 TJ in the federal pathway scenario to net zero (79 TJ in the reference sensitivity) as illustrated in Figure 24 below.

Figure 24: Hydrogen demand in the NWT (range across sensitivities)



Most hydrogen demand occurs in the transportation sector, with heavy-duty vehicles being particularly conductive to the technology. Figure 25 shows the share of heavy-duty vehicles that are fuel cell electric (FCEVs) in the reference sensitivity, reaching 3% by 2050 in a net zero future. Note that results suggest electrification and biofuels remain more competitive options for decarbonizing heavy-duty vehicles in the NWT due to the high cost of production hydrogen in the North.

Figure 25: Heavy duty vehicles in the NWT (reference sensitivity)



Other potential sources of hydrogen demand include process heat in the NWT's mines, and marine, rail and air transportation. Adoption of fuel cell ships, trains and airplanes is highly uncertain due to the limited ability of GNWT to influence the design of interjurisdictional transportation.

The adoption of hydrogen depends on how the cost of technologies and fuel production evolve. Results indicate that adoption of hydrogen is greatest when the cost for emerging low carbon transportation technologies and fuels decline more rapidly over time. Results from this analysis indicate that the cost of hydrogen production via electrolysis is high (over $100/GJ by 2050 in many scenarios), which impacts its attractiveness as a fuel.

4.6. Carbon dioxide removals

Carbon dioxide removals (CDR) involve removing carbon from the atmosphere and storing it in products or in geological, terrestrial, or ocean reservoirs. To achieve net zero, CDR is necessary to counterbalance residual emissions. For example, all pathways considered by the IPCC's most recent Assessment Report that limited global warming to 1.5°C with no or limited overshoot required significant global use of CDR, on the order of 20-660 $GtCO_2e$ over the 21st century.[94]

CDR can take many forms, from new technologies to land management practices. Broadly speaking, CDR options include:

- Natural solutions that use photosynthesis to remove CO_2 from the atmosphere and store it in wood and soil.
- Technological solutions that accelerate or mimic natural processes to remove CO_2 from the atmosphere.
- Ocean-based solutions that facilitate ocean carbon removal systems.

Below, we discuss two options that may be available to help the NWT achieve net zero emissions: natural solutions and direct air capture (a leading technological solution). Ocean-based CDR offsets could also become available in the Northwest Territories, though they are outside the scope of this project and are not discussed further.[95]

4.6.1. Natural solutions

Natural CDR solutions include a suite of protection, improvement, management and restoration actions in forests, grasslands, agricultural areas and wetlands.

A 2021 study by Nature United provides the most comprehensive assessment to date of the mitigation potential from these types of actions in Canada[96]. Its scope is “nature-based solutions”, which encompass pathways to reduce GHGs as well as those that sequester additional carbon in living organisms and soils. In total, it identified 105 Mt of annual offset potential from land-use and forestry measures by 2050, albeit with

[94] IPCC, 2022: Summary for Policymakers. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.001

[95] World Resources Institute. (2022). Ocean-based Carbon Dioxide Removal: 6 Key Questions, Answered. Available from: https://www.wri.org/insights/ocean-based-carbon-dioxide-removal

[96] Drever, C. et al. 2021. Natural climate solutions for Canada. Science Advances 7 (23). www.science.org/doi/10.1126/sciadv.abd6034

a large range of uncertainty. This result has been used to guide assumptions in national net zero analyses for Canada.[97]

The Nature United study provides a regional breakdown for some, but not all, pathways, and provides limited information for options in the territories.

4.6.2. Direct air capture

Direct air capture (DAC) uses chemical reactions to pull CO_2 out of the air. When air moves over these chemicals, they react with and trap CO_2. Most systems today use either liquid solvents or solid sorbents, which are composed of common chemicals that are already in use in other applications, from soap to water filtration.

Once CO_2 is captured from the atmosphere, heat is typically applied to release it from the solvent or sorbent. Captured CO_2 can then be injected underground for geological sequestration or used in various products, such as concrete. DAC can also be used to produce synthetic fuels, which could be carbon neutral (though not negative).

According to the International Energy Agency, there were 18 direct air capture plants operating around the world as of late 2022. While most of these plants are for testing and demonstration purposes, plans for a total of eleven more facilities are now in advanced development.[98] The first large-scale DAC plant, capturing up to 1 $MtCO_2$ annually, is anticipated to become operational in the U.S. in the mid-2020s. This project uses technology developed by Carbon Engineering, which has been capturing CO_2 from the air since 2015 at its pilot plant in Squamish, British Columbia.

Figure 26 summarizes estimates of the levelized cost of carbon capture from DAC, which are used to parameterize the technology in gTech. Costs today are relatively high (over $410/t), reflecting the emerging nature of this technology and its current low level of deployment. However, boosting the deployment of DAC could bring costs down to between $120/t and $217/t in the future.

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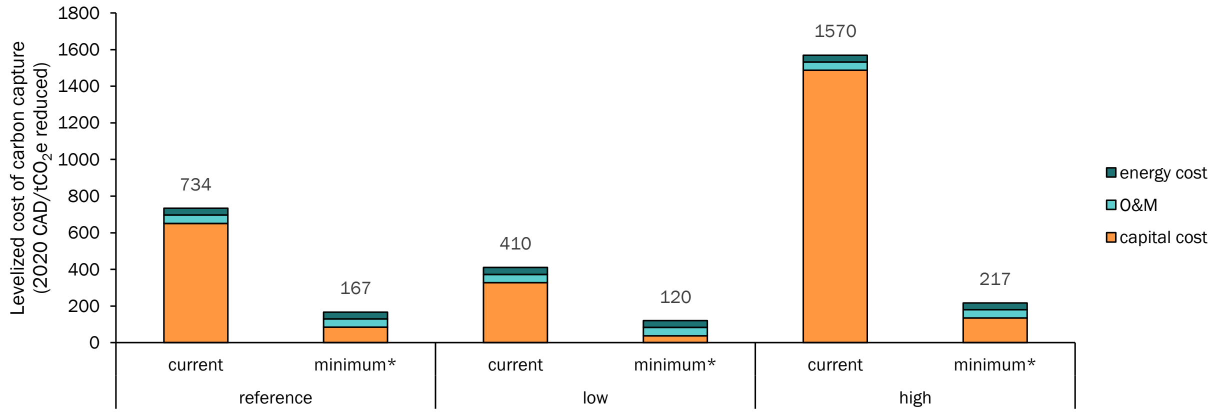
[97] For example, see: Navius Research. 2021. Achieving net zero emissions by 2050 in Canada: An evaluation of pathways to net zero prepared for the Canadian Climate Institute. https://www.naviusresearch.com/publications/climate-choices-net-zero/

[98] International Energy Agency. 2022. Direct air capture. https://www.iea.org/reports/direct-air-capture

Figure 26: Levelized cost of carbon capture from DAC



*Future minimum costs are based on 1557 Mt CO_2 of capture.

Parameterization based on: Fasihi et al. (2019). Techno-economic assessment of CO2 direct air capture plants. Journal of Cleaner Production, 224, 957-980; Larsen et al. (2019). Capturing Leadership, Policies for the US to Advance Direct Air Capture Technology. Rhodium Group; Keith et al. (2018). A process for Capturing CO2 from the Atmosphere. Joule, 2, 1-22. Costs harmonized using a 15% discount rate, 30-year life, $27.13/GJ electricity price, and $2.64/GJ natural gas price (2020 CAD).

In the NWT, DAC could be sufficient to offset hard to decarbonize source of emissions, such as in the mining sector. The implication of pursuing DAC as a net zero strategy is that the NWT's emissions (as currently tracked by the NIR) would have some positive value that would then be offset via DAC (likely operated in Alberta or Saskatchewan). Yet another option would be for the NWT to purchase DAC credits from other jurisdictions (e.g., outside North America, in locations with especially high renewable energy availability and geological sequestration potential).

5. What is the cost of achieving deep emissions reductions in the NWT?

This section explores the cost of achieving deep emissions reductions in the NWT. Section 5.1 presents the abatement cost (in $/tCO_2e$) of the pathways to net zero, and section 5.2 reviews the potential impact on GDP, investment, and jobs.

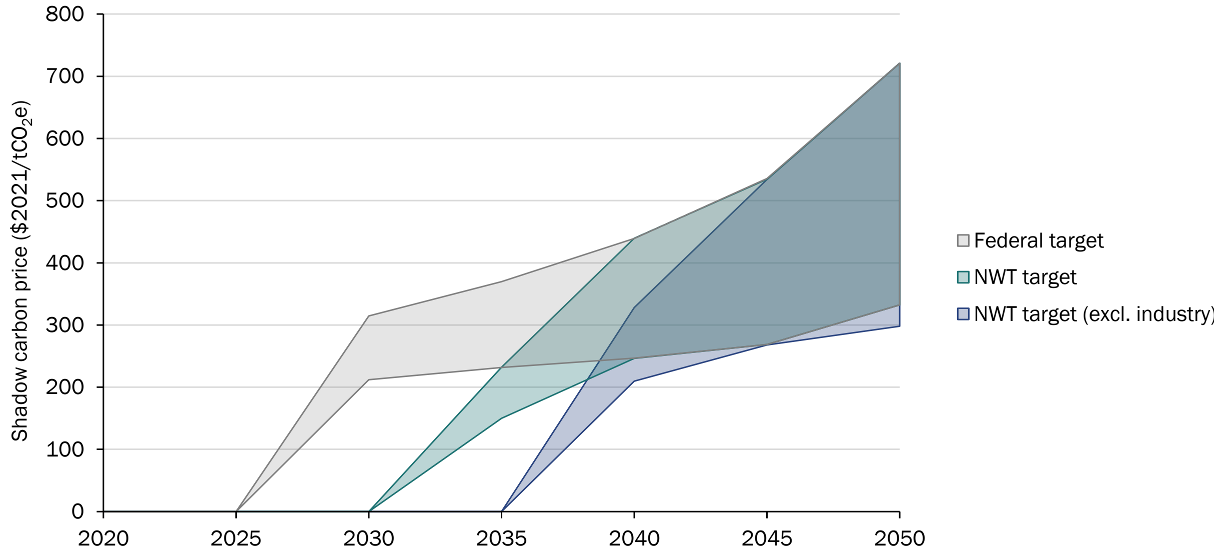
5.1. Abatement cost

The shadow carbon price is a measure of the marginal abatement cost, or the level of policy stringency required to meet an emissions target. Figure 27 shows the shadow carbon price for the three pathways scenarios across all sensitivity scenarios simulated.

The NWT is on track to meet its 2030 target, so the shadow carbon price is zero in 2030 under the NWT target pathway. In other words, no additional emissions reductions are required. Achieving a 45% reduction in emissions in 2030 implies a shadow carbon price of $212-315/tCO_2e$ ($262/tCO_2e$ in the reference sensitivity), while achieving net zero by 2050 implies a carbon price of $300-700/tCO_2e$ ($411/tCO_2e$ in the reference sensitivity).

The implication is that achieving these targets would require policy that encourages all abatement actions up to these prices, whether it's an actual carbon price set at this level or a package of non-pricing policies that induce similar abatement actions.

Figure 27: Abatement cost of achieving climate targets in the NWT (range across scenarios)



Uncertainty in the abatement cost of achieving net zero is demonstrated by the range of observed costs in 2050 ($300-700/t$CO_2$e). Results suggest that the cost is likely to be lowest when the capital cost of emerging low carbon transportation technologies and fuels declines more significantly than reference estimates. On the other hand, the cost is highest when the rest of the U.S. and Canada also implements stringent climate policy. Action on climate change in other jurisdictions increases the demand for bioenergy across the continent, which drives up the price of agricultural commodities (e.g., soy) used in the production of biofuels which is the marginal abatement action in the NWT.

While this analysis accounts for a reasonable range in the cost of emerging low carbon technologies and fuels, technological innovation could move more rapidly than anticipated. Due to the potential for unforeseen technological breakthroughs, the reported abatement costs should be considered an upper boundary.

Similarly, as described in section 4.6, the use of carbon dioxide removal (CDR) offsets could also lower cost of achieving net zero emissions.

5.2. Economic impacts

Achieving deep emissions reductions requires firms and households to switch to low carbon technologies and fuels. These fuels and technologies tend to be more expensive than fossil fuel alternatives, and as such impose costs on the economy. For example, plug-in electric vehicles have higher upfront costs than conventional internal combustion engine vehicles. Likewise, renewable fuels (e.g., biofuels) are more costly than fossil fuels.

In the absence of additional policies, the NWT's GDP grows at an average annual rate of 0.76% from 2030 to 2050. In the net zero scenarios, this rate of growth is reduced to between 0.49% and 0.55% (Figure 28). In other words, GDP still grows, but it grows more slowly when the NWT pursues deep decarbonization.

GDP growth is highest when the emissions constraint excludes industry (0.55%) and lowest when it applies to the entire economy (0.49%). Undertaking greater abatement in the near term (i.e., in 2030) reduces the economic impact by mid-century by more evenly spreading out abatement effort over time (0.54%).

As a reminder, net zero in this analysis is defined as a virtual elimination of all energy-related emissions tracked by the National Inventory Report (NIR). As outlined in section 4.6, an alternative definition could enable carbon dioxide removals (CDR) to offset emissions from hard to decarbonize sources. The use of CDR (based on national availability of nature-based solutions and direct air capture) approximately halves the economic impact, with GDP growing at an average annual rate of 0.68% between 2030 and 2050 in the NWT.

Figure 28: Average annual GDP growth rate between 2030 and 2050 in the NWT (reference sensitivity)

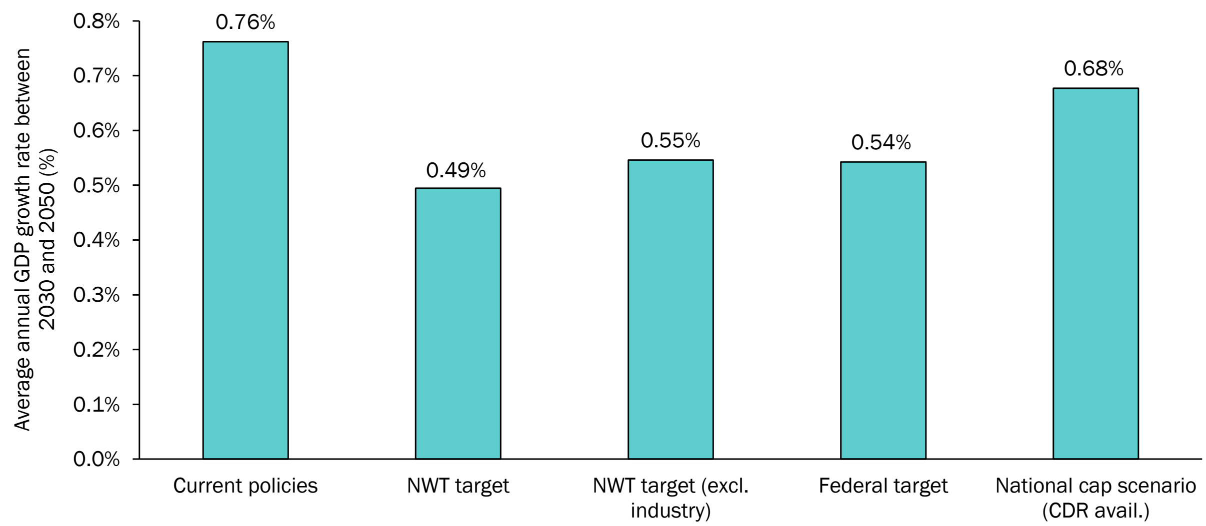


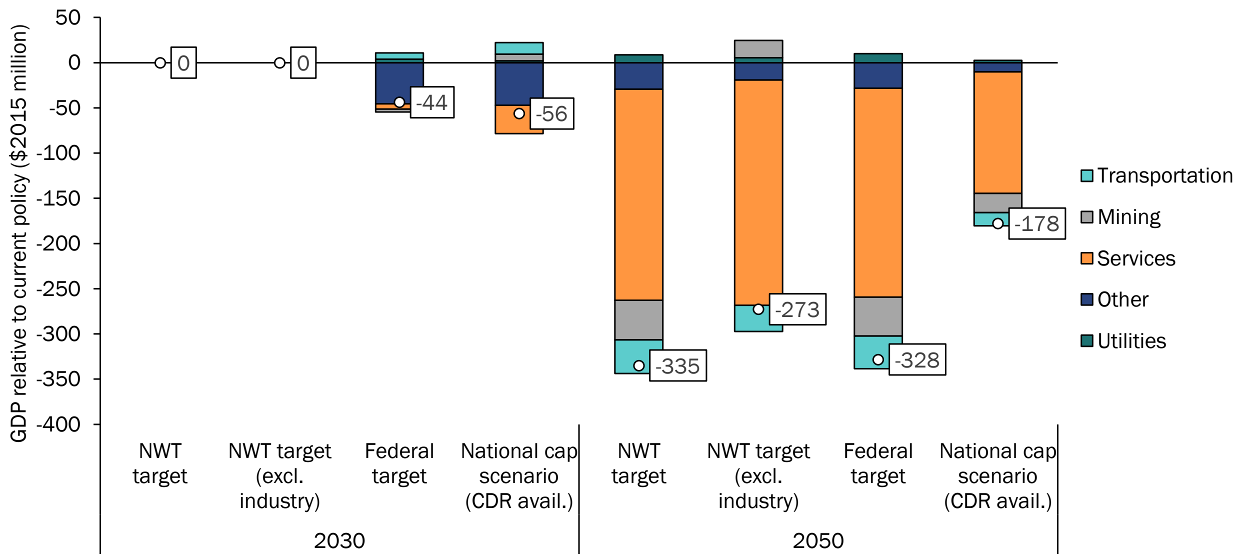
Figure 29 below shows GDP in the NWT in the pathways scenarios relative to current policies in 2030 and 2050. The reduction in GDP is driven by the services and transportation sectors across all pathways scenarios due to lower demand across the economy and increased costs for the sectors (e.g., through increased fuel costs).

In most pathways scenarios there is also a decline in GDP from the mining sector. Additional climate policy increases the cost of production, driving down activity in the sector. Mining GDP is $44 billion lower in the NWT target scenario in 2050. On the other hand, if industry is excluded from the emissions constraint, mining GDP is not adversely affected.

Note that the GDP impact of deep decarbonization on the mining sector is heavily dependent on the future growth of mining activity. Put another way, the impact of alternative scenarios for mining growth – before the imposition of climate policy – could have a greater impact on mining GDP than the imposition of additional carbon constraints.

Achieving net zero increases GDP from the electricity sector because deep decarbonization increases electricity demand through electrification of vehicles and buildings (see section 4.3). For example, GDP is $9 million greater in the NWT target scenario compared to under current policies in 2050.

Figure 29: GDP in the NWT under pathways scenarios relative to under current policies (reference sensitivity)



Achieving deep emissions reductions in the NWT also impacts investment and jobs in the territory, as shown in Figure 30 and Figure 30 below. Impacts on investment and jobs largely mirror the changes to GDP. Investment and job impacts are greatest in scenarios where the NWT as a whole achieves net zero, less if industry is excluded from additional emissions constraint, and least when CDR is available.

Across all pathways, the reduction in investment and jobs is concentrated in the transportation and services sectors. However, all pathways to net zero imply greater investment and jobs in the utilities sector in response to increases in electricity demand (see section 4.3). While jobs in the mining sector mirror the GDP impacts, investment is higher in the mining sector across all pathways scenarios due to additional investment in abatement options.

Figure 30: Investment in the NWT under pathways scenarios relative to under current policies (reference sensitivity)

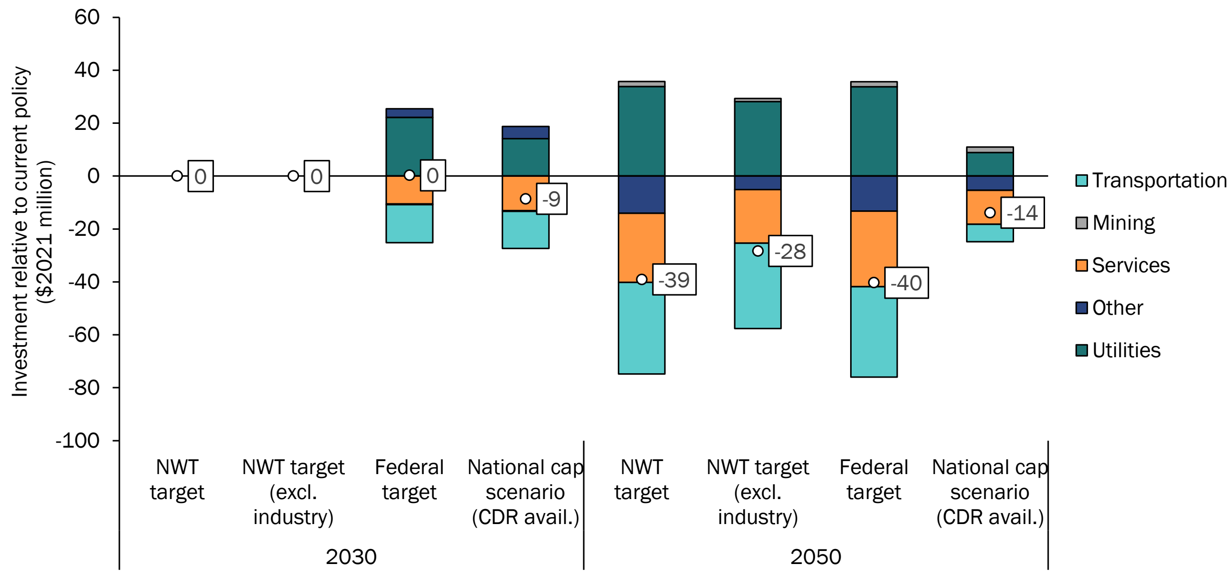
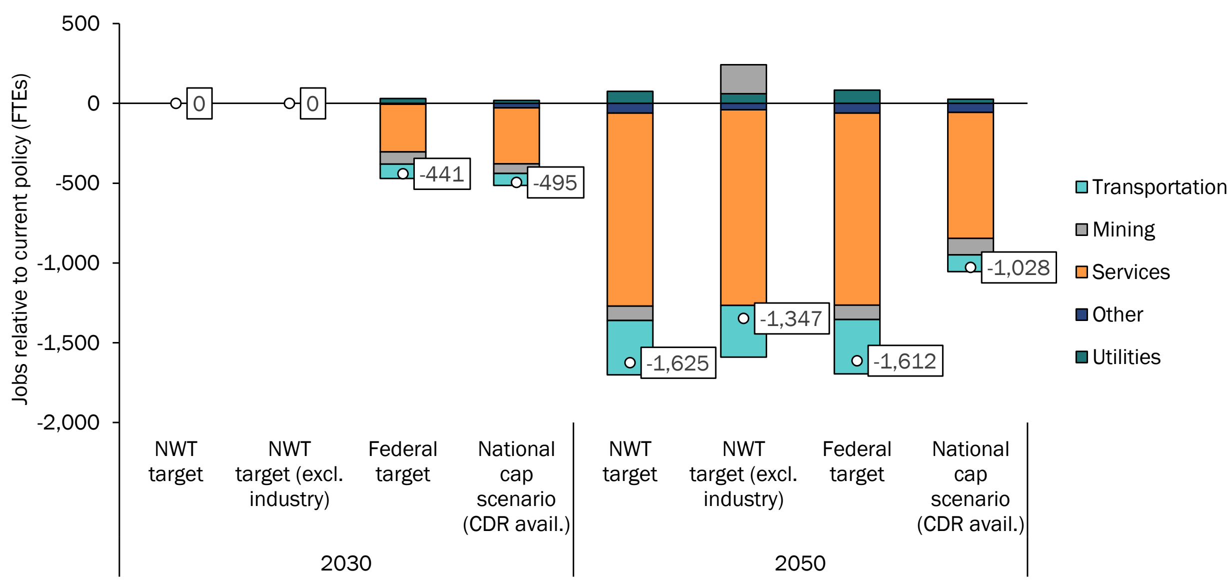


Figure 31: Change to the NWT's jobs under pathways scenarios relative to current policies (reference sensitivity)



Lastly, note that the economic impacts presented in this section may be overstated for the following reasons:

- They do not account for the benefits of avoided climate change.
- They do not account for all abatement options (e.g., small modular nuclear reactors, renewable electricity generation in mines).

- Federal transfers could reduce the cost of investments in low carbon technologies and fuels (this analysis is policy agnostic and does not simulate additional transfers from the federal government).

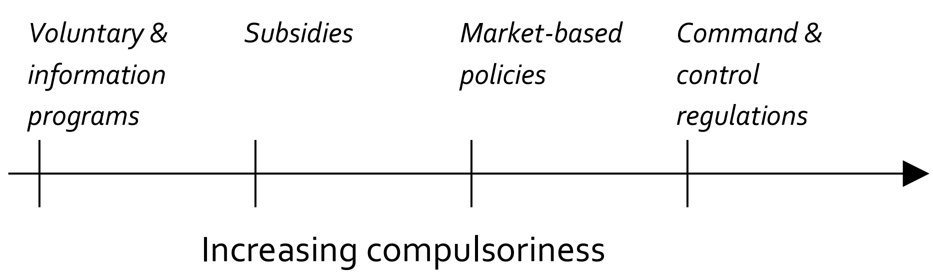
The design of climate policy also influences the economic impacts of achieving deep decarbonization. The next section outlines potential policy options that could be used to achieve deep decarbonization in the NWT.

6. What are policy options for achieving emissions reductions in the NWT?

This section provides an overview of the types of policies that could be implemented or expanded in the NWT to reduce emissions. It also identifies examples of policies implemented elsewhere that are consistent with net zero.

Policies can be categorized based on their compulsoriness, or the degree to which certain technologies or practices are required by government. As shown in Figure 32, the left end of the spectrum depicts policies that are completely non-compulsory in which government simply encourages voluntary behaviour by consumers and businesses. The right end of the spectrum depicts policies that require a specific action.

Figure 32: Spectrum of policy compulsoriness



Adapted from: Rivers & Jaccard. 2005. Canada's efforts towards greenhouse gas emission reduction: a case study on the limits of voluntary action and subsidies. *Int. J. Global Energy Issues, 23*(4): 307-323.

6.1. Voluntary and information programs

Voluntary and information programs encourage consumers and businesses to undertake an action. Government functions as information provider, facilitator or role model. For example, government might provide information about the benefits of electric vehicles by operating public trials and demonstration programs. Due to their voluntary nature, such policies are insufficient for achieving deep emissions reductions.

6.2. Subsidies

Subsidies or financial incentives offer financial returns to those who take specified actions to reduce emissions. The financial returns could be in the form of grants, low-interest loans and tax credits. For example, government could subsidize the purchase of electric vehicles or invest in charging infrastructure.

Subsidies could achieve deep levels of emissions reductions in targeted end-uses (e.g. home heating, light-duty vehicle travel) if they are strong and long-lasting (i.e., over a period of one to two decades). An example of strong incentives, of the scale required to achieve decarbonization, is Norway's electric vehicle program. This program has provided tens of thousands of dollars per electric vehicle, including the value of incentives and disincentives on conventional vehicles.[99]

6.3. Market-based policies

6.3.1. Carbon pricing

Carbon pricing imposes a cost on greenhouse gas emissions, providing a financial disincentive for consumers and businesses to use fossil fuels. This policy can be implemented via a carbon tax, cap-and-trade or tradable performance standard. These policies don't specify a particular action (i.e., individuals may choose between taking no action to reduce emissions and paying taxes, or reducing emissions in order to pay less tax).

Carbon pricing could be strengthened to achieve net zero emissions. Analysis for GNWT suggests that a carbon price of several hundred dollars per tonne is likely required to decarbonize the NWT's energy system. We are not aware of any jurisdictions that have implemented carbon pricing at this level.

6.3.2. Flexible regulations

Flexible regulations adopt the market-oriented approach of carbon pricing but apply it to specific sectors. In practice, this policy can look like a tradable performance standard that sets a target (e.g. greenhouse gas emissions intensity) while providing firms and consumers the flexibility to minimize compliance costs. Examples of flexible

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[99] Norsk elbilforening. *Norwegian EV policy*. Available from: https://elbil.no/english/norwegian-ev-policy/

regulations include vehicle emission standards and low-carbon fuel standards. Neither of these policies require the adoption of a specific technology by a specific firm or household.

Flexible regulations can be strengthened to be consistent with net zero (e.g. ZEV standards can reach 100%, vehicle emission standards can reach 0 grams of CO_2e per 100km and low carbon fuel standards could require a 100% reduction in carbon intensity).

Light-duty zero emission vehicle mandates consistent with net zero have been implemented in California[100] (100% by 2035) and announced federally in Canada[101] (100% by 2035). California's medium and heavy-duty zero emission vehicle mandates are also likely consistent with net zero if remaining internal combustion engine vehicles operate on zero carbon liquid fuels. Similarly, the federal Emissions Reduction Plan (ERP) also announced plans to develop a medium- and heavy-duty ZEV sales mandate with the goal of achieving 35% ZEV sales by 2030 and 100% by 2040 in selected medium- and heavy-duty categories, based on feasibility.[102]

6.4. Command and control regulations

Command and control regulations require specific actions be taken, with noncompliance incurring stringent financial or legal penalties. For example, government could ban the purchase, sale or installation of technologies reliant on fossil fuels (or require the adoption of zero carbon technologies).

Some examples of regulations consistent with deep emissions reductions include:

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[100] Office of Governor Gavin Newsom. (2020, September 23). *Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuel in California's Fight Against Climate Change.* Available from: https://www.gov.ca.gov/2020/09/23/governor-newsom-announces-california-will-phase-out-gasoline-powered-cars-drastically-reduce-demand-for-fossil-fuel-in-californias-fight-against-climate-change/

[101] Government of Canada. (2022). *Canada's Zero Emission Vehicle (ZEV) sales targets*. Available from: https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/canada-s-zero-emission-vehicle-zev-sales-targets

[102] Environment and Climate Change Canada. (2022). *2030 Emissions Reduction Plan.* Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

- Banning the use of fossil-fired heating in new buildings (ban on heating oil in new homes in Québec as of 2023[103]; ban on all fossil-fired heating proposed in the United Kingdom by 2025[104] and Washington state by 2030[105]).
- Banning the sale of new light-duty vehicles with internal combustion engines (as proposed by several countries and municipalities, with the earliest being Norway by 2025[106]).
- Renewable portfolio standards requiring that all electricity generation be from renewable sources (for example, BC[107]).

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103 CBC News. (2021). *Quebec bans oil heating in new homes starting Dec. 31.* Available from: https://www.cbc.ca/news/canada/montreal/quebec-bans-oil-heating-1.6252420

104 EDF. (2020). *UK Gas Boiler Ban - Everything You Need to Know.* Available from: https://www.edfenergy.com/heating/advice/uk-boiler-ban

105 Governor Jay Inslee. (2020). *Inslee announces bold climate package for 2021–2023 biennium.* Available from: https://www.governor.wa.gov/news-media/inslee-announces-bold-climate-package-2021%E2%80%932023-biennium

106 Reuters. (2020). *Fossil fuel-based vehicle bans across the world.* Available from: https://www.reuters.com/article/climate-change-britain-factbox-idINKBN27Y19F

107 BC Laws. *Clean Energy Act. SBC 2010, ch 22.* Available from: https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/10022_01

Appendix A: Modeling of renewables in IESD

This Appendix provides additional details on how hydro, solar and wind is modeled in IESD.

Hydrological module

The hydrological module is intended to provide a general representation of how hydro assets are utilized in the NWT, and their potential flexibility in helping to integrate other renewable generation sources like wind or solar. Model parameters were derived from NTPC's water licenses and the real-world operating characteristics of NTPC's individual hydroelectric generators.

The remainder of this section provides some background on hydroelectric generation in the NWT, describes the mathematical structure of the model, and presents the input assumptions for the Snare, Bluefish, and Taltson systems.

Background

The Snare grid has five hydroelectric generators: four cascading dams on the Snare River, and the Bluefish Hydro facility on Bluefish Lake. In periods of low inflows, generation on the North Slave system is constrained by water availability, causing NTPC to rely on diesel generation. Each generator (including those with two turbines) is modeled as a single facility in IESD, with water availability for each of the lower three Snare River facilities constrained by the turbine discharge and spillage of each of the upstream facilities. The Snare grid also has the Bluefish Hydro generator independent of the Snare Facilities, which contributes 15-25% of the total hydro generation on the grid.

The Taltson grid has one hydroelectric facility, Taltson Hydro. The Taltson Hydro facility is 18 MW, compared to an estimated 200 MW of generation potential from the site.[108] Due to the large inflow of water, generation on this system is not constrained by inflows; most of the Taltson River passes through the spillway instead of the hydroelectric generator.

[108] Government of Northwest Territories, Taltson Hydroelectricity Expansion Project, Available from: https://www.inf.gov.nt.ca/en/Taltson

Model structure

IESD is a linear programming model that optimizes generator dispatch and operation of control structures in every hour of the year to minimize total system cost. When integrating variable renewable capacity such as wind and solar, or battery energy storage, the model simulates how to shift hydroelectric generation from one hour to the next in a manner that remains limited by seasonal inflows and that respects water license conditions. The hydroelectric facilities are represented by 11 equations in the linear program:

(1) **Generation is linearly proportional to turbine discharge**: electrical output is equal to:

$$Generation(MW)\ \alpha\ \left(Discharge\ - Minimum\ turbine\ flow\left(\frac{m^3}{s}\right)\right) * Potential\ \left(\frac{MJ}{m^3}\right)$$

Where "discharge" is the decision variable for the model, and "Minimum turbine flow" and the "Potential" constant are fixed parameters derived from a linear fit of turbine characteristics. Calculation of these parameters is discussed below.

(2) **Turbine capacity**: Generation from (1) must be less than the capacity of the facility.

(3) **Outflows**: outflows from a facility are equal to discharge from (1) plus spillage from the facility.

(4) **Inflows**: hourly inflows are equal to outflows from (3) from any upstream dams, plus the exogenous seasonal inflows into the river system.

(5) **Changes to reservoir level**: the change in hourly forebay level at a facility is equal to inflows minus outflows, divided by reservoir surface area

(6) and (7) **Minimum flow and maximum**: Outflows from (3) must be greater than the specified minimum in the water license and less than the maximum.

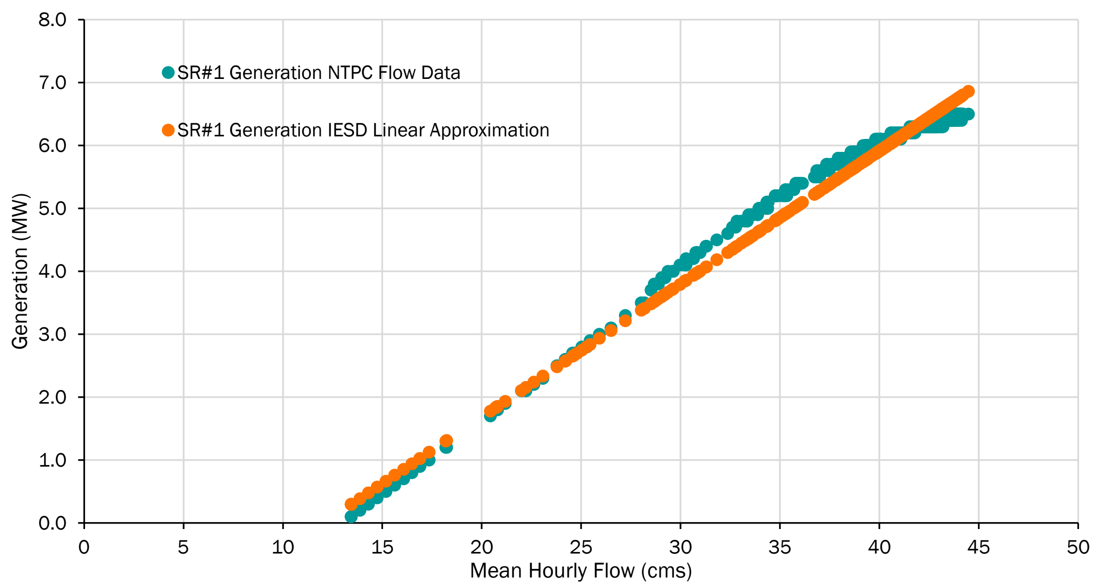
(8) and (9) **Minimum and maximum reservoir levels:** the reservoir level at a facility must be more than the minimum and less than the maximum level, in meters, specified in the water license.

(10) and (11) **Upwards and downwards ramping constraints**: the facilities can be constrained to respect constraints on how much water flows can change from one hour to the next[109].

With estimated monthly upstream flows on the Snare, Yellowknife, and Taltson rivers, the model uses these equations to optimize turbine discharge and spillage on an hourly basis at each facility to minimize cost.

Hydroelectric turbine parameters in equation (1) were derived by creating a linear fit of NTPC's historic flow and generation data for each hydro facility. The case of the Snare Rapids facility is shown in Figure 33, below. The actual turbine has a non-linear relationship between flow and generation above the minimum turbine flow (the point at which flow is great enough to produce non-zero generation), shown in green. A linear fit represents this data quite closely, shown in orange, where the minimum turbine flow parameter is the x intercept of the line, and the potential parameter is the slope. The same calculation was performed for the four Snare sites and Bluefish Hydro[110].

Figure 33: IESD representation of Snare Rapids turbine characteristics



[109] No ramping constraints were found in the water licenses, but these were set at a 10 cms change from one hour to the next in IESD. Absent some constraint (or cost) on hourly changes to flow, the decision to spill in one or another has no cost in the model, causing physically impossible outcomes in which an entire months' spillage is completed in one hour, with zero spillage for the next month.

[110] For Taltson Hydro, the reported net head of the facility was used to calculate potential per cubic meter, and a minimum flow of zero was used. Historic turbine flow data was not provided for Taltson so a simpler approach was used.

Snare River System

NTPC provided Navius with seven years of hourly data regarding the operation of its hydroelectric facilities, including forebay level, discharge, and spillage at each of the facilities. Model inflows into Big Spruce Lake are the 2015-2021 average values, calculated as the change in reservoir volume between the first of each month, plus outflows from the Snare Rapids facility. These estimates are shown in Table 15 below.

Table 15: Inflows into Big Spruce Lake used in IESD

Month	Inflow (cms)
Jan	29
Feb	21
Mar	16
Apr	12
May	31
Jun	58
Jul	103
Aug	75
Sep	56
Oct	52
Nov	50
Dec	41

Facility parameters were found in public documents online and or estimated from the hourly data provided by NTPC. The values used in the model are shown in Table 16.

Table 16: Facility Parameters in IESD

Facility	Reservoir Surface Area (km2)	Minimum allowable level (m)	Maximum allowable level (m)	Minimum license flow (cms)	Maximum license flow (cms)	Minimum turbine flow (cms)	Potential (MW/cms)
SR	131	217.9	222.3	0	52.8	12.0	0.21
SF	6	201.8	202.4	0		6.4	0.20
SC	0.3	182.6	183.3	0		2.8	0.09
SK	11	173.2	173.8	0		5.7	0.15

Sources:

1. Surface area: NWT Power Company, December 2000, Snare Hydro Reservoirs Mapping and Area/Capacity
2. Water license constraints: Wek'èezhil Land and Water Board, 2013, Water license N1L4-0150 Amendment

3. Turbine flow/net head: Navius calculation from NTPC hourly data. Potential was calculated using a linear regression of the relationship between hourly turbine discharge and hourly generation.

Bluefish Hydro

The Bluefish facility is a smaller contributor to electricity generation than the Snare River facilities, with Bluefish representing 15-25% of the generation on the Snare grid between 2015 and 2021.

The main water storage for Bluefish is Duncan lake, Northeast of where the hydro dam is located.[111] Duncan lake has a control structure allowing NTPC to control flows in an out of Bluefish lake. To simplify this structure, IESD treats Duncan as the forebay for the Bluefish facility.

The hourly and daily hydrological data provided by NTPC appears to have measurement issues for flow and level at Duncan lake: both outflows and level are effectively constant for every month of the year, for every year 2015-2021. Given the highly seasonal variation of flows and levels for the Snare facilities and that the constant Duncan mean level is not equal to the top of the spillway, we assume this is a data quality issue (or we are misinterpreting its meaning). Further, the daily water level data from Environment Canada shows much larger variation.[112]

Due to these measurement issues in NTPC dataset, we created a proxy for water availability for the Bluefish facility by using the same monthly profile as the Snare system but adjusted to match the total annual discharge from the Bluefish Hydro facility. These estimates are shown below.

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[111] NTPC, October 2010, Bluefish Hydro Facility Draft Abandonment and Restoration Plan

[112] Environment Canada, Daily Water Level Graph for DUNCAN LAKE NEAR YELLOWKNIFE (07SB012) [NT], Available from: https://wateroffice.ec.gc.ca/report/historical_e.html?stn=07SB012&dataType=Daily&parameterType=Level&year=2017&mode=Graph

Table 17: Assumed Inflows into Duncan Lake used in IESD

Month	Inflow (cms)
Jan	14
Feb	10
Mar	8
Apr	6
May	15
Jun	29
Jul	51
Aug	38
Sep	28
Oct	26
Nov	25

The following parameters are used to constrain facility operation:

Table 18: Bluefish Hydro Parameters in IESD

Facility	Reservoir Surface Area (km2)	Minimum allowable level (m)	Maximum allowable level (m)	Minimum license flow (cms)	Maximum license flow (cms)	Minimum turbine flow (cms)	Gross Heat (m)	Poten tial (MW/ cms)
BH	68	209.5	212.5	6	n/a	0	33	0.23

Sources:

1. Surface area: NTPC, October 2010, Bluefish Hydro Facility Draft Abandonment and Restoration Plan, Navius calculation from data on Page 3

2. Water license constraints: Mackenzie Valley Land and Water Board, March 10, 2021, Type A Water Licence MV2020L4-0005

3. Turbine flow/potential: Navius calculation from NTPC hourly data. Potential was calculated using a linear regression of the relationship between hourly turbine discharge and hourly generation.

Taltson Hydro

The Taltson Hydro facility provides generation on the Taltson grid. Compared to the facilities on the Snare grid, hydroelectric generation at the Taltson facility is less constrained by inflows; water use for generation is a small portion of overall river flows.

In 1968, a dam and control structure were built on Nonacho lake, providing a relatively large storage reservoir upstream from the Twin Gorges hydroelectric dam. In IESD, a simplifying assumption of having the hydroelectric dam on Nonacho lake is used.

Environment Canada data for "Taltson River Below Hydro Dam" was used to calculate average monthly inflows[113] (flow data was not available from NTPC). This data correctly represents the flow available to the hydro generator, but overstates the flow into Nonacho lake, the catchment for which reflects about half of the total for the hydro generator. The impact of this assumption is that the reservoir would be able to fill up faster during the freshet than would actually be the case. Given the comparatively low water use of the hydroelectric generator (10-20% of river flow), we do not expect this simplification to materially affect results.

Table 19: Inflows to Taltson Hydro in IESD (1996-2021 average)

Month	Inflow (cms)
Jan	177
Feb	144
Mar	121
Apr	115
May	176
Jun	259
Jul	293
Aug	258
Sep	243
Oct	246
Nov	242

[113] Environment Canada, Real-Time Hydrometric Data Graph for TALTSON RIVER BELOW HYDRO DAM (07QD007) [NT], Available at: https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=07QD007

Table 20: Taltson Hydro Parameters in IESD

Facility	Reservoir Surface Area (km2)	Minimum allowable level (m)	Maximum allowable level (m)	Minimum license flow (cms)	Maximum license flow (cms)	Minimum turbine flow (cms)	Gross Heat (m)	Potential (MW/cms)
TA	697	319.3	321.6	28	n/a	0	29	0.25

Sources:

1. Surface area: Wikipedia, Nonacho Lake, available from: https://en.wikipedia.org/wiki/Nonacho_Lake
2. Water license constraints: Mackenzie Valley Land and Water Board, August 31, 2012, Water Licence MV2011 L4-0002
3. Potential calculated from Net head: Dezé Energy Corporation, May 2007, Taltson Hydroelectric Expansion Project – Project Description, Navius Calculation from Table 11-1

Variable renewable energy sources

The model may build variable renewable energy sources (VREs), wind and solar beyond currently announced projects starting in the model year 2030 (see section 2.3.1 for more details). Historical weather data and cost information (see section 2.3.2) is used to inform the uptake of wind and solar in the model. Weather data was obtained from the NASA POWER database[114], including temperature, solar insolation, wind speeds and relative humidity for one-hour intervals at each of the seven regions in IESD model over the course of 2015, the model's base year.

To obtain hourly values for the relevant weather parameters from NASA, we defined each modeled region to a single longitude and latitude pair, defined in Table 21. For the larger Snare and Taltson grids, we used Yellowknife and Hay River, respectively.

[114] NASA POWER. *POWER Docs.* Available from: https://power.larc.nasa.gov/docs/

Table 21: Coordinates for communities modeled

Community	Longitude, W	Latitude, N
Taltson (South Slave)[115]	115.9	60.7
Snare (North Slave)[116]	114.4	62.5
Sachs Harbour	125.2	72.0
Wrigley	123.4	63.2
Paulatuk	124.0	69.3
Fort McPherson	134.8	67.4
Ulukhaktok	117.8	70.7
Inuvik	133.7	68.4

Using this weather data, we determine an hourly capacity factor which quantifies the proportion of hourly electricity available from a given type of VRE generator relative to the maximum amount from that type of VRE. The following two subsections explain how these impact solar and wind power generation.

Solar

Solar energy can be converted into electricity using a photovoltaic (PV) panel. The total energy extracted from a PV panel is given by:

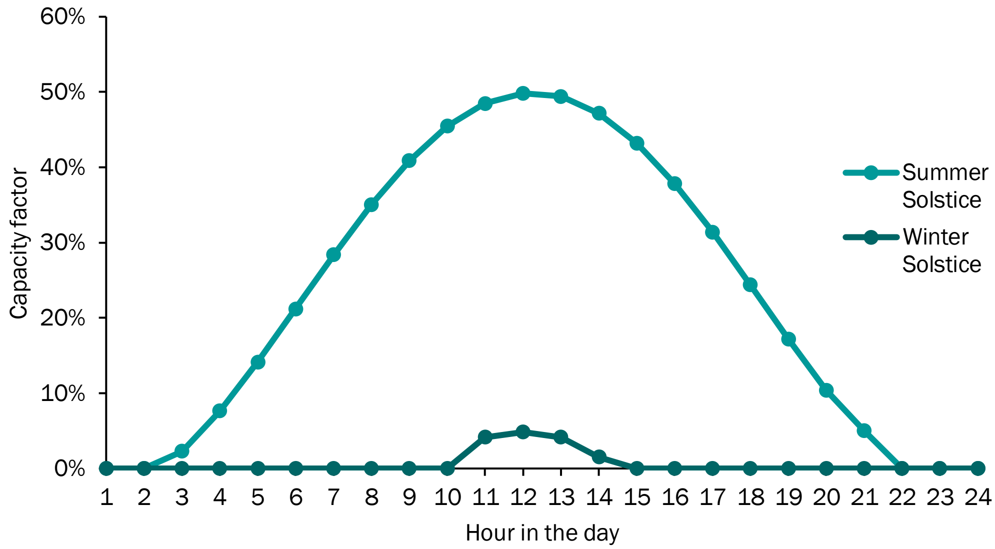
$$E = G * \eta,$$

G is the total solar insolation incident on a panel and η is the efficiency of the panel. The efficiency, in turn, is inversely proportional to the temperature of the cell (itself directly related to the ambient temperature). The low temperatures and high levels of solar insolation during the summer months in the NWT are ideal operating conditions for solar PV cells. The opposite is true during the winter. This is highlighted in Figure 34 below which show the hourly capacity factors for solar PV at the summer and winter solstices in Paulatuk. The below plot, which reflects actual data inputs to the model, was selected to illustrate how seasonal and hourly variations are combined in IESD.

[115] For Taltson, wind speeds were taken from a site near the Hay River Dene 1 boundary. This was due to low average wind speeds at or near Hay River.

[116] For Snare, wind speeds were taken from coordinates 119.2 W and 69.38 N to provide a more realistic estimate of wind speed.

Figure 34: Hourly average solar PV capacity factors in Paulatuk in 2015



The capacity factor for a given hour is the ratio of the output of the panels at a given hour to the capacity of the panels. Values for the solar capacity factor were obtained by inputting temperature, wind speed and solar insolation data from the weather data and comparing that to the theoretical maximum output of the panels at any given hour.

Wind

The hourly availability of wind power depends strongly on the wind speed at that moment. The basic premise of wind power is that the wind blowing through the surface area of a turbine contains an amount of (kinetic) energy. Assuming we know the surface area of a turbine ("the swept area"), the speed of the wind and the density of air (assumed throughout to be a constant 1.255 kg/m^3), we can calculate the instantaneous power in the wind. The value of the instantaneous kinetic energy (power) in the wind cross-section within a turbine can be quantified as:

$$P = 0.5 * \rho * A_{turbine} * v_{hub}^3$$

Where v_{hub} is the wind speed taken at the hub height of the turbine and ρ is the density of air. We scale up the wind speeds at 10 m to a wind speed at hub height using a well-established relation:

$$v_{hub} = v_{10} * \frac{\log H/z}{\log 10/z}$$

Where *H* is the hub height of the turbine in meters and *z* is the "roughness length," which we assume to be 0.005 throughout, consistent with open, flat terrain.

We note here that we have made the conservative assumption in our modeling that the density of air remains a constant at 1.255 kg/m^3. By adopting this assumption, we help to ensure that the projected amounts of wind power capacity built are not overly optimistic.

For any wind turbine, there is a cut-in wind speed, below which there is no wind generation; a region where there is a linear relationship between the power generated and the speed of the wind; a rated wind speed, at which point the turbine generates its rated power; and a cut-out wind speed, at which point the turbine is turned off to avoid damage. When the wind speeds are within the range between the cut-in wind speeds and cut-out speeds, the power output of any turbine is directly proportional to a coefficient of performance, c_p , itself a function of the wind speed:

$$P_{turbine} = c_P * P_{wind}$$

Having reviewed a number of reports published in the NWT[117,118,119], in addition to the Canadian Wind Turbine Database[120], to determine a small number of wind turbine archetypes which could be deployed in the NWT, we use The NPS 100C-21 from a NWT report previously shared with us by the GNWT[121] as specified Table 22 below. Beyond using this archetype, we do not restrict wind generation by temperature or weather conditions.

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117 Government of Northwest Territories. (2017). *Sachs Harbour Wind Scoping Study.* Available from: https://www.inf.gov.nt.ca/sites/inf/files/resources/h354025_-_sachs_harbour_wind_scoping_study_summary.pdf

118 Government of Northwest Territories. (2017). *Inuvik High Point Wind Feasibility Study.* Available from: https://www.inf.gov.nt.ca/sites/inf/files/resources/6.16.11251.van_.r.003_-_gnwt_inuvik_wtg_feasibility_study_final_report_b2_updated.pdf

119 HATCH. (2017). *Sachs Harbour Wind Scoping Study.* Available from: https://www.inf.gov.nt.ca/sites/inf/files/resources/h354025_-_sachs_harbour_wind_scoping_study_rev0.pdf

120 See: https://open.canada.ca/data/en/dataset/79fdad93-9025-49ad-ba16-c26d718cc070

121 HATCH. (2017). *Sachs Harbour Wind Scoping Study.* Available from: https://www.inf.gov.nt.ca/sites/inf/files/resources/h354025_-_sachs_harbour_wind_scoping_study_rev0.pdf

Table 22: Specifications for the Northern Power NPS 100C-21[122].

Metric	Value
Hub height	37 m
Rated capacity	95 kW
Cut-in speed	3 m/s
Cut-out speed	25 m/s

Using the information listed above we calculated capacity factors. Table 23 below outlines the 2015 average capacity factors for illustrative purposes.

Table 23: Estimated average wind capacity factors for 2015.

Community	Wind power capacity factor
Ulukhaktok	38.2%
Fort McPherson	14.8%
Sachs Harbour	34.0%
Paulatuk	28.4%
Wrigley	11.3%
Snare	36.3%
Talston	20.7%
Inuvik	18.7%

[122] Northern Power Systems Srl. *NPS 100C-21.* Available from: http://www.nps100.com/wp/wp-content/uploads/2020/12/brochure-NPS-100C-21_ed2020_light_ENG.pdf

Appendix B: Additional IESD results

Eight grids in the NWT were modeled, including Snare[123], Taltson[124], Sachs Harbour, Paulatuk, Fort McPherson, Wrigley, Ulukhaktok and Inuvik. Together, these regions account for approximately 76% of utility generation in the NWT. The choice of communities was based on the availability of data from the Northwest Territories Power Corporation (NTPC).

While section 4.4.1 presents results for the whole hydro zone (Snare and Taltson), and section 4.4.2 scales up the thermal zone to cover the rest of the communities that were not explicitly modeled, this Appendix contains generation and storage results for each modeled region. All figures in this Appendix present results with reference emerging low-carbon transportation technology costs and no additional climate action in the rest of Canada and the U.S.

[123] Main grid in North Slave.

[124] Main grid in South Slave.

Snare

Figure 35: Utility electricity generation in Snare (optimistic renewable/battery cost)

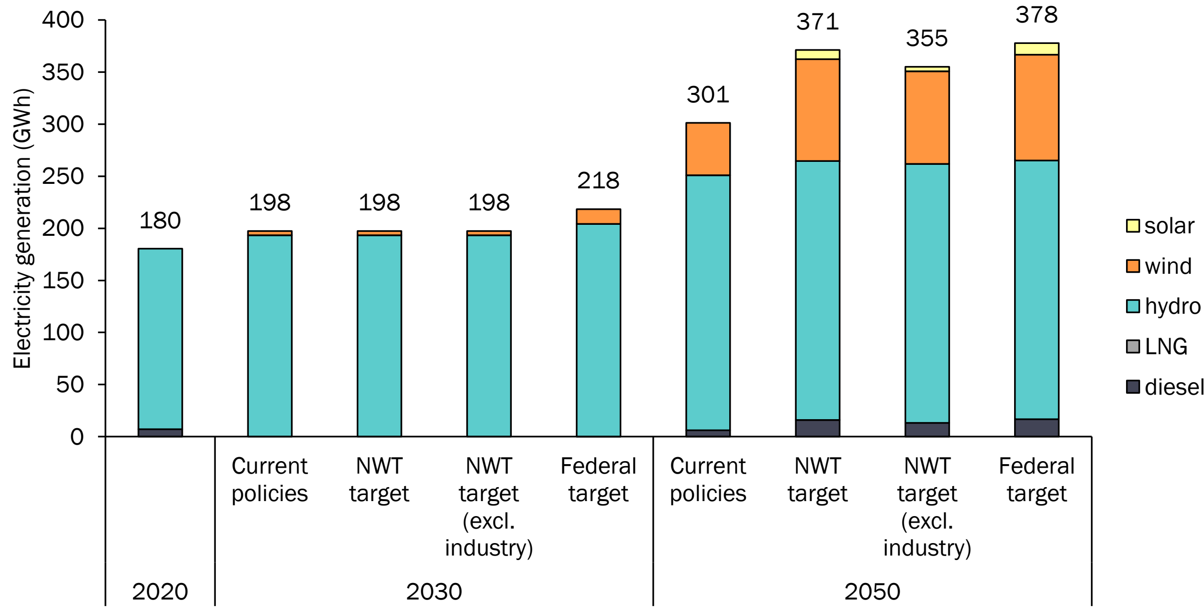


Figure 36: Utility electricity generation in Snare (pessimistic renewable/battery cost)

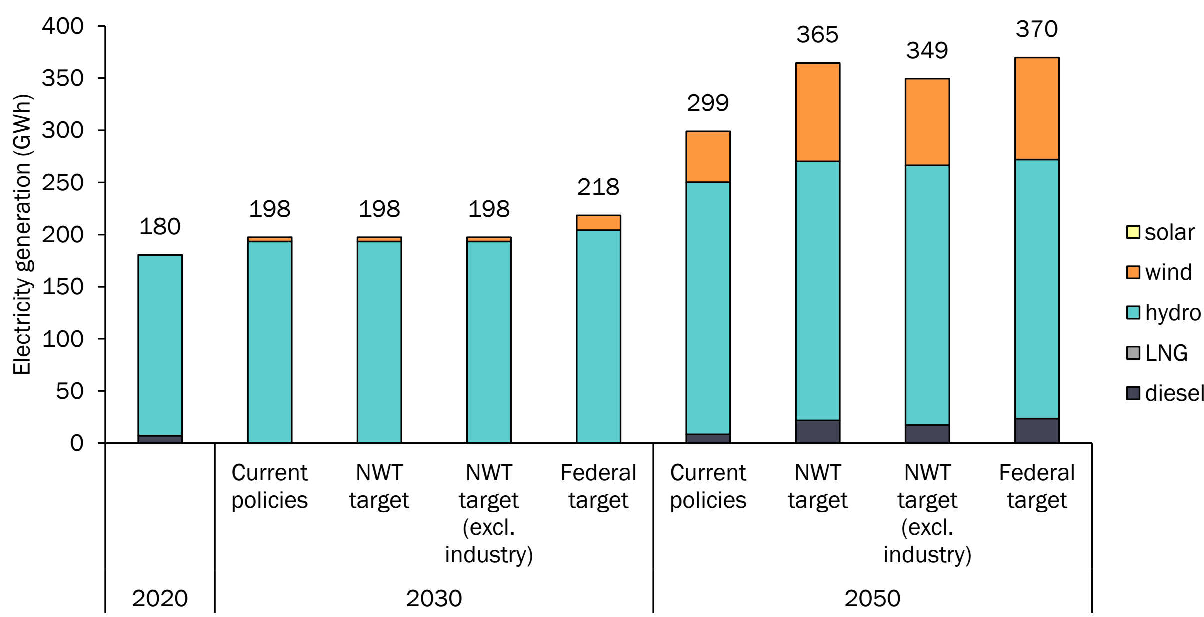
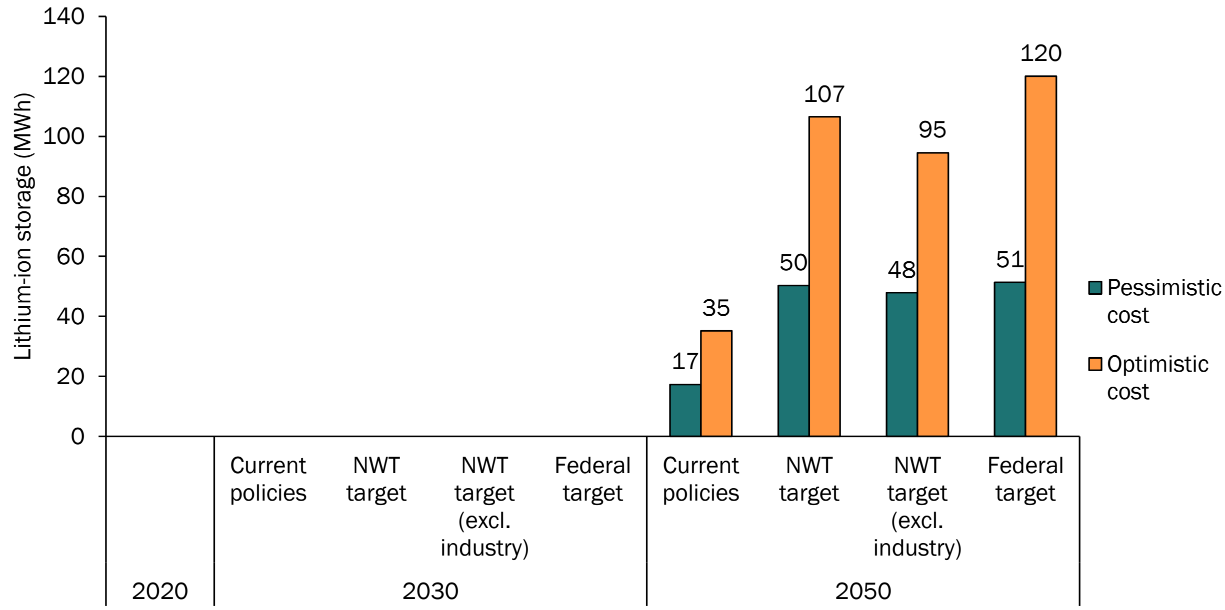


Figure 37: Utility adoption of batteries in Snare



Taltson

Figure 38: Utility electricity generation in Taltson (optimistic renewable/battery cost)

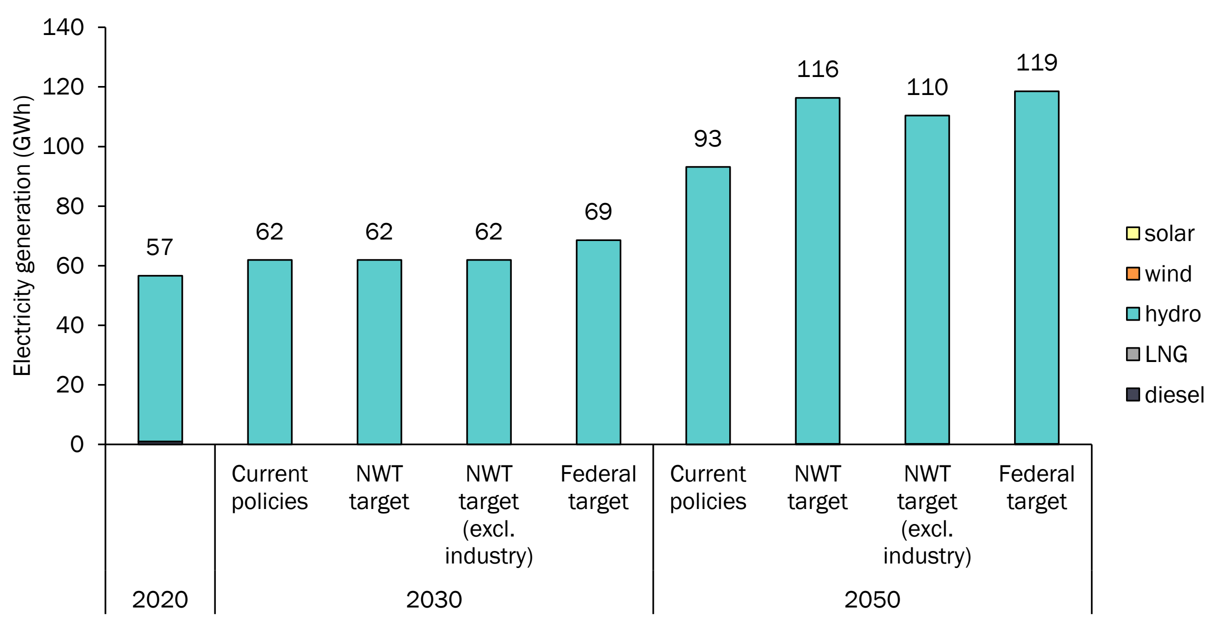


Figure 39: Utility electricity generation in Taltson (pessimistic renewable/battery cost)

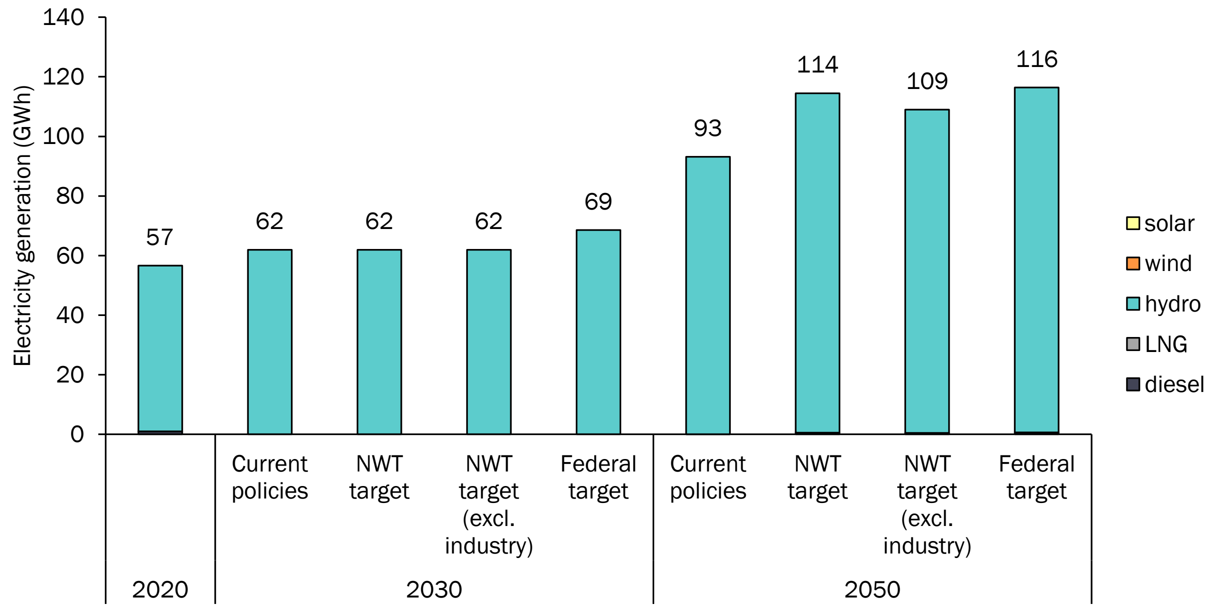
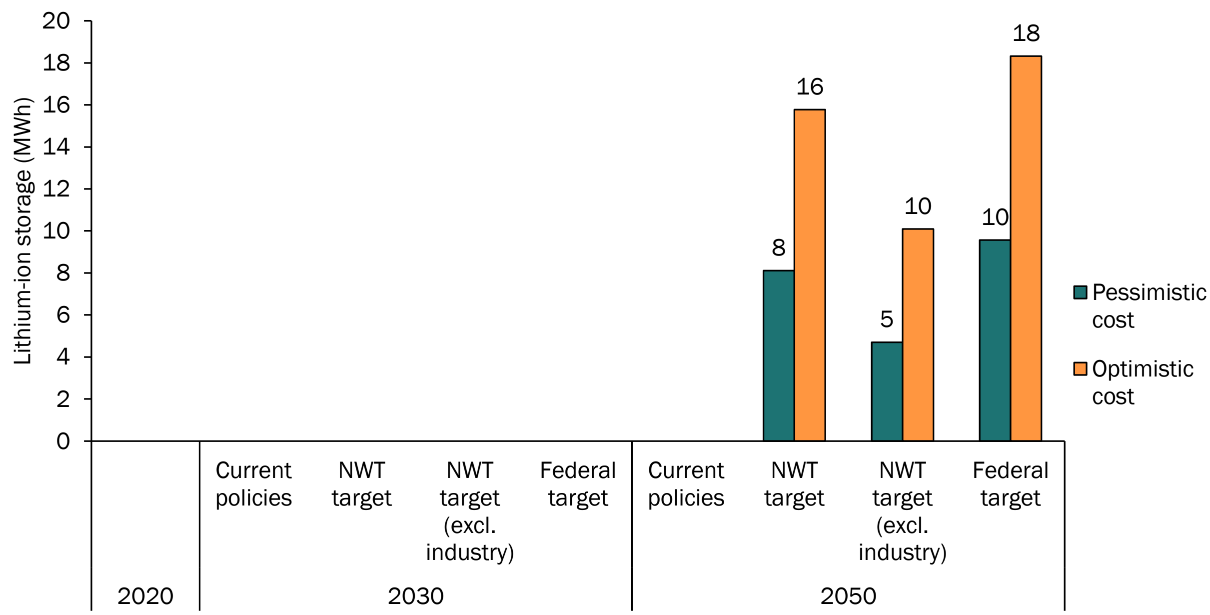


Figure 40: Utility adoption of batteries in Taltson



Inuvik

Figure 41: Utility electricity generation in Inuvik (optimistic renewable/battery cost)

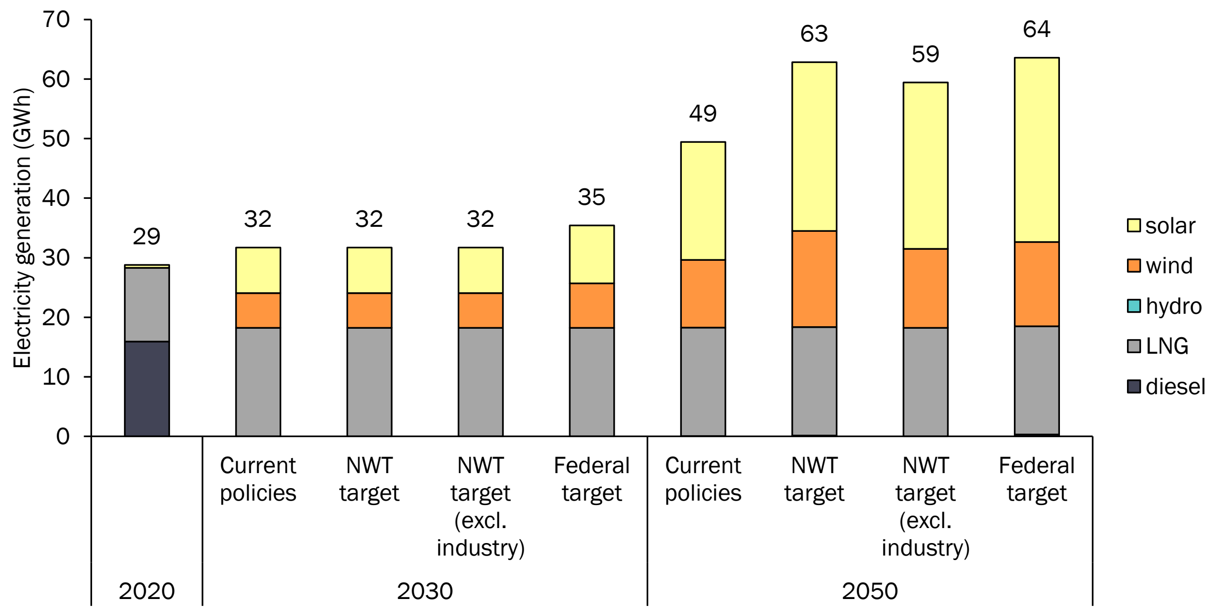


Figure 42: Utility electricity generation in Inuvik (pessimistic renewable/battery cost)

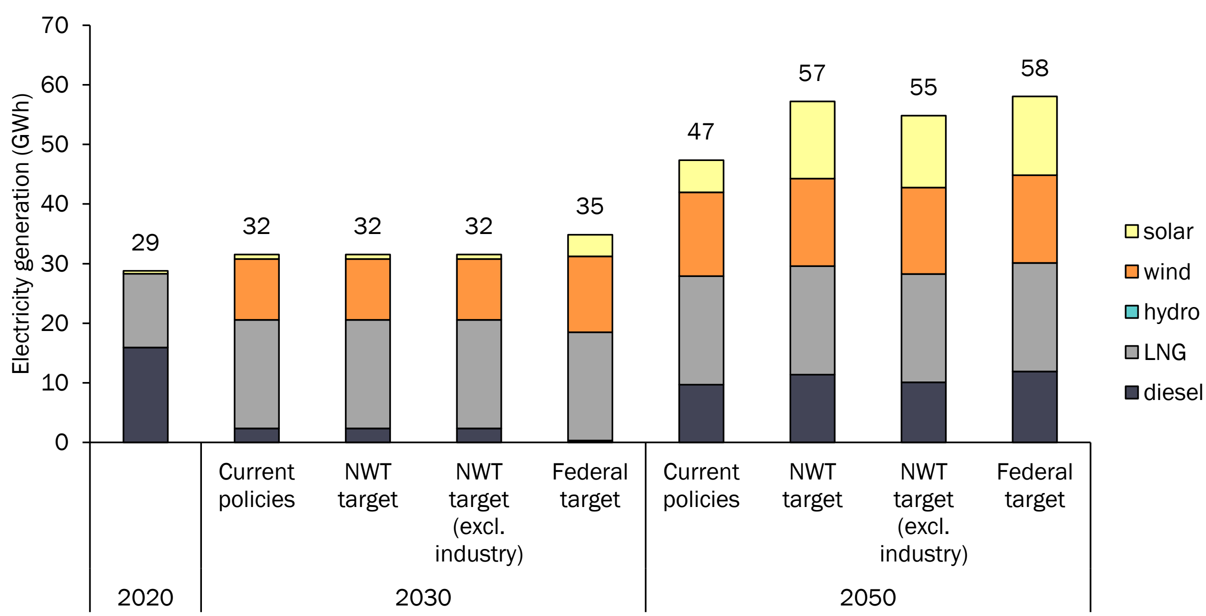
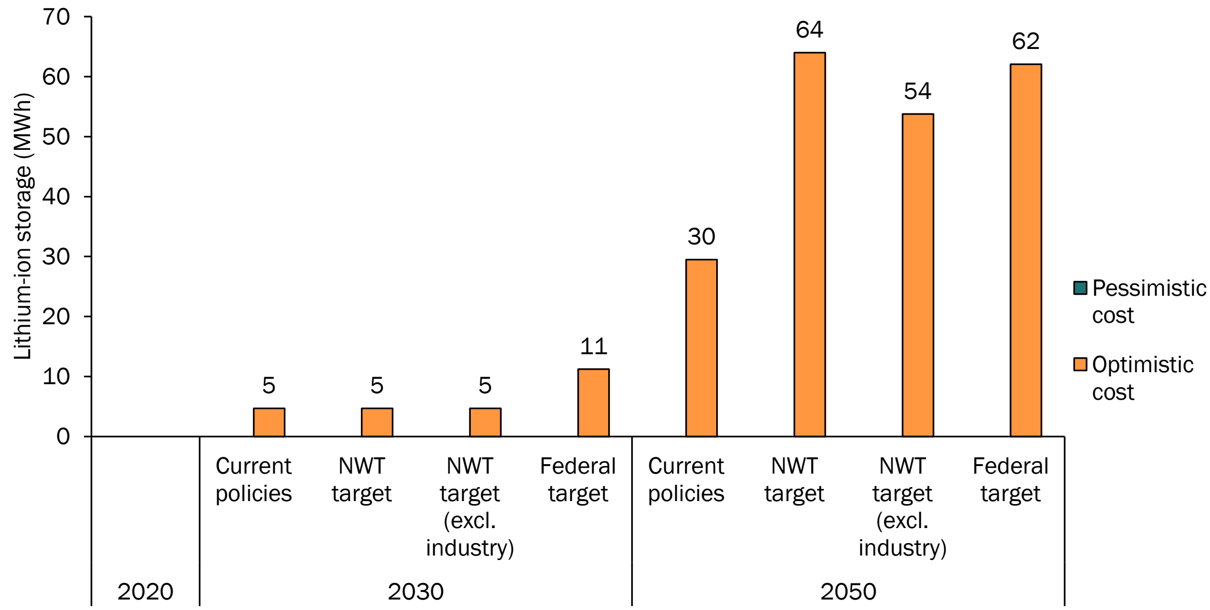


Figure 43: Utility adoption of batteries in Inuvik



Sachs Harbour

Figure 44: Utility electricity generation in Sachs Harbour (optimistic renewable/battery cost)

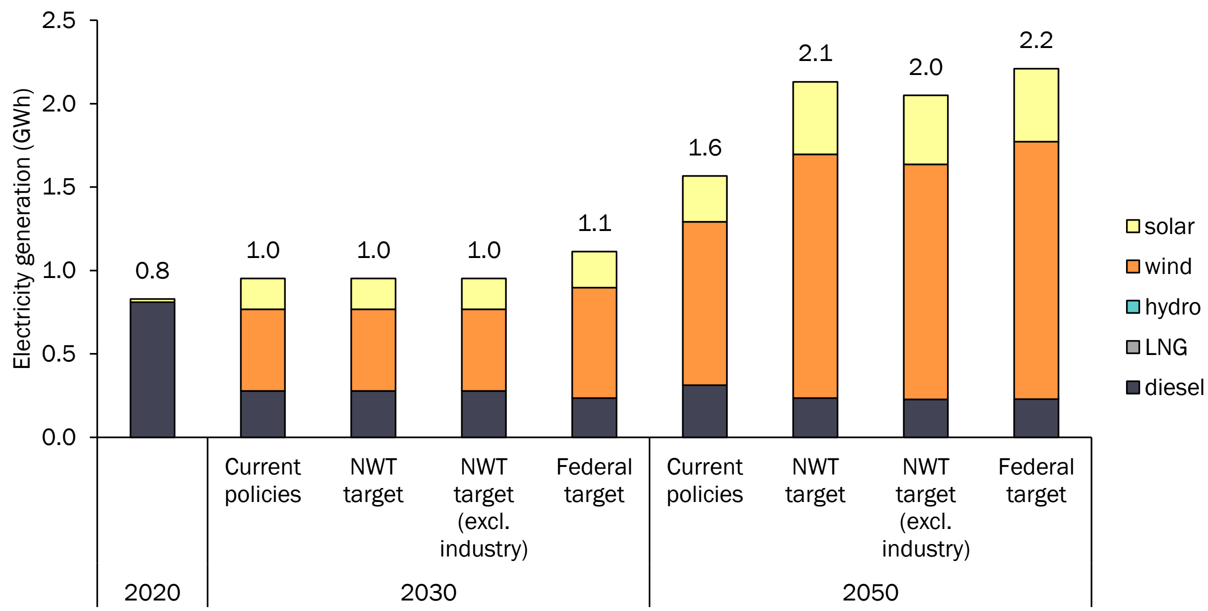


Figure 45: Utility electricity generation in Sachs Harbour (pessimistic renewable/battery cost)

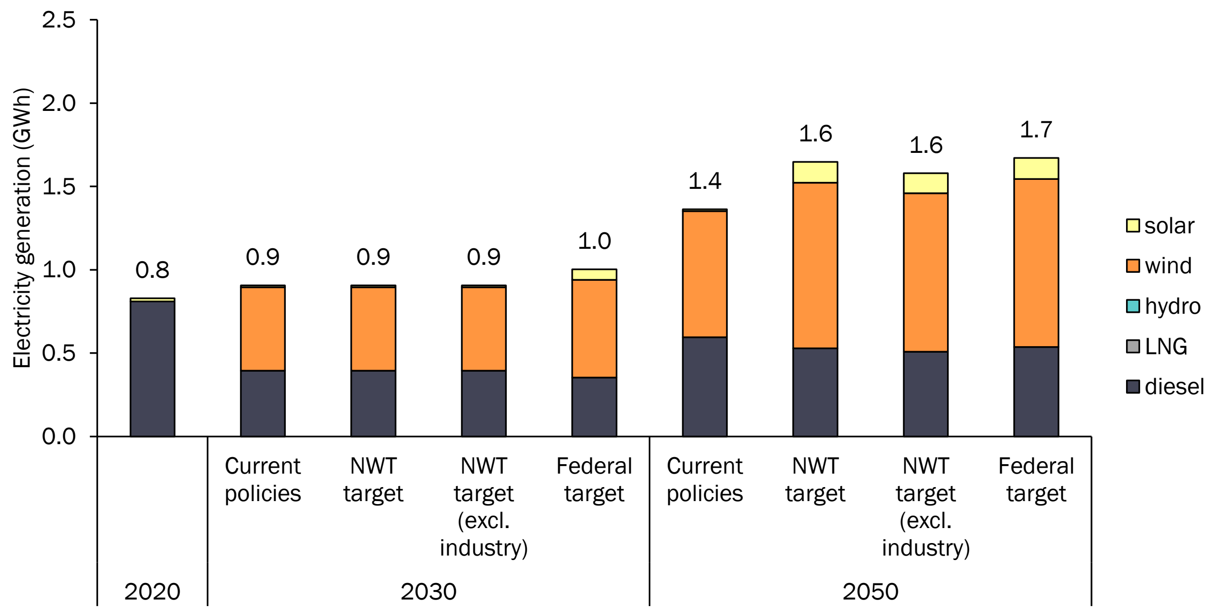
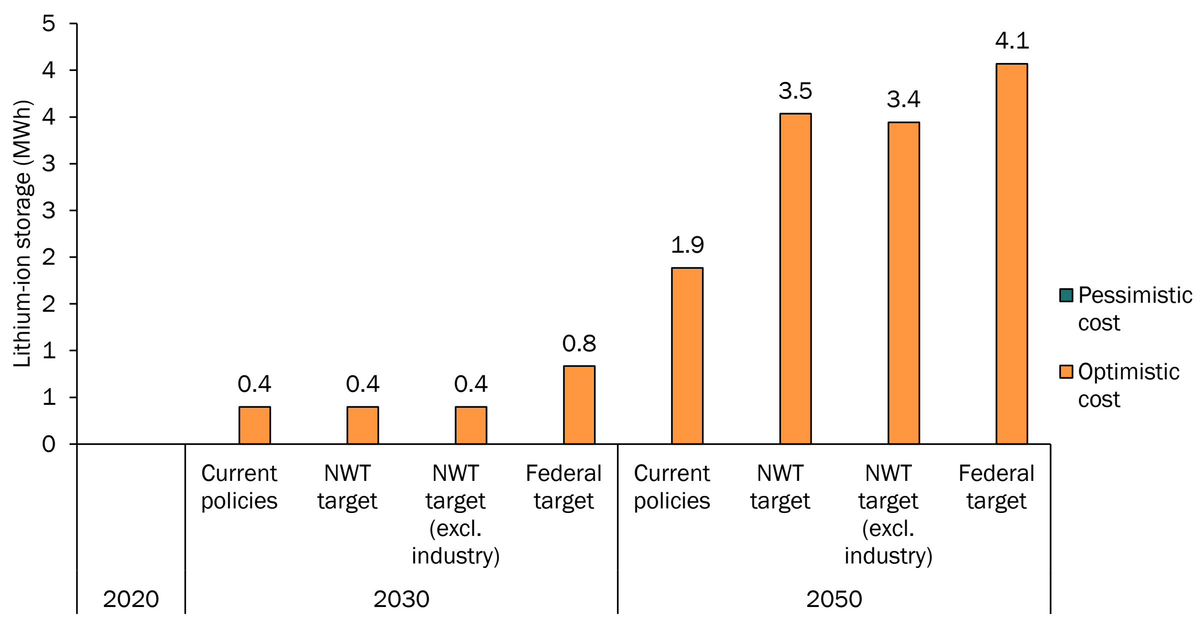


Figure 46: Utility adoption of batteries in Sachs Harbour



Paulatuk

Figure 47: Utility electricity generation in Paulatuk (optimistic renewable/battery cost)

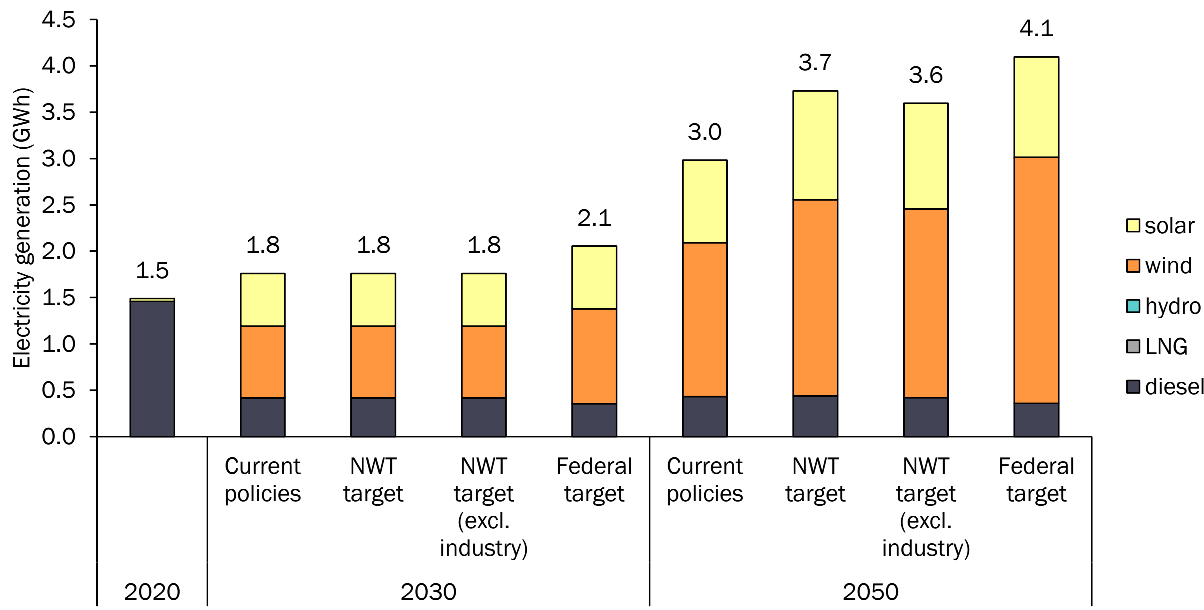


Figure 48: Utility electricity generation in Paulatuk (pessimistic renewable/battery cost)

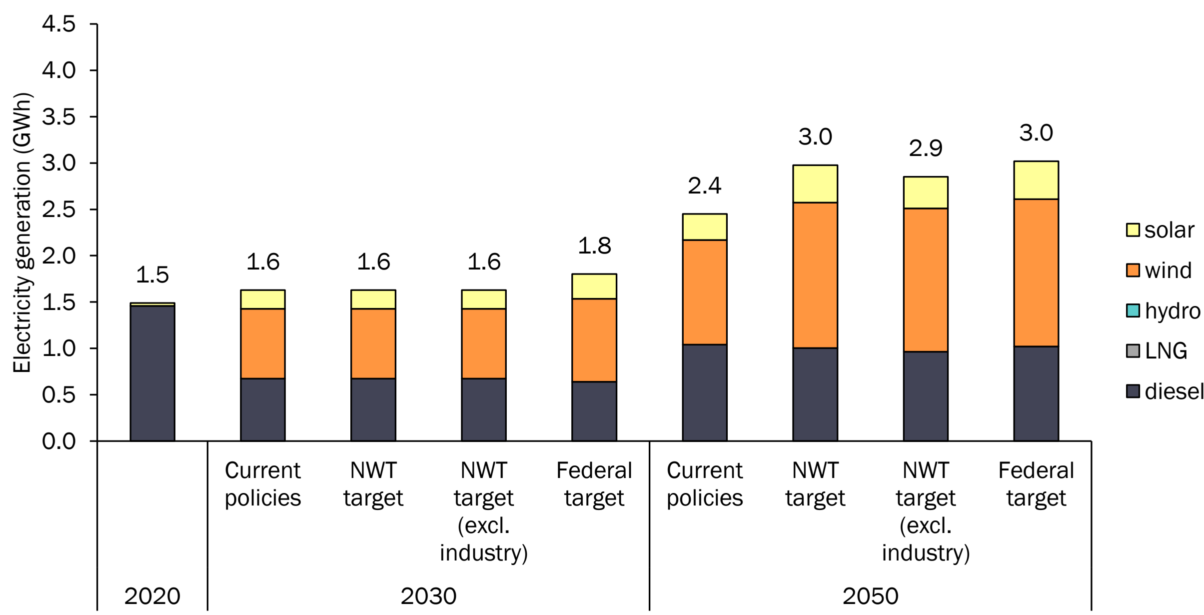
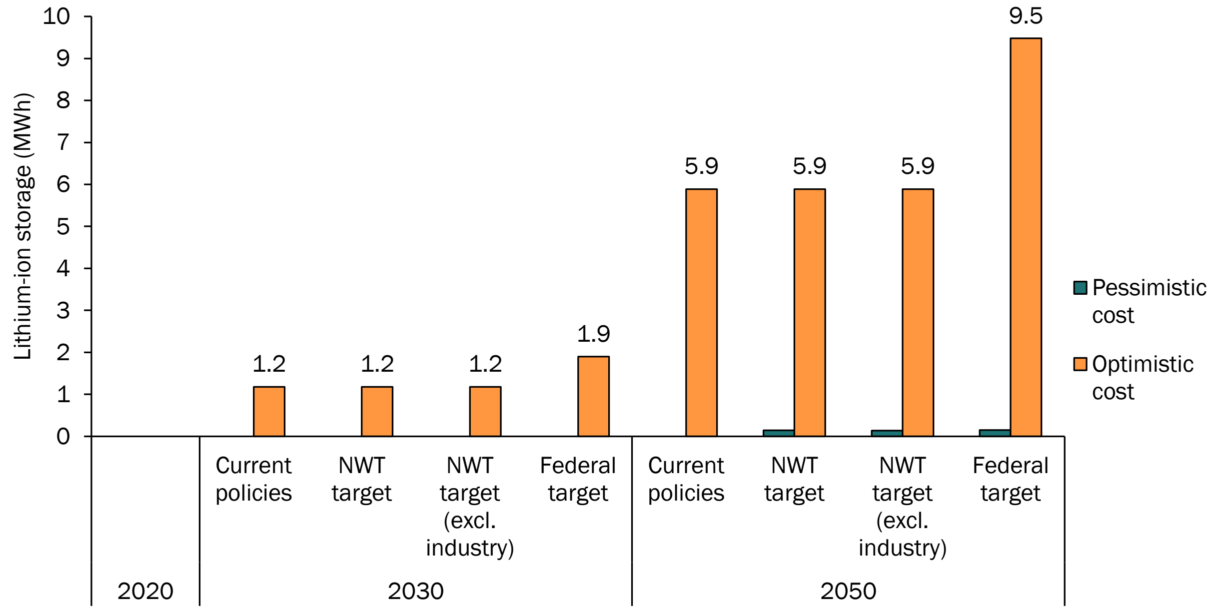


Figure 49: Utility adoption of batteries in Paulatuk



Fort McPherson

Figure 50: Utility electricity generation in Fort McPherson (optimistic renewable/battery cost)

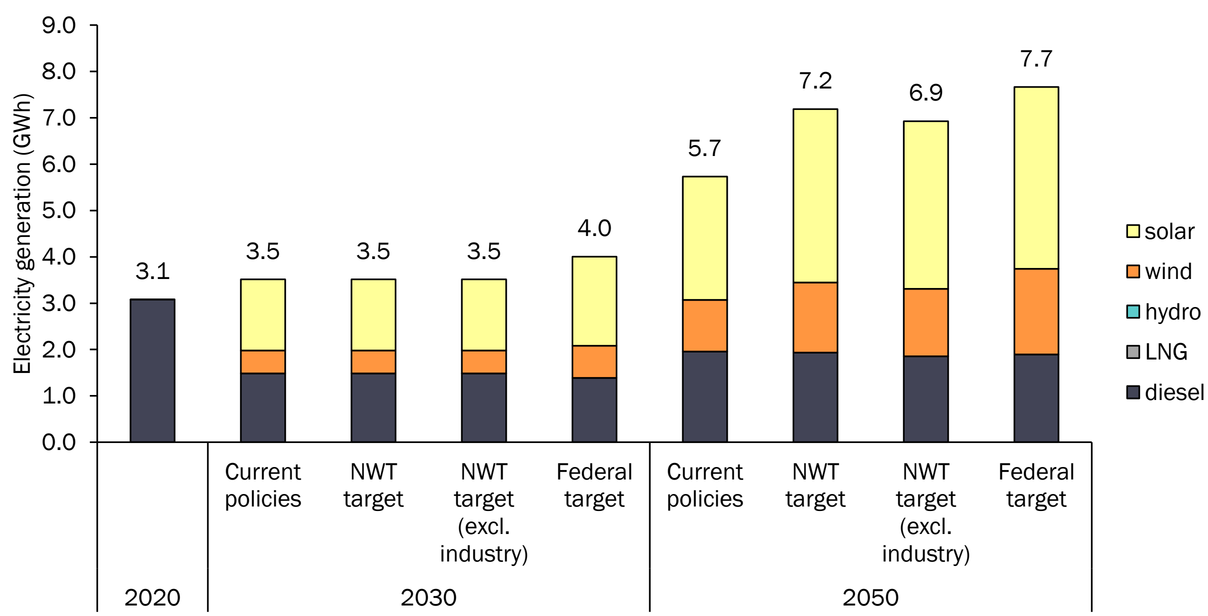


Figure 51: Utility electricity generation in Fort McPherson (pessimistic renewable/battery cost)

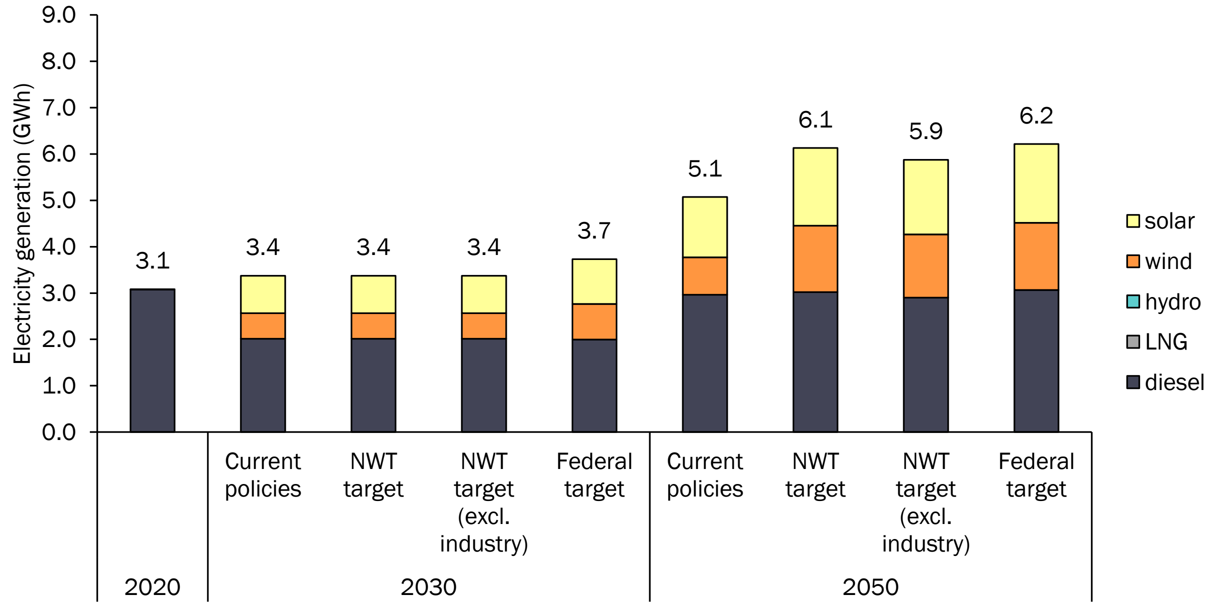
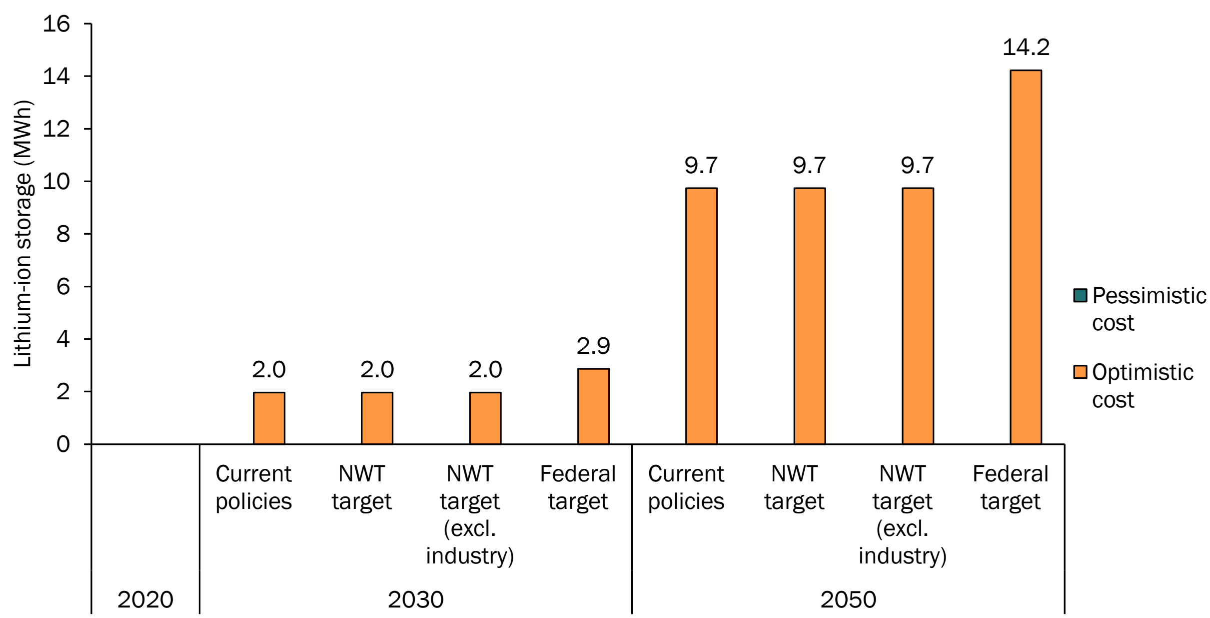


Figure 52: Utility adoption of batteries in Fort McPherson



Wrigley

Figure 53: Utility electricity generation in Wrigley (optimistic renewable/battery cost)

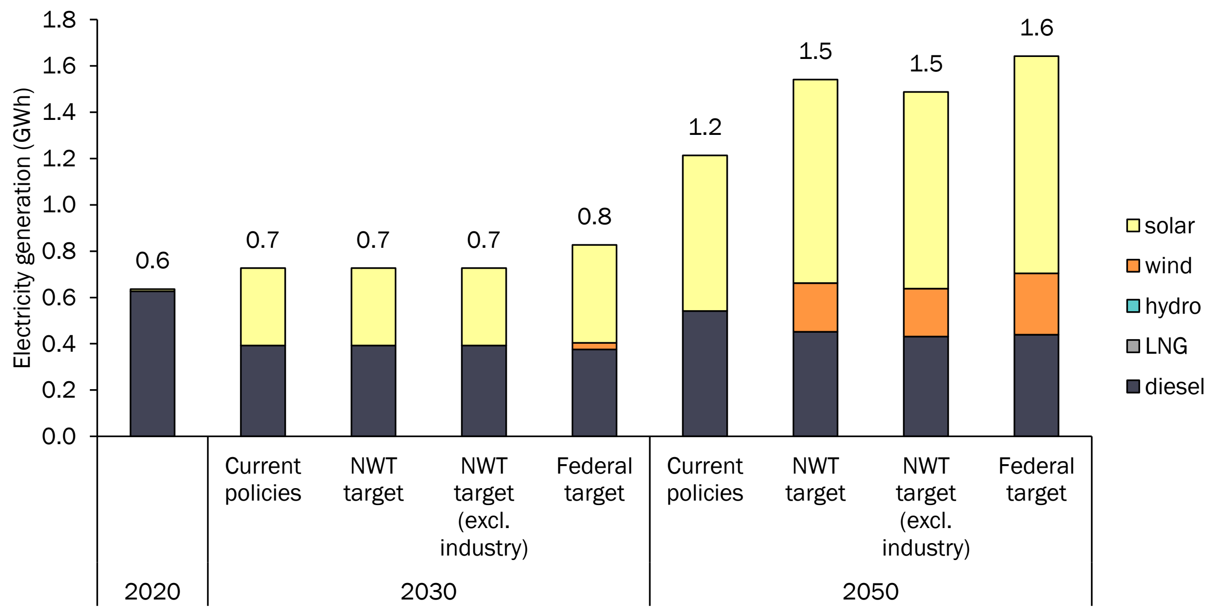


Figure 54: Utility electricity generation in Wrigley (pessimistic renewable/battery cost)

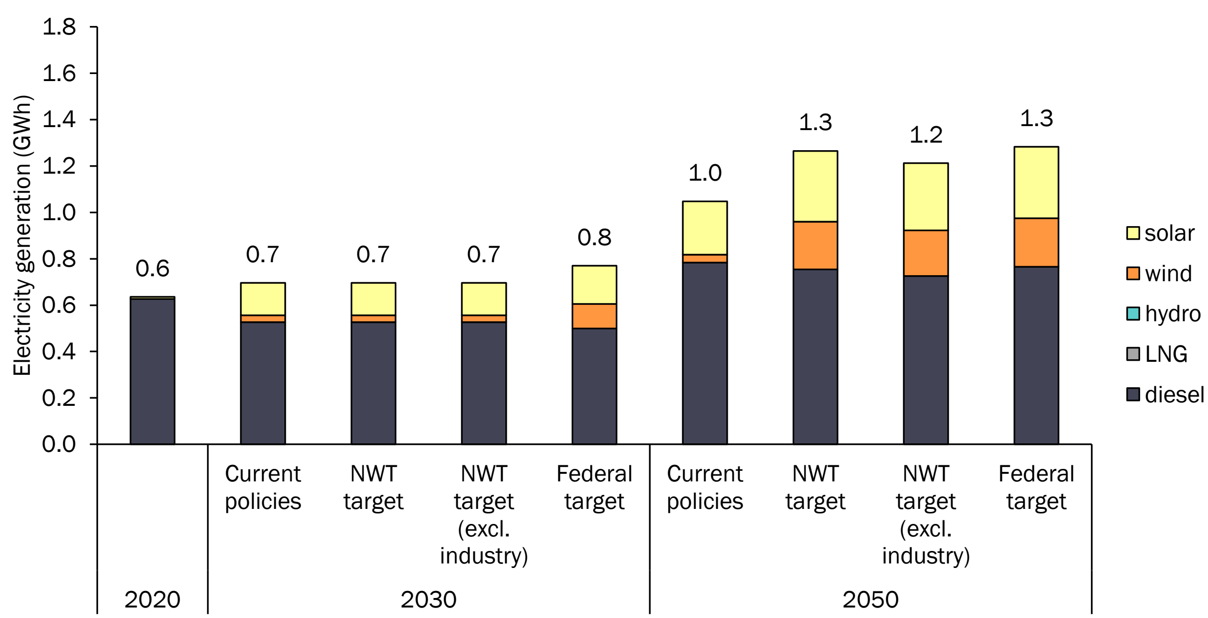
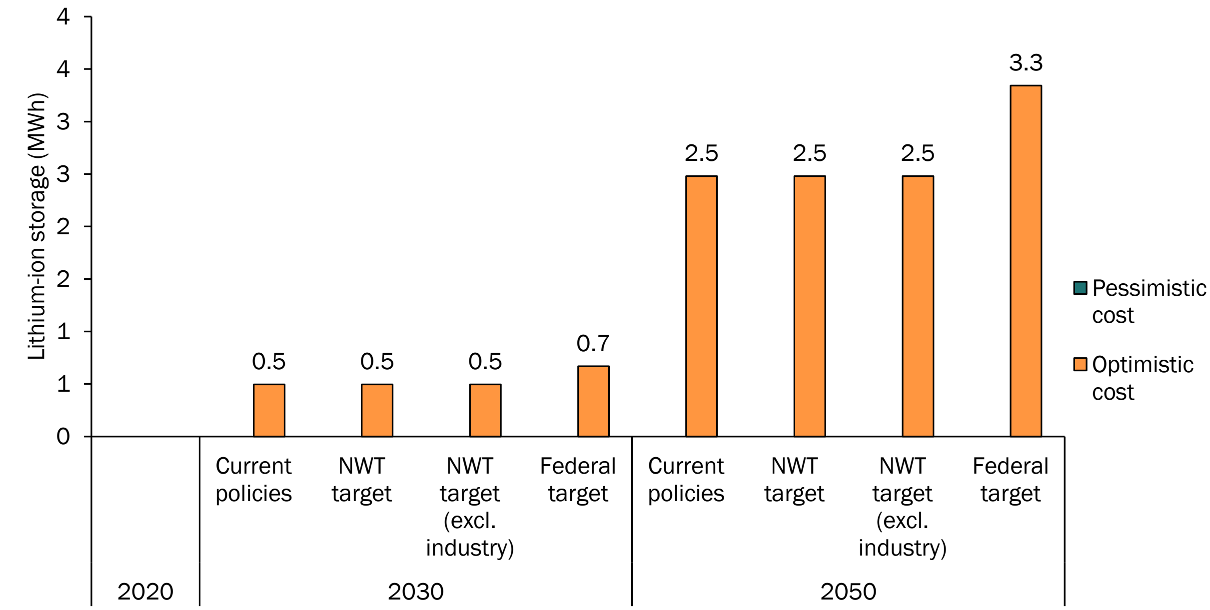


Figure 55: Utility adoption of batteries in Wrigley



Ulukhaktok

Figure 56: Utility electricity generation in Ulukaktok (optimistic renewable/battery cost)

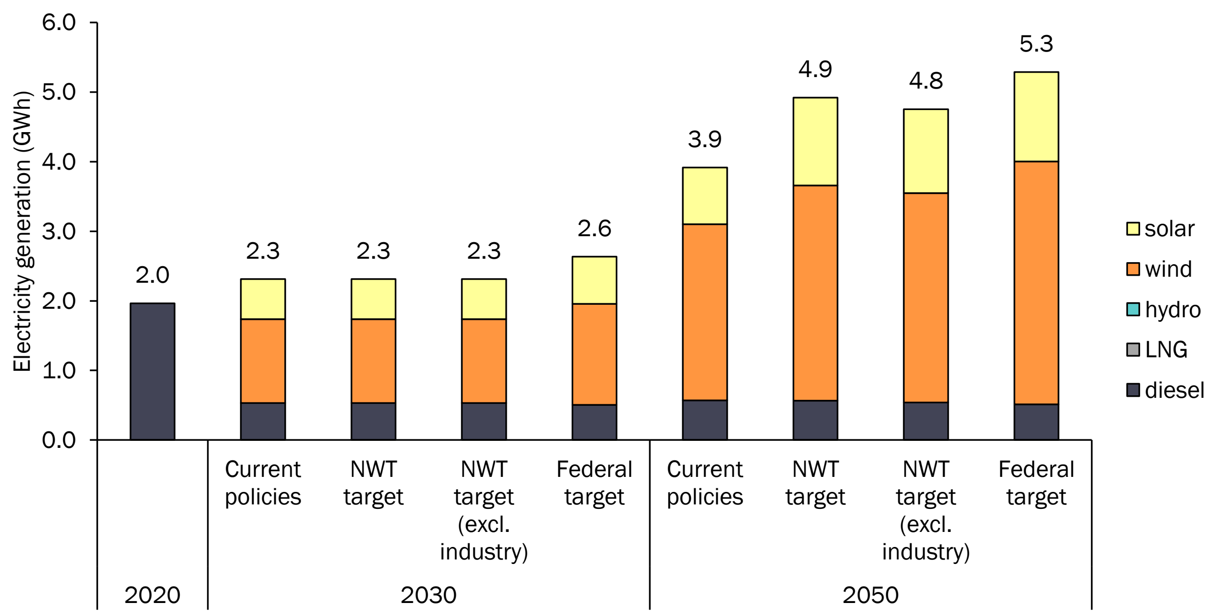


Figure 57: Utility electricity generation in Ulukaktok (pessimistic renewable/battery cost)

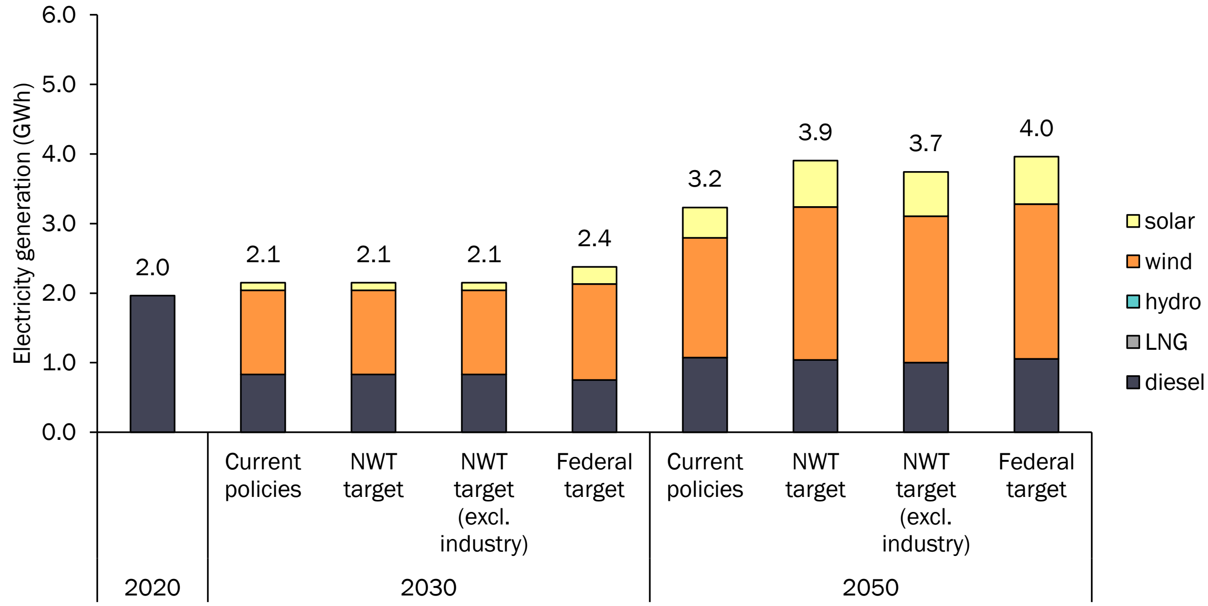
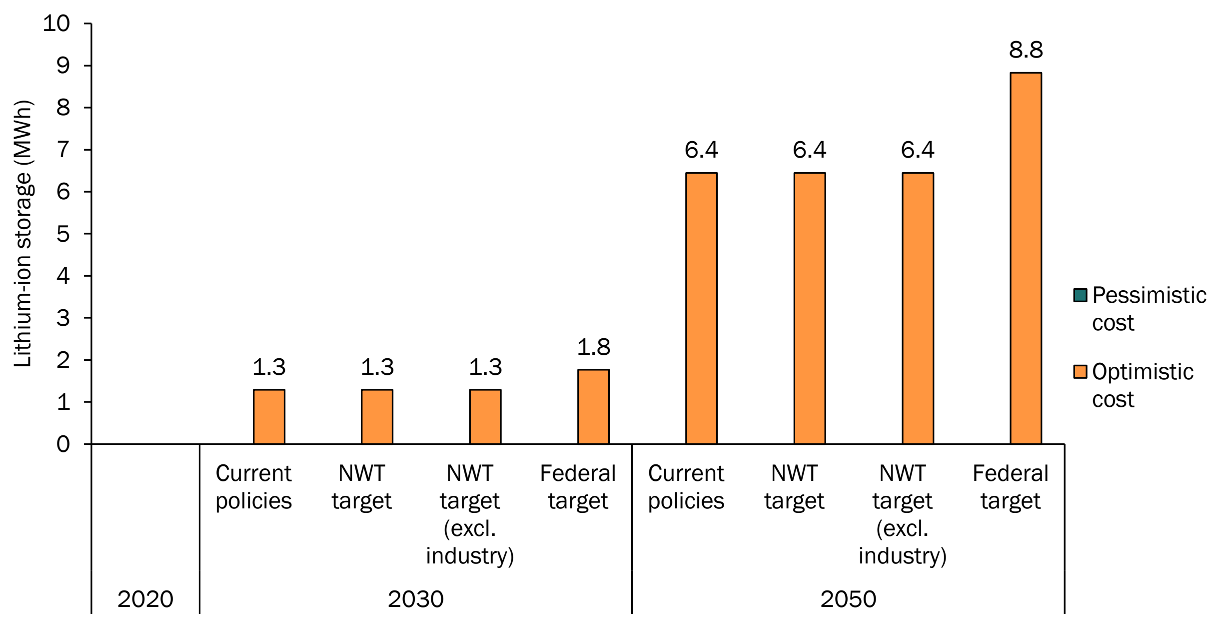


Figure 58: Utility adoption of batteries in Ulukaktok



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