Scenario Analysis of Embodied Greenhouse Gas Emissions for Transit-Oriented Development in Five Scenarios

Prepared for:
School of Cities
University of Toronto

By:
Letzai Ruiz, Ph.D.
Santiago Zuluaga Mayorga, Ph.D.
Keagan H. Rankin, M.A.Sc.
Shoshanna Saxe, Ph.D., P.Eng.

Department of Civil and Mineral Engineering
University of Toronto

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1. Introduction

This report provides a summary of the quantification of embodied greenhouse gas (GHG) emissions in residential buildings for ten development scenarios located in five different neighbourhoods (2 scenarios for each):

- Cooksville, a neighbourhood in Mississauga, Ontario.
- Northfield, a neighbourhood in Waterloo, Ontario.
- Arbutus, a neighbourhood in Vancouver, British Columbia.
- McKernan-Belgravia, a neighbourhood in Edmonton, Alberta.
- Panama, a neighbourhood in Brossard - Montreal, Quebec.

Specifically, we compared the embodied GHG emissions—those associated with upstream material production and energy use—from proposed buildings in a scenario of intensified, transit-oriented development (TOD), and compare these emissions to a baseline scenario that reflects the current trajectory developed by the School of Cities. For each scenario, we evaluate total embodied emissions and emissions per capita. Critically, we analyze the sensitivity of the results to key input parameters such as the average expected occupancy of new residential units.

2. Methods summary

Embodied GHG emissions represent those associated with upstream processes of manufacturing and transporting materials within a product, such as raw material extraction, material manufacturing, material transport to site and onsite energy use in construction (Huang *et al.*, 2024). Embodied emissions are sometimes emitted within local/national boundaries but also include emissions outside of these territories, representing the manufacturing of material abroad, which are then imported. In Canada, around 35 per cent (or 31 $MtCO_2e$ per year) of all embodied GHG emissions from the construction sector happen outside of the Canadian territory, largely in the US and China, major sources of imported construction materials (Yoffe *et al.*, 2024).

To estimate the embodied GHG emissions (expressed in $kgCO_2e$) from building construction in all scenarios, we use a database of material use and embodied GHG emissions in residential buildings published by University of Toronto researchers led by Prof. Shoshanna Saxe (Civil and Mineral Engineering) (Guven *et al.*, 2022; Rankin *et al.*, 2024). We use this database to simulate the embodied GHG intensity per unit added for each building in both the baseline and TOD scenarios using a Monte Carlo approach with 10,000 realizations, following the methodology proposed by Rankin & Saxe (Rankin and Saxe, 2024). These simulations allow us to examine the uncertainty in GHG emissions for individual buildings, as well as to understand the overall uncertainty and sensitivity associated with each scenario.

Below, we summarize the key considerations and assumptions for scope and boundaries in our embodied GHG estimations:

2.1. Buildings

Embodied GHG emissions from **buildings** for each scenario were calculated based on the number of units and building types for all proposed buildings under each scenario, based on the simulation methodology proposed by Rankin & Saxe (Rankin and Saxe, 2024). For each scenario, we use detailed data on the number of units and building type for each proposed building to simulate the emissions associated with each building.

The embodied GHG estimates presented here include both structural (e.g., concrete, steel), architectural (e.g., masonry, glass), and mechanical, electrical, and plumbing (MEP) elements. Additionally, design considerations such as the presence and amount of underground parking or common areas are embedded within the range of GHG emissions from the referenced building GHG dataset (Guven *et al.*, 2022).

In terms of scope, GHG emission estimates for buildings include the A1-A5 lifecycle stages; in other words, they include the emissions associated with material extraction and manufacturing (A1-A3), as well as the emissions from transporting materials to the construction site and emissions from the construction process (A4-A5). While the GHG estimates per unit for different building types in the dataset from Guven et al. have an A1-A3 scope and do not consider all materials and components (Guven *et al.*, 2022), we apply a scaling factor of 1.3 to account for emissions from the A4-A5 stages and for MEP components in line with past work (Rankin and Saxe, 2024). More details on the scope, boundaries, and implications of the GHG emissions accounting methodology can be found in (Rankin and Saxe, 2024; Rankin *et al.*, 2024).

2.2. Road infrastructure

Embodied GHG emissions from **road** infrastructure were calculated following the methodology and background data from (Rankin and Saxe, 2024). For the case studies that added new roads, we had detailed data on the type and geometry of all existing roads within the study area, including local, collector, and arterial roads. We used this data to estimate the embodied GHG emissions associated with the asphalt, concrete, and granular materials in these roads, which we then normalized by the total length of existing roads to obtain the GHG intensity of roads per unit of length in each scenario (e.g., Cooksville, Northfield). Finally, this GHG intensity was used to calculate the embodied GHG emissions associated with the additional roads needed in the TOD scenario.

2.3. Other considerations

The GHG emission intensity of different construction materials is expected to change over time. For this case study, we follow the expected reductions in GHG intensity over time proposed in (Rankin and Saxe, 2024), however, it is important to note that these reductions do not follow a best-case scenario where material production decarbonizes in line with what industries state in their net-zero goals. While Rankin and Saxe use 2023 as the base year for emissions, here we use 2025 as the base year for the initial GHG emission estimates of both scenarios.

Finally, to calculate the per capita GHG footprint of each scenario, we divide the total emissions of each scenario (i.e., emissions from the construction of all buildings and roads for each scenario) by the expected number of *new* occupants (population growth).

3. Cooksville Station, Mississauga

3.1. Summary

Table 1 presents a summary of the proposed residential developments in Cooksville for the baseline and the TOD scenarios based on the proposed development information provided by the School of Cities. To estimate future population, we add the most recent population estimate of Cooksville (19,614 people) and the expected number of occupants for all new units built in each scenario. The average occupancy rate for *low occupancy* is 1.3 people per unit, which is obtained by assuming a minimum of one person per bedroom built in the baseline scenario. The second population estimate in Table 1 uses the current average dwelling occupancy in Cooksville, calculated as the ratio of residents and existing dwellings (19,614 people / 7,363 units = 2.66 people per unit). Finally, the third population is the average occupancy for new residential units, considering the assumptions on unit mix and sizes in both scenarios, assuming one person per bedroom, the TOD scenario is 1.9 people/unit, and the baseline scenario is assumed to be 1.35 people/unit.

Table 1. Summary of residential building construction for the baseline and transit-oriented development scenarios in the neighbourhood of Cooksville, Mississauga.

	Baseline scenario	**TOD scenario**
Number of proposed developments	45	47
Number of proposed residential units	31,077	24,950
Estimated future population (low occupancy)	60,014	52,049
Estimated future population (high average occupancy)	102,279	85,981
Estimated future population (average occupancy in proposed residential units)	41,954	47405

3.2. Results

Figure 1 shows a histogram of the total embodied GHG emissions associated with each of the analyzed scenarios. On average, the construction of the 45 developments in the baseline scenario would have an associated embodied GHG footprint of 0.88 MtCO_2e (with a 95 per cent confidence interval between 0.782-0.9767 MtCO_2e), while the 47 proposed developments in the TOD scenario would result in a total embodied GHG footprint of 0.668 MtCO_2e (with a 95 per cent confidence interval between 0.594-0.749 MtCO_2e). For context, it is estimated that in 2020, the embodied GHG emissions footprint from the construction sector in the City of Toronto was 13.8 MtCO_2e (Rankin *et al.*, 2025). However, it is important to note that the total footprint of the analyzed scenarios would be spread out over several years of construction and development, reducing the yearly GHG emission footprint of each scenario relative to their total embodied GHG footprint.

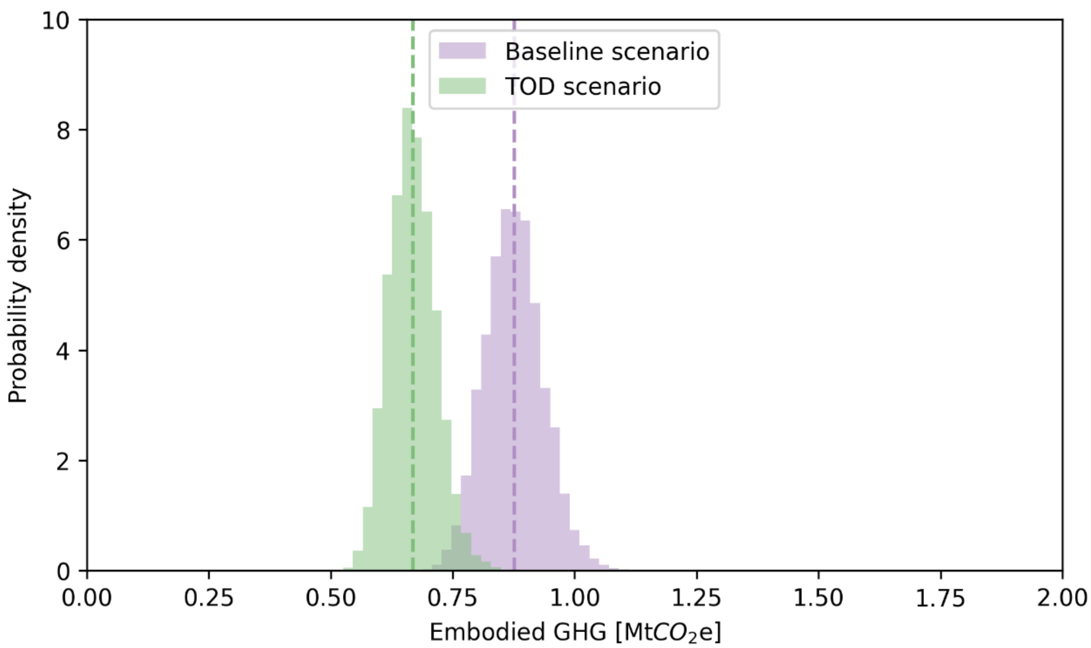

Figure 1. Histogram of the total embodied GHG emissions associated with residential building construction for the baseline and TOD scenarios in Cooksville. The average values for each distribution are shown with dashed lines.

To better contextualize the overall emission estimates shown in Figure 1, we also quantified the embodied GHG emissions per capita of growth for each scenario, as shown in Figure 2. While building fewer buildings requires less resource use and less associated embodied GHG, fewer buildings house many fewer people, and additional construction (not accounted for in the baseline scenario) would be needed elsewhere to house the same number of people as in the TOD scenario. We estimate that, on average, the developments in the baseline scenario will result in a GHG emission footprint of 20.9 tCO_2e/person (with a 95 per cent confidence interval between 18.7-23.3 tCO_2e/person), while the TOD scenario will result in a footprint of 14.1 tCO_2e/person (with a 95 per cent confidence interval between

12.5-15.8 tCO_2e/person). The overall and per capita embodied GHG emissions results are significantly lower for the TOD scenario in Cooksville than the baseline scenario.

Since the per capita GHG footprint of each scenario depends on the occupancy levels of the units within the proposed developments, the per capita estimates in Figure 2 assume that new buildings would have a one-person-per-bedroom occupancy level. Since the TOD scenario includes the development of more family-oriented units, the average occupancy for the TOD scenario is 1.9 people/unit, while the average occupancy of new units in the baseline scenario is assumed to be 1.35 people/unit.

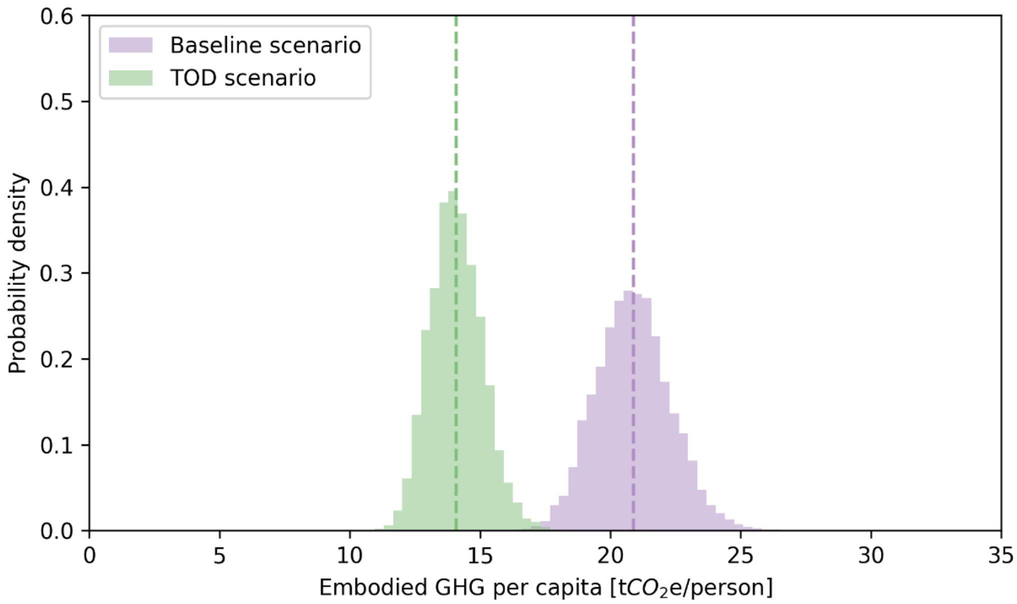

Figure 2. Histogram of embodied GHG emissions per capita associated with residential building construction for the baseline and TOD scenarios in Cooksville. The average values for each distribution are shown with dashed lines. (Baseline 1.35 people/unit; TOD 1.9 people/unit)

Since the unit occupancy has a considerable effect on the per capita GHG emission estimates, we examined the effect of occupancy more closely through a sensitivity analysis. In Figure 3, we show the relationship between dwelling occupancy and the per capita emissions for each scenario. Our results show that the TOD and the baseline scenarios have a similar relationship with unit occupancy, but the differences in the unit mix for each scenario lead to divergence in the GHG per capita estimates. Figure 3 also shows that promoting higher occupancy in both scenarios is an important measure to reduce the embodied GHG footprint per capita of development in Cooksville.

Finally, Figure 4 explores the relationship between the per capita embodied GHG estimates for each scenario and the year of construction. As described in the methods, literature shows that the GHG intensity of construction materials is expected to reduce over time (Rankin and Saxe, 2024). Figure 4 shows that the TOD scenario has the largest gap with the baseline scenario under 2025 conditions, and this gap reduces as the construction is delayed further into the future. Note that this sensitivity analysis assumes that all buildings for each scenario are built in the same year, which is unlikely given that large multi-unit buildings are often multi-year endeavours and will not all be built simultaneously.

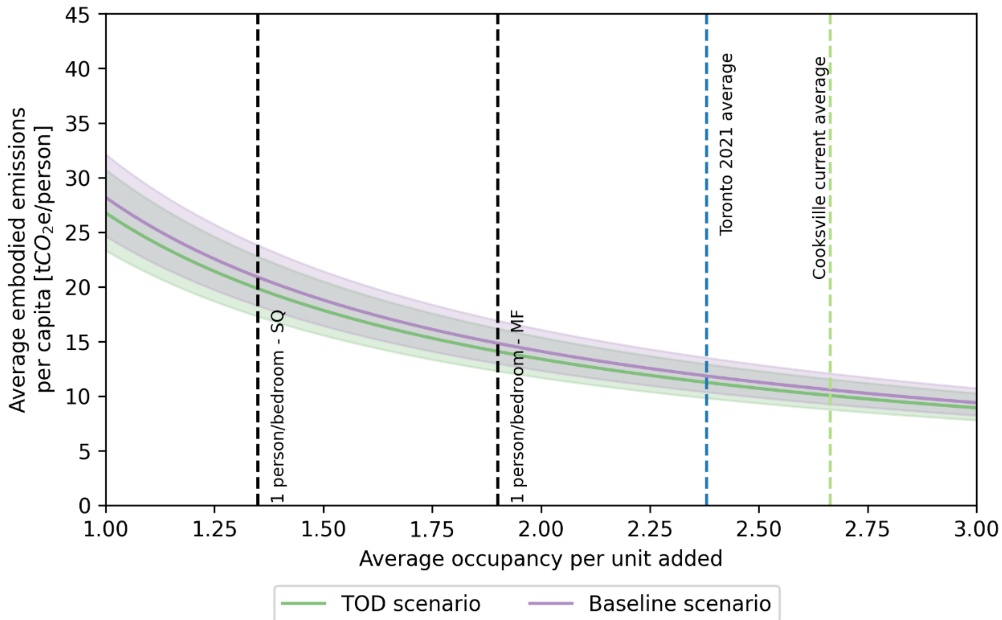

Figure 3. Sensitivity analysis for the embodied GHG per capita vs. average unit occupancy of newly built units for the baseline and TOD scenarios. Average embodied GHG per capita for each scenario are shown with solid lines, 95 per cent confidence intervals are shown in surrounding shaded areas, and reference occupancy values are shown in dashed lines. (SQ = Status Quo unit mix, or 1.35 people/unit; MF = Multi-Family unit mix, or 1.9 people/unit)

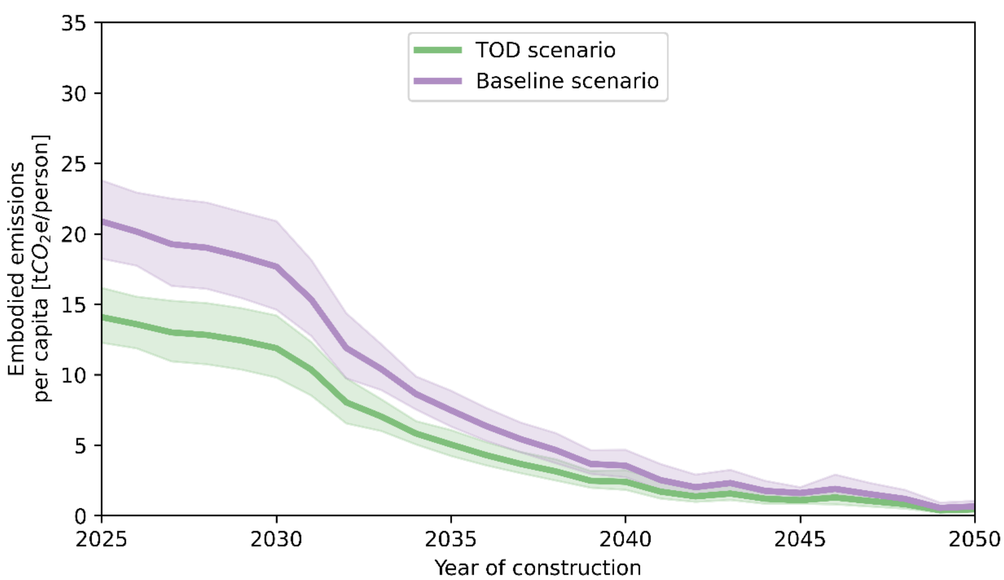

Figure 4. Sensitivity analysis for the embodied GHG per capita vs. year of construction accounting for future improvements in material manufacturing for the baseline and TOD scenarios. Average embodied GHG per capita for each scenario are shown with solid lines, while 95 per cent confidence intervals are shown in surrounding shaded areas.

4. Northfield Station, Waterloo

4.1. Summary

Table 2 presents a summary of the proposed residential developments in Northfield for the baseline and the TOD scenarios based on the proposed development information provided by the School of Cities. To estimate future population, we add the most recent population estimate of Northfield (2,723 people) and the expected number of occupants for all new units built in each scenario. The average occupancy rate for *low occupancy* is 1.3 people per unit, which is obtained by assuming a minimum of one person per bedroom built in the baseline scenario. The second population estimate in Table 2 uses the current average dwelling occupancy in Northfield, calculated as the ratio of residents and existing dwellings (2,723 people / 759 units = 3.58 people per unit). Finally, the third population is the average occupancy for new residential units, considering the assumptions on unit mix and sizes in both scenarios, assuming one person per bedroom, the TOD scenario and the baseline scenario is 1.6 people/unit.

Table 2. Summary of residential building construction for the baseline and transit-oriented development scenarios in the neighbourhood of Northfield, Waterloo.

	Baseline scenario	TOD scenario
Number of proposed developments	15	43
Number of proposed residential units	14,346	14,151
Estimated future population (low occupancy)	21,373	21,119
Estimated future population (high average occupancy)	54,082	53,384
Estimated future population (average occupancy in proposed residential units)	22,954	22,642

4.2. Results

Figure 5 shows a histogram of the total embodied GHG emissions associated with each of the analyzed scenarios. On average, the construction of the 15 developments in the baseline scenario would have an associated embodied GHG footprint of 0.489 $MtCO_2e$ (with a 95 per cent confidence interval between 0.404-0.591 $MtCO_2e$), while the 43 proposed developments in the TOD scenario would result in a total embodied GHG footprint of 0.483 $MtCO_2e$ (with a 95 per cent confidence interval between 0.402-0.581 $MtCO_2e$).

To better contextualize the overall emission estimates shown in Figure 5, we also quantified the embodied GHG emissions per capita of growth for each scenario, as shown in Figure 6. While building fewer buildings requires less resource use and less associated embodied GHG, fewer buildings house many fewer people. We estimate that, on average, the developments in the baseline scenario will result in a GHG emission footprint of 21.3

tCO_2e/person (with a 95 per cent confidence interval between 17.6-25.8 tCO_2e/person), while the TOD scenario will result in a footprint of 21.3 tCO_2e/person (with a 95 per cent confidence interval between 17.8-25.7 tCO_2e/person). The overall and per capita embodied GHG emissions are similar for the TOD scenario and baseline scenarios in Northfield.

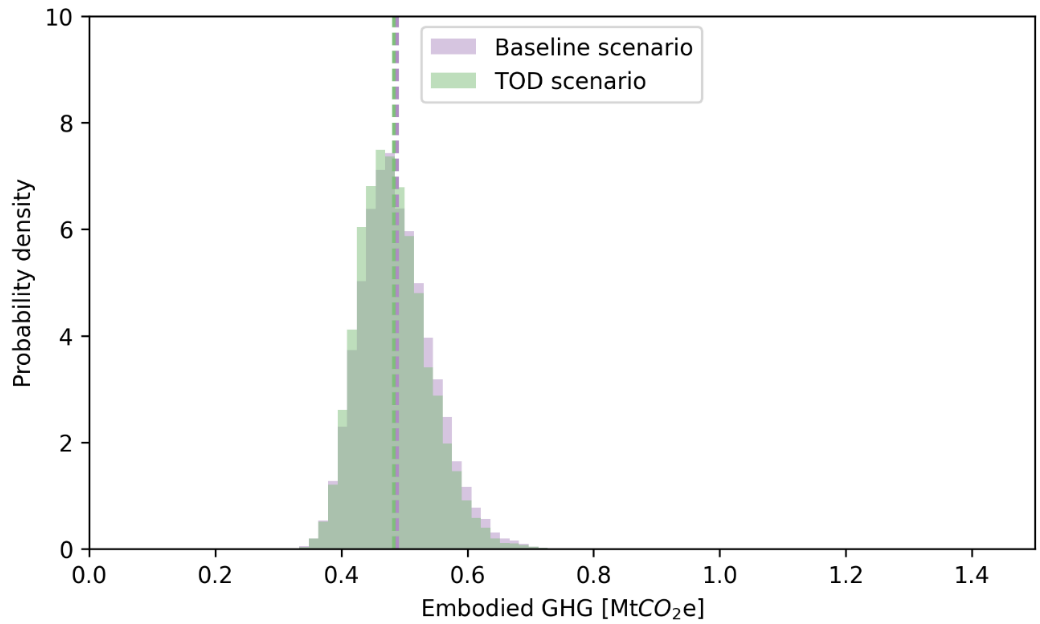

Figure 5. Histogram of the total embodied GHG emissions associated with residential building construction for the baseline and TOD scenarios in Northfield. The average values for each distribution are shown with dashed lines.

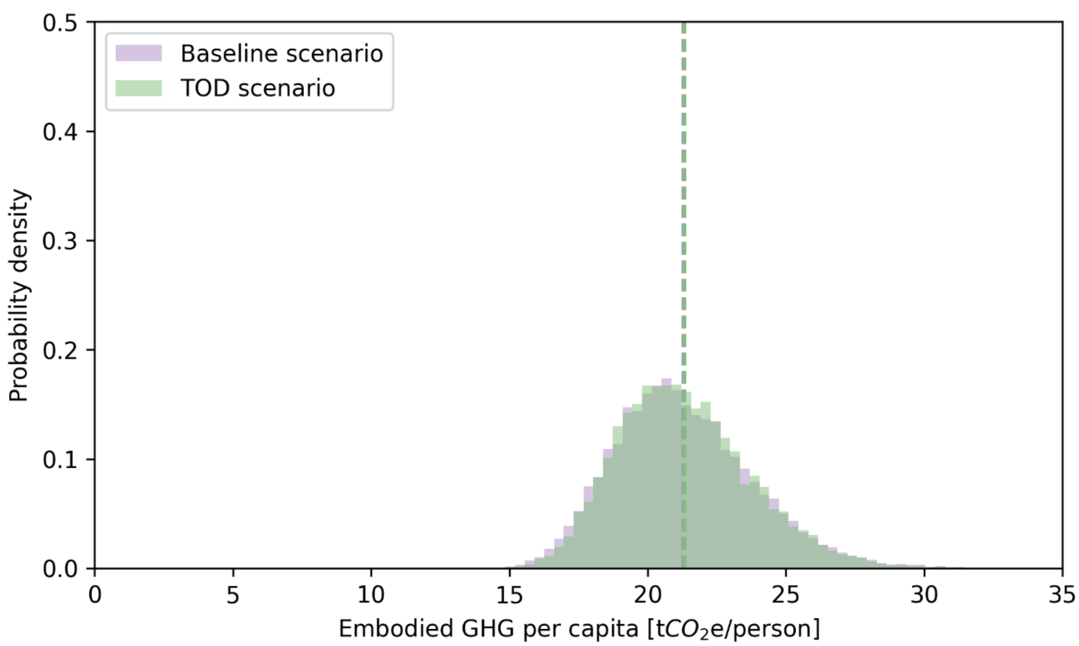

Figure 6. Histogram of embodied GHG emissions per capita associated with residential building construction for the baseline and TOD scenarios in Northfield. The average values for each distribution are shown with dashed lines. (Baseline 1.6 people/unit; TOD 1.6 people/unit)

Since the per capita GHG footprint of each scenario depends on the occupancy levels of the units within the proposed developments, the per capita estimates in Figure 6 assume that new buildings would have a one-person-per-bedroom occupancy level. However, in the case of both scenarios (baseline and TOD), the average occupancy is the same at 1.6 people/unit, resulting in the same average of embodied GHG emissions per capita in Northfield. The spread is different in per capita emissions due to the higher variability in the embodied GHG in the building type.

The relationship between dwelling occupancy and the per capita emissions for the baseline and TOD scenarios is shown in Figure 7. Our results show that the TOD and the baseline scenarios have a similar relationship with unit occupancy, as it is the same for both scenarios, and the differences in the unit mix for each scenario overlap, showing equivalent GHG emissions per capita.

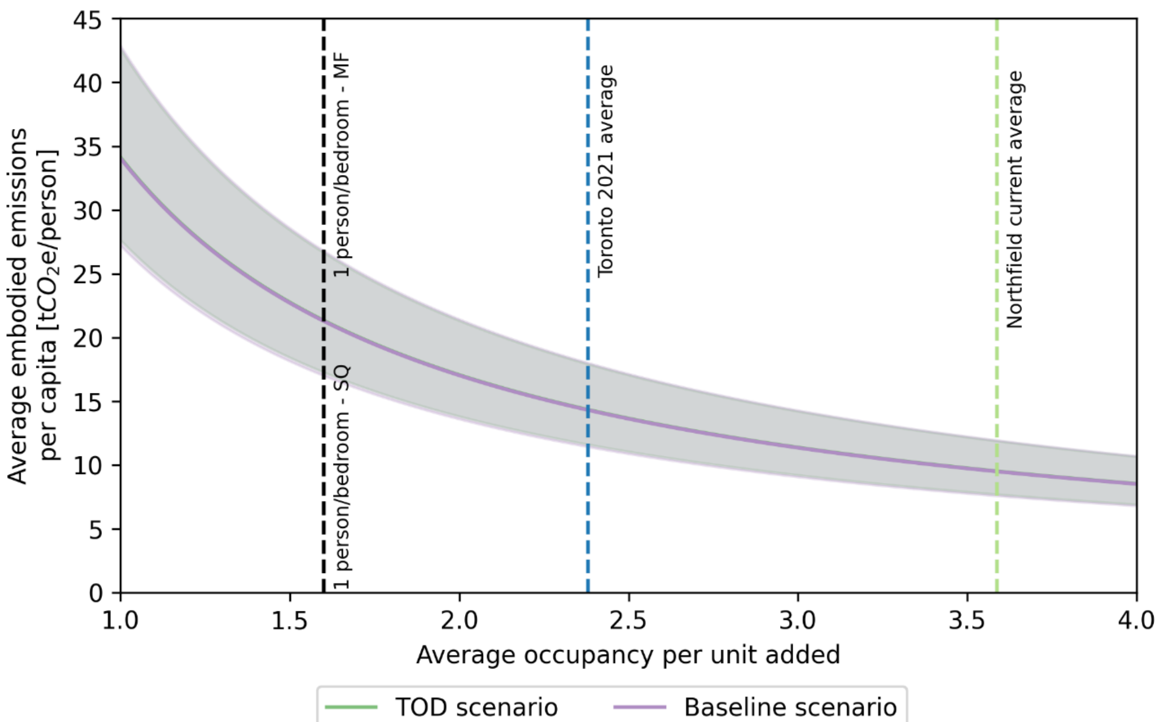

Figure 7. Sensitivity analysis for the embodied GHG per capita vs. average unit occupancy of newly built units for the baseline and TOD scenarios. Average embodied GHG per capita for each scenario are shown with solid lines, 95 per cent confidence intervals are shown in surrounding shaded areas, and reference occupancy values are shown in dashed lines. (SQ = Status Quo unit mix, or 1.6 people/unit; MF = Multi-Family unit mix, or 1.6 people/unit)

Finally, Figure 8 explores the relationship between the per capita embodied GHG estimates for each scenario and the year of construction. Figure 8 shows that the TOD scenario and the baseline scenario exhibit the same behavior throughout all years, because the average occupancy is the same. Note that this sensitivity analysis assumes that all buildings for each scenario are built in the same year, which is unlikely given that large multi-unit buildings are often multi-year endeavours and will not all be built simultaneously.

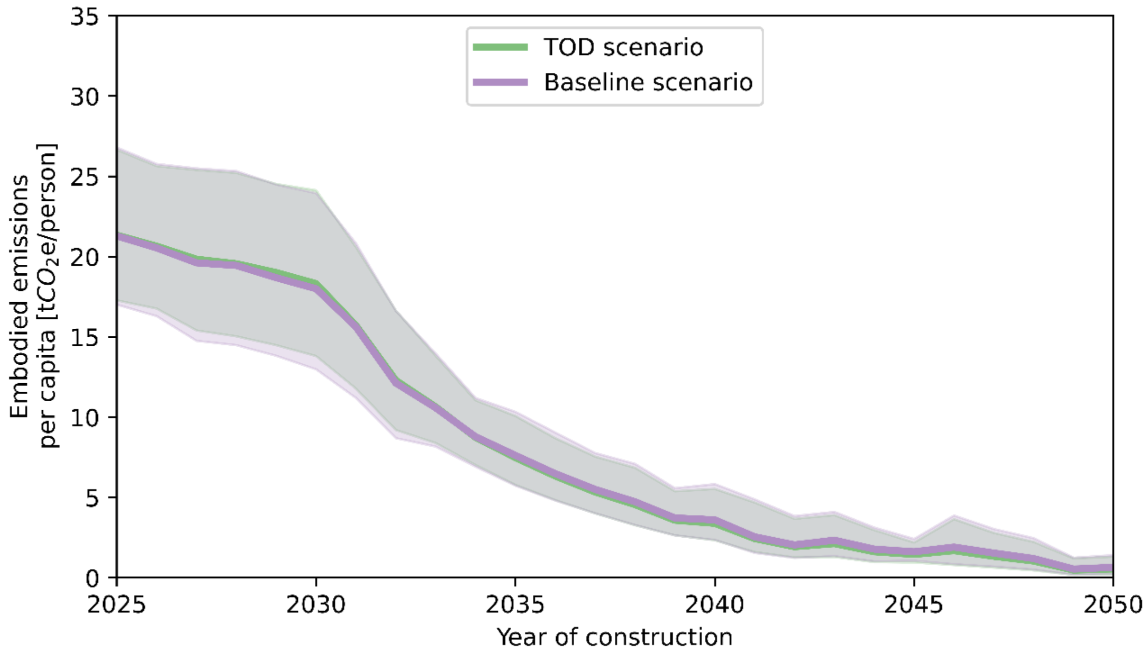

Figure 8. Sensitivity analysis for the embodied GHG per capita vs. year of construction, accounting for future reductions in the GHG intensity of material manufacturing for the baseline and TOD scenarios. Average embodied GHG per capita for each scenario are shown with solid lines, while 95 per cent confidence intervals are shown in surrounding shaded areas.

5. Arbutus Station, Vancouver

5.1. Summary

Table 3 presents a summary of the proposed residential developments in Arbutus for the baseline and the TOD scenarios based on the proposed development information provided by the School of Cities. To estimate future population, we add the most recent population estimate of Arbutus (25,250 people) and the expected number of occupants for all new units built in each scenario. The average occupancy rate for *low occupancy* is 1.3 people per unit, which is obtained by assuming a minimum of one person per bedroom built in the baseline scenario. The second population estimate in Table 3 uses the current average dwelling occupancy in Arbutus, calculated as the ratio of residents and existing dwellings (25,250 people / 13,423 units = 1.88 people per unit). Finally, the third population is the average occupancy for new residential units, considering the assumptions on unit mix and sizes in both scenarios, assuming one person per bedroom, the TOD scenario is 1.9 people/unit, and the baseline scenario is assumed to be 1.45 people/unit.

Table 3. Summary of residential building construction for the baseline and transit-oriented development scenarios in the neighbourhood of Arbutus, Vancouver.

	Baseline scenario	TOD scenario
Number of proposed developments	49	106
Number of proposed residential units	7,121	7,004
Estimated future population (low occupancy)	34,507	34,355
Estimated future population (high average occupancy)	38,637	38,418
Estimated future population (average occupancy in proposed residential units)	10,325	13,308

5.2. Results

Figure 9 shows a histogram of the total embodied GHG emissions associated with each of the analyzed scenarios. On average, the construction of the 49 developments in the baseline scenario would have an associated embodied GHG footprint of 0.243 MtCO_2e (with a 95 per cent confidence interval between 0.223-0.263 MtCO_2e), while the 106 proposed developments in the TOD scenario would result in a total embodied GHG footprint of 0.239 MtCO_2e (with a 95 per cent confidence interval between 0.221-0.258 MtCO_2e).

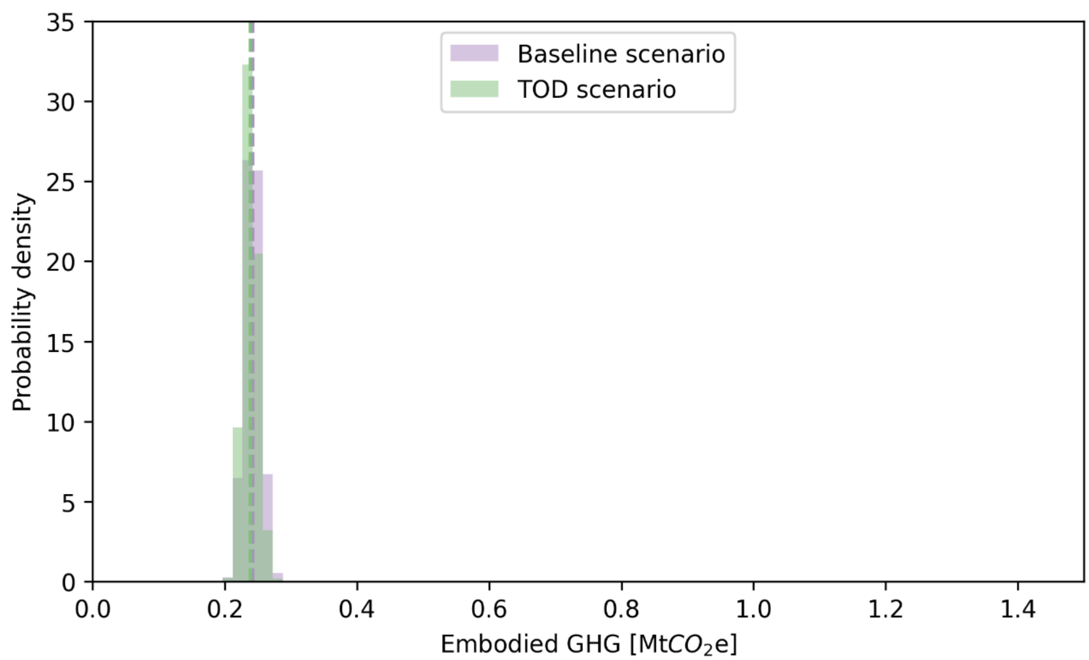

Figure 9. Histogram of the total embodied GHG emissions associated with residential building construction for the baseline and TOD scenarios in Arbutus. The average values for each distribution are shown with dashed lines.

To better contextualize the overall emission estimates shown in Figure 9, we also quantified the embodied GHG emissions per capita of growth for each scenario, as shown in Figure 10.

While building fewer buildings requires less resource use and less associated embodied GHG, fewer buildings house many fewer people. We estimate that, on average, the developments in the baseline scenario will result in a GHG emission footprint of 23.5 tCO_2e/person (with a 95 per cent confidence interval between 21.6-25.5 tCO_2e/person), while the TOD scenario will result in a footprint of 17.9 tCO_2e/person (with a 95 per cent confidence interval between 16.6-19.3 tCO_2e/person). While the overall embodied GHG emissions are similar for the TOD scenario and the baseline scenario in Arbutus, the TOD scenario results are lower in GHG emissions per capita than the baseline scenario.

Since the per capita GHG footprint of each scenario depends on the occupancy levels of the units within the proposed developments, the per capita estimates in Figure 10 assume that new buildings would have a one-person-per-bedroom occupancy level. Since the TOD scenario includes the development of unit mix and size-oriented units, the average occupancy for the TOD scenario is 1.9 people/unit, while the average occupancy of new units in the baseline scenario is assumed to be 1.45 people/unit.

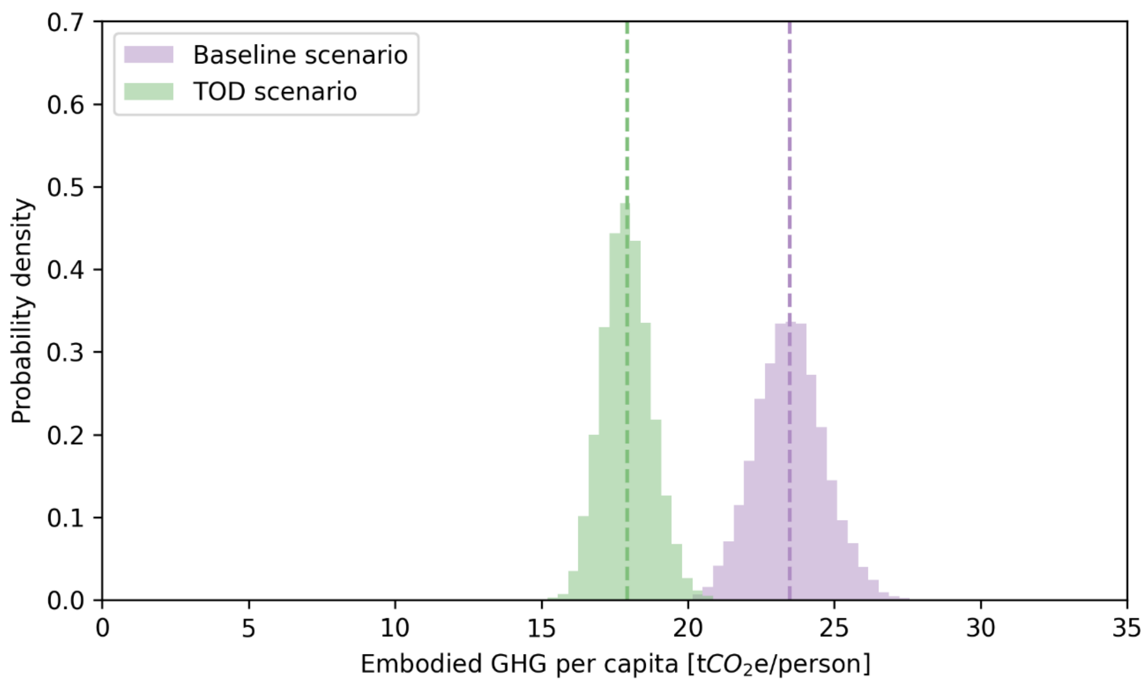

Figure 10. Histogram of embodied GHG emissions per capita associated with residential building construction for the baseline and TOD scenarios in Arbutus. The average values for each distribution are shown with dashed lines. (Baseline 1.45 people/unit; TOD 1.9 people/unit)

Because the unit occupancy has a considerable effect on the per capita GHG emission estimates, we examined the effect of occupancy more closely through a sensitivity analysis. In Figure 11, we show the relationship between dwelling occupancy and the per capita emissions for each scenario. Our results show that the TOD and the baseline scenarios have an almost identical relationship with unit occupancy, but the differences in the unit mix for each scenario lead to divergence in the GHG per capita estimates. Figure 11 also shows that promoting higher occupancy in both scenarios is an important measure to reduce the embodied GHG footprint per capita of development in Arbutus.

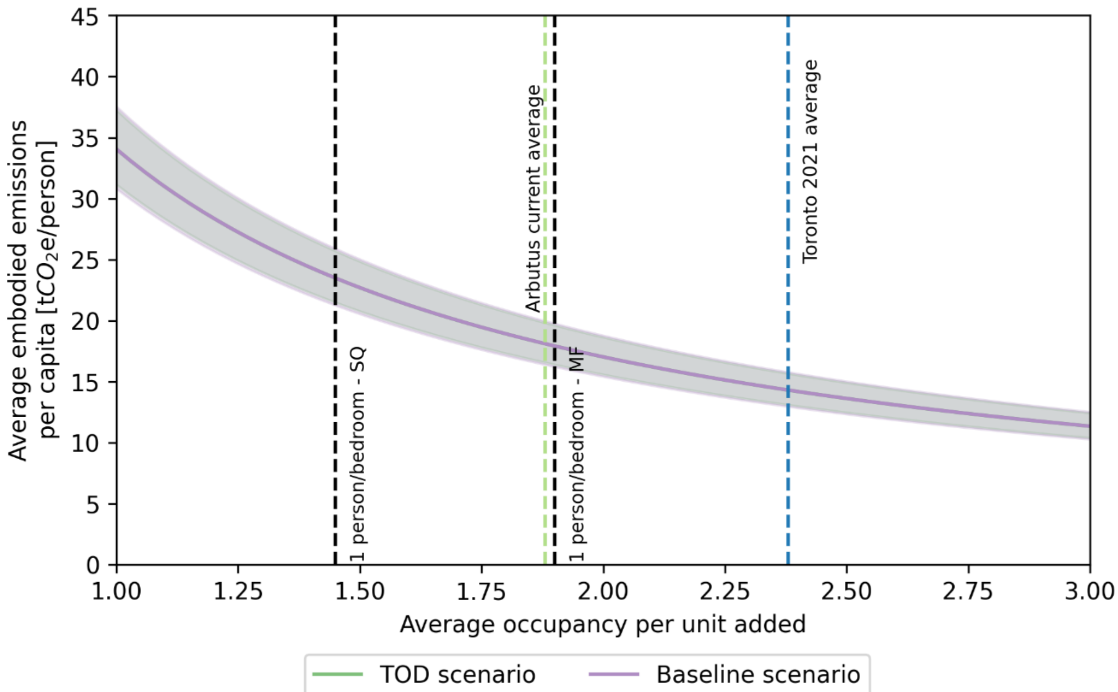

Figure 11. Sensitivity analysis for the embodied GHG per capita vs. average unit occupancy of newly built units for the baseline and TOD scenarios. Average embodied GHG per capita for each scenario are shown with solid lines, 95 per cent confidence intervals are shown in surrounding shaded areas, and reference occupancy values are shown in dashed lines. (SQ = Status Quo unit mix, or 1.45 people/unit; MF = Multi-Family unit mix, or 1.9 people/unit)

Finally, Figure 12 explores the relationship between the per capita embodied GHG estimates for each scenario and the year of construction. Figure 12 shows that the TOD scenario has the largest gap with the baseline scenario under 2025 conditions, and this gap reduces as the construction is delayed further into the future. Note that this sensitivity analysis assumes that all buildings for each scenario are built in the same year, which is unlikely given that large multi-unit buildings are often multi-year endeavours and will not all be built simultaneously.

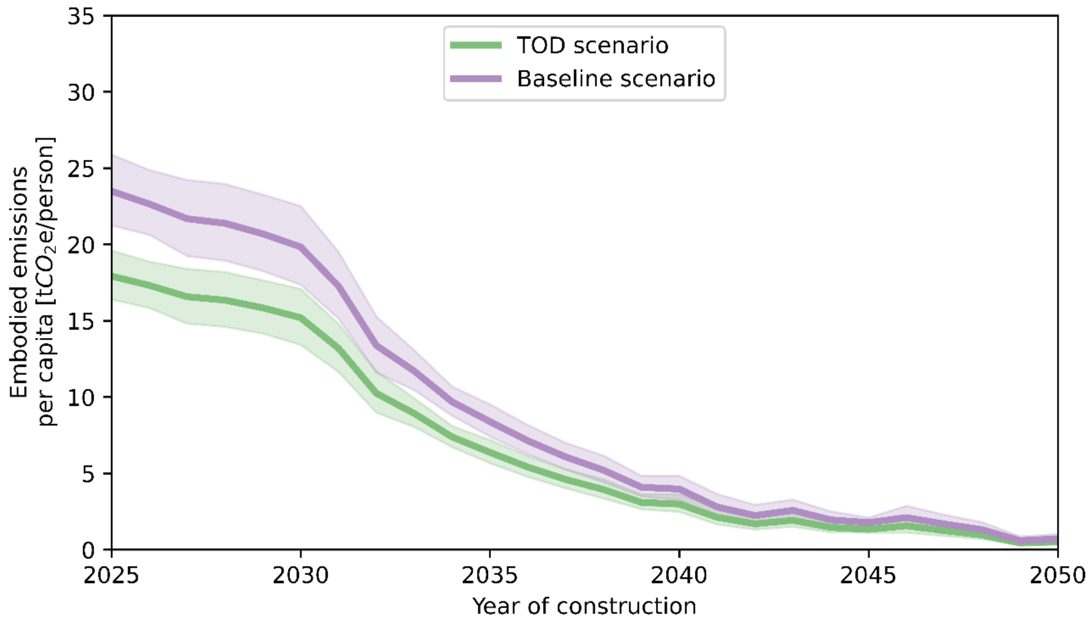

Figure 12. Sensitivity analysis for the embodied GHG per capita vs. year of construction, accounting for future reductions in the GHG intensity of material manufacturing for the baseline and TOD scenarios. Average embodied GHG per capita for each scenario are shown with solid lines, while 95 per cent confidence intervals are shown in surrounding shaded areas.

6. McKernan-Belgravia Station, Edmonton

6.1. Summary

Table 4 presents a summary of the proposed residential developments in McKernan-Belgravia for the baseline and the TOD scenarios based on the proposed development information provided by the School of Cities. To estimate future population, we add the most recent population estimate of McKernan-Belgravia (6,005 people) and the expected number of occupants for all new units built in each scenario. The average occupancy rate for *low occupancy* is 1.3 people per unit, which is obtained by assuming a minimum of one person per bedroom built in the baseline scenario. The second population estimate in Table 4 uses the current average dwelling occupancy in McKernan-Belgravia, calculated as the ratio of residents and existing dwellings (6,005 people / 1,759 units = 3.41 people per unit). Finally, the third population is the average occupancy for new residential units, considering the assumptions on unit mix and sizes in both scenarios, assuming one person per bedroom, the TOD scenario is 1.9 people/unit, and the baseline scenario is assumed to be 1.45 people/unit.

Table 4. Summary of residential building construction for the baseline and transit-oriented development scenarios in the neighbourhood of McKernan-Belgravia, Edmonton.

	Baseline scenario	TOD scenario
Number of proposed developments	353	286
Number of proposed residential units	2,361	2,457
Estimated future population (low occupancy)	9,074	9,199
Estimated future population (high average occupancy)	14,056	14,383
Estimated future population (average occupancy in proposed residential units)	3,423	4,668

6.2. Results

Figure 13 shows a histogram of the total embodied GHG emissions associated with each of the analyzed scenarios. On average, the construction of the 353 developments in the baseline scenario would have an associated embodied GHG footprint of 0.081 MtCO_2e (with a 95 per cent confidence interval between 0.076-0.087 MtCO_2e), while the 286 proposed developments in the TOD scenario would result in a total embodied GHG footprint of 0.084 MtCO_2e (with a 95 per cent confidence interval between 0.078-0.172 MtCO_2e).

To better contextualize the overall emission estimates shown in Figure 13, we also quantified the embodied GHG emissions per capita of growth for each scenario, as shown in Figure 14. While building fewer buildings requires less resource use and less associated embodied GHG, fewer buildings house many fewer people. We estimate that, on average, the developments in the baseline scenario will result in a GHG emission footprint of 23.5 tCO_2e/person (with a 95 per cent confidence interval between 21.9-25.3 tCO_2e/person), while the TOD scenario will result in a footprint of 17.9 tCO_2e/person (with a 95 per cent confidence interval between 16.7-19.2 tCO_2e/person). While the overall embodied GHG emissions are similar for the TOD scenario and the baseline scenario in McKernan-Belgravia, the TOD scenario results are lower in GHG emissions per capita than the baseline scenario.

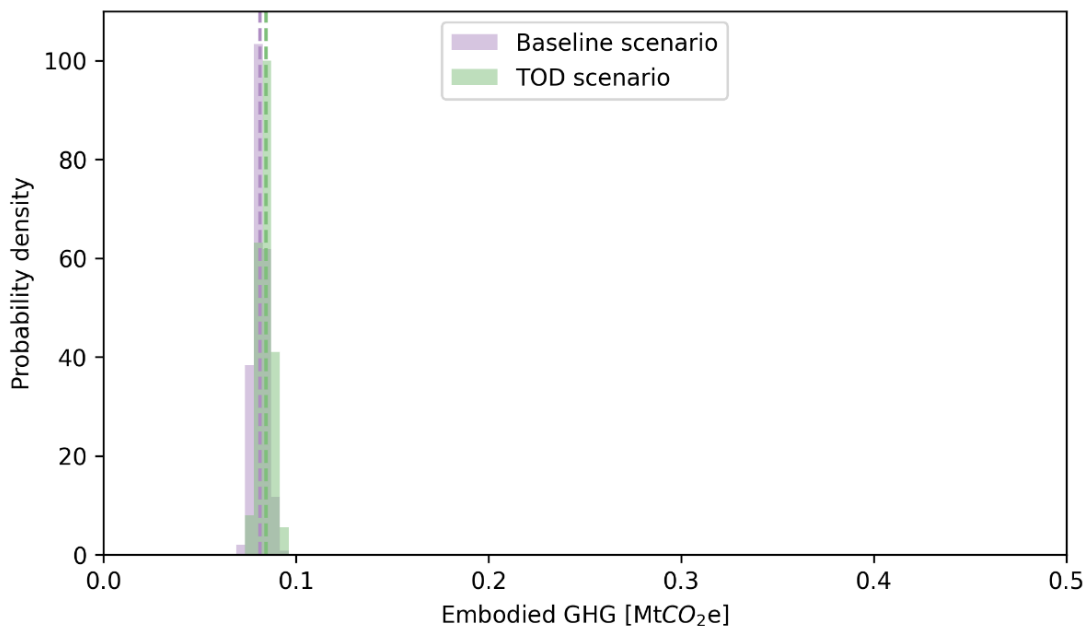

Figure 13. Histogram of the total embodied GHG emissions associated with residential building construction for the baseline and TOD scenarios in McKernan-Belgravia. The average values for each distribution are shown with dashed lines.

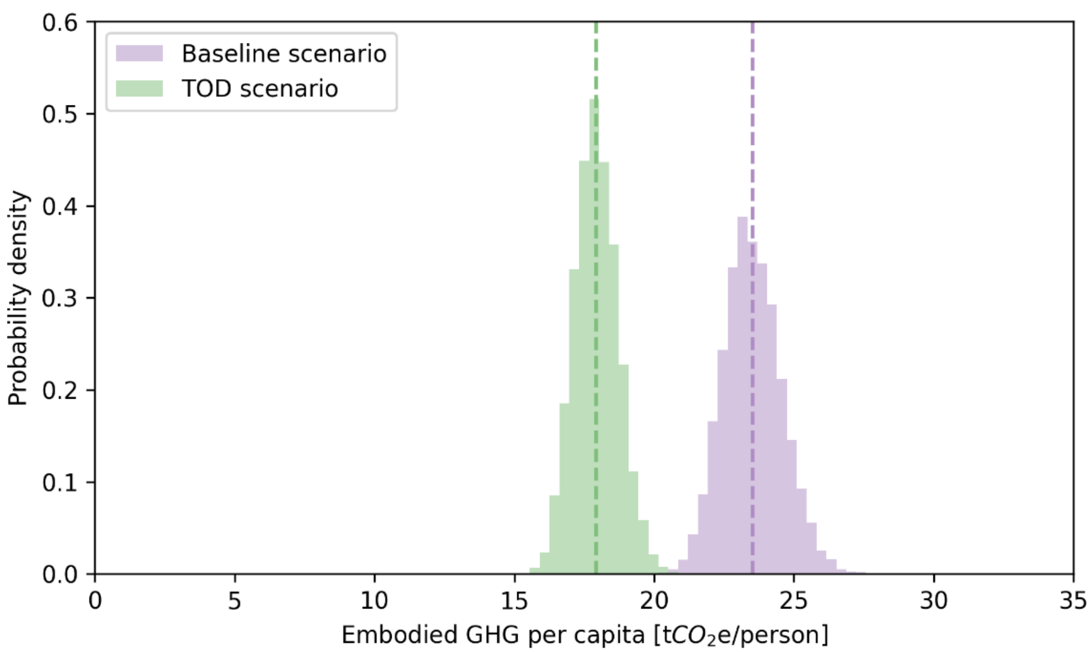

Figure 14. Histogram of embodied GHG emissions per capita associated with residential building construction for the baseline and TOD scenarios in McKernan-Belgravia. The average values for each distribution are shown with dashed lines. (Baseline 1.45 people/unit; TOD 1.9 people/unit)

Since the per capita GHG footprint of each scenario depends on the occupancy levels of the units within the proposed developments, the per capita estimates in Figure 14 assume that new buildings would have a one-person-per-bedroom occupancy level. Since the TOD scenario includes the development of unit mix and size-oriented units, the average occupancy for the TOD scenario is 1.9 people/unit, while the average occupancy of new units in the baseline scenario is assumed to be 1.45 people/unit.

Because the unit occupancy has a considerable effect on the per capita GHG emission estimates, we examined the effect of occupancy more closely through a sensitivity analysis. In Figure 15, we show the relationship between dwelling occupancy and the per capita emissions for each scenario. Our results show that the TOD and the baseline scenarios have an almost identical relationship with unit occupancy, but the differences in the unit mix for each scenario lead to divergence in the GHG per capita estimates. Figure 15 also shows that promoting higher occupancy in both scenarios is an important measure to reduce the embodied GHG footprint per capita of development in McKernan-Belgravia.

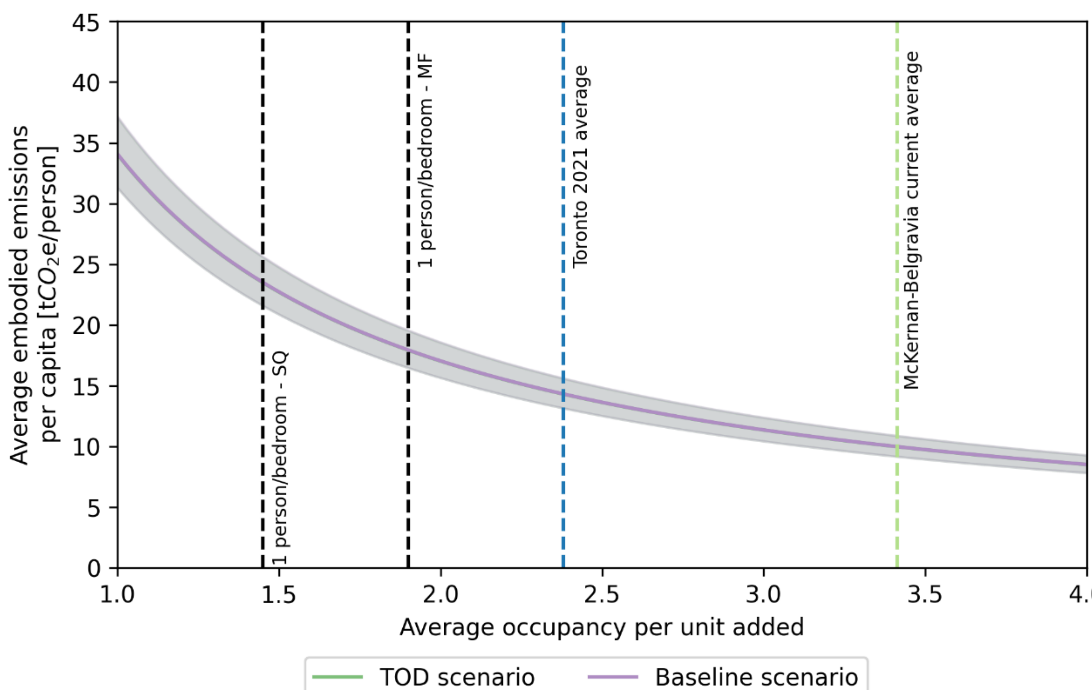

Figure 15. Sensitivity analysis for the embodied GHG per capita vs. average unit occupancy of newly built units for the baseline and TOD scenarios. Average embodied GHG per capita for each scenario are shown with solid lines, 95 per cent confidence intervals are shown in surrounding shaded areas, and reference occupancy values are shown in dashed lines. (SQ = Status Quo unit mix, or 1.45 people/unit; MF = Multi-Family unit mix, or 1.9 people/unit)

Finally, Figure 16 explores the relationship between the per capita embodied GHG estimates for each scenario and the year of construction. Figure 16 shows that the TOD scenario has the largest gap with the baseline scenario under 2025 conditions, and this gap reduces as the construction is delayed further into the future. Note that this sensitivity analysis assumes that all buildings for each scenario are built in the same year, which is unlikely given that large multi-unit buildings are often multi-year endeavours and will not all be built simultaneously.

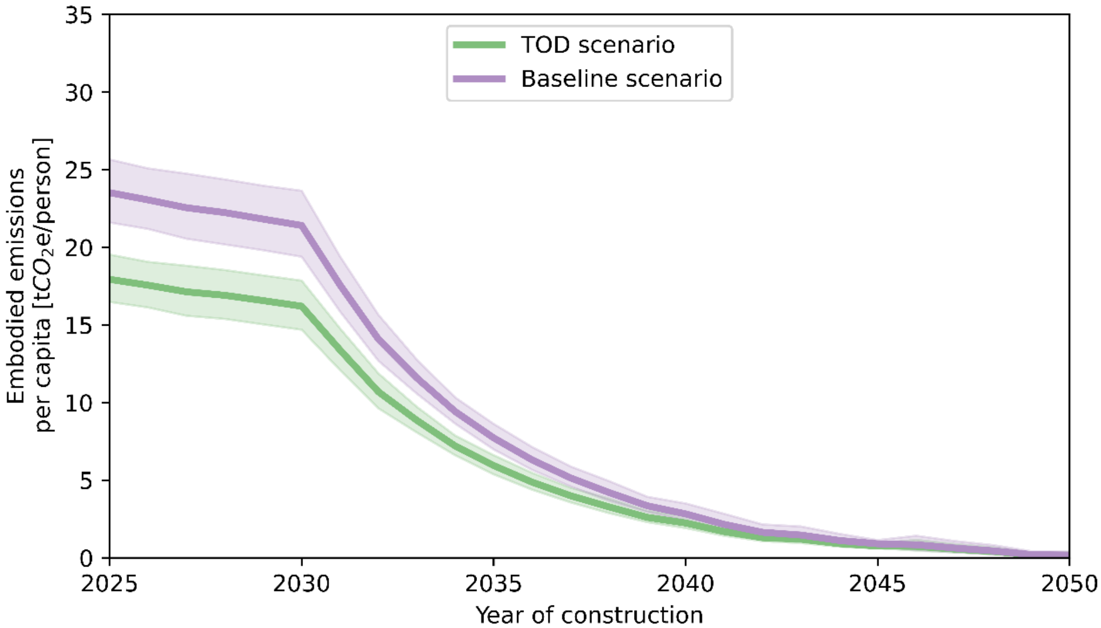

Figure 16. Sensitivity analysis for the embodied GHG per capita vs. year of construction, accounting for future reductions in the GHG intensity of material manufacturing for the baseline and TOD scenarios. Average embodied GHG per capita for each scenario are shown with solid lines, while 95 per cent confidence intervals are shown in surrounding shaded areas.

7. Panama Station, Brossard

7.1. Summary

Table 5 presents a summary of the proposed residential developments in Panama for the baseline and the TOD scenarios based on the proposed development information provided by the School of Cities. To estimate future population, we add the most recent population estimate of Panama (5,279 people) and the expected number of occupants for all new units built in each scenario. The average occupancy rate for *low occupancy* is 1.3 people per unit, which is obtained by assuming a minimum of one person per bedroom built in the baseline scenario. The second population estimate in Table 5 uses the current average dwelling occupancy in Panama, calculated as the ratio of residents and existing dwellings (5,279 people / 2,124 units = 2.48 people per unit). Finally, the third population is the average occupancy for new residential units, considering the assumptions on unit mix and sizes in both scenarios, assuming one person per bedroom, the TOD scenario and the baseline scenario is 1.6 people/unit.

Table 5. Summary of residential building construction for the baseline and transit-oriented development scenarios in the neighbourhood of Panama, Waterloo.

	Baseline scenario	TOD scenario
Number of proposed developments	24	25
Number of proposed residential units	7,903	7,550
Estimated future population (low occupancy)	15,553	15,094
Estimated future population (high average occupancy)	24,878	24,003
Estimated future population (average occupancy in proposed residential units)	12,645	12,080

7.2. Results

Figure 17 shows a histogram of the total embodied GHG emissions associated with each of the analyzed scenarios. On average, the construction of the 24 developments in the baseline scenario would have an associated embodied GHG footprint of 0.272 $MtCO_2e$ (with a 95 per cent confidence interval between 0.228-0.322 $MtCO_2e$), while the 25 proposed developments in the TOD scenario would result in a total embodied GHG footprint of 0.260 $MtCO_2e$ (with a 95 per cent confidence interval between 0.218-0.310 $MtCO_2e$).

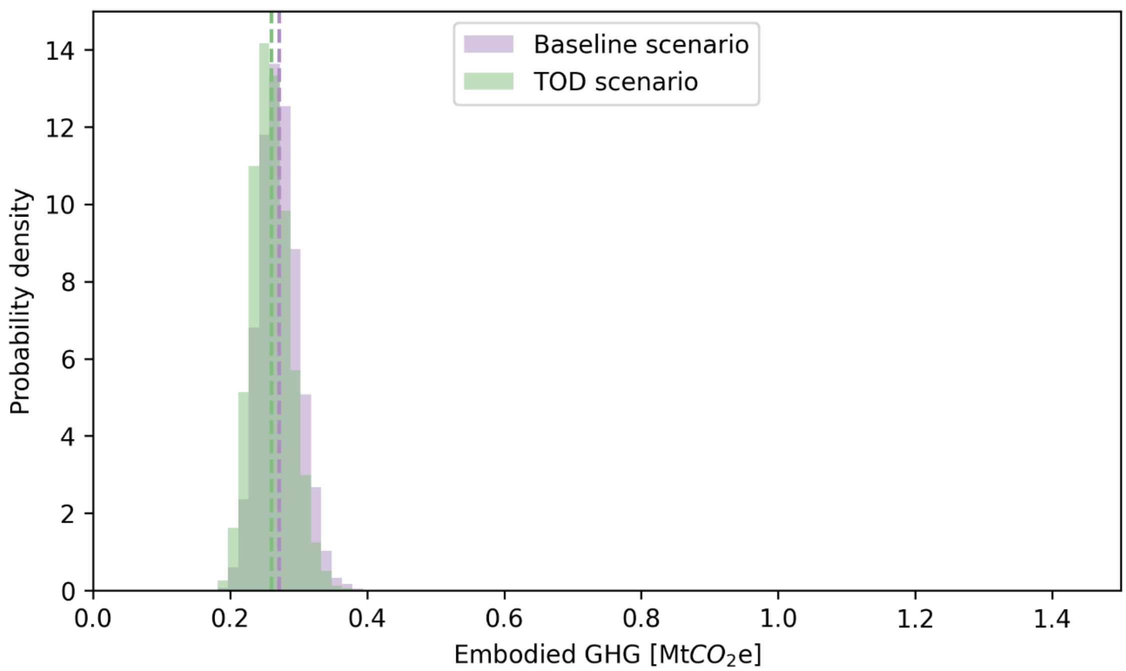

Figure 17. Histogram of the total embodied GHG emissions associated with residential building construction for the baseline and TOD scenarios in Panama. The average values for each distribution are shown with dashed lines.

To better contextualize the overall emission estimates shown in Figure 17, we also quantified the embodied GHG emissions per capita of growth for each scenario, as shown in Figure 18. While building fewer buildings requires less resource use and less associated embodied GHG, fewer buildings house many fewer people. We estimate that, on average, the developments in the baseline scenario will result in a GHG emission footprint of 21.5 tCO_2e/person (with a 95 per cent confidence interval between 18.0-25.5 tCO_2e/person), while the TOD scenario will result in a footprint of 21.6 tCO_2e/person (with a 95 per cent confidence interval between 18.0-25.7 tCO_2e/person). The overall and per capita embodied GHG emissions are similar for the TOD scenario and the baseline scenario in Panama.

Since the per capita GHG footprint of each scenario depends on the occupancy levels of the units within the proposed developments, the per capita estimates in Figure 18 assume that new buildings would have a one-person-per-bedroom occupancy level. However, in the case of both scenarios (baseline and TOD), the average occupancy is the same at 1.6 people/unit, resulting in a similar average of embodied GHG emissions per capita in Panama.

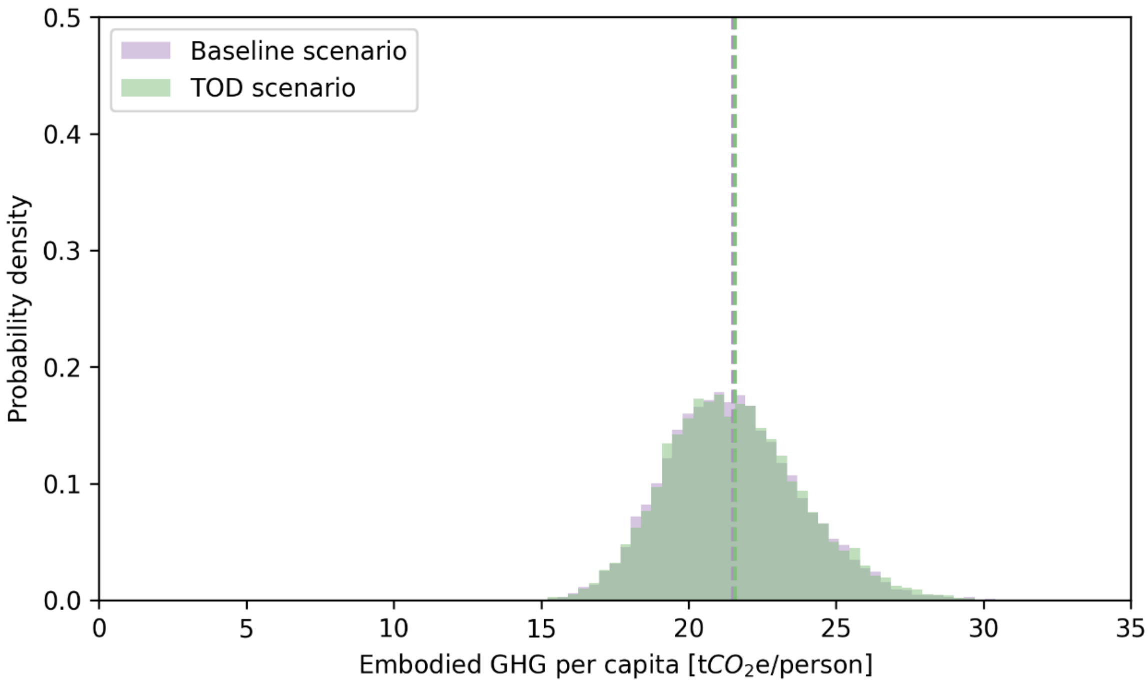

Figure 18. Histogram of embodied GHG emissions per capita associated with residential building construction for the baseline and TOD scenarios in Panama. The average values for each distribution are shown with dashed lines. (Baseline 1.6 people/unit; TOD 1.6 people/unit)

The relationship between dwelling occupancy and the per capita emissions for the baseline and TOD scenarios is shown in Figure 19. Our results show that the TOD and the baseline scenarios have a similar relationship with unit occupancy, as it is the same for both scenarios, and the differences in the unit mix for each scenario overlap, showing equivalent GHG emissions per capita.

Finally, Figure 20 explores the relationship between the per capita embodied GHG estimates for each scenario and the year of construction. Figure 20 shows that the TOD scenario and the baseline scenario exhibit the same behavior throughout all years, because the average occupancy is the same. Note that this sensitivity analysis assumes that all buildings for each scenario are built in the same year, which is unlikely given that large multi-unit buildings are often multi-year endeavours and will not all be built simultaneously.

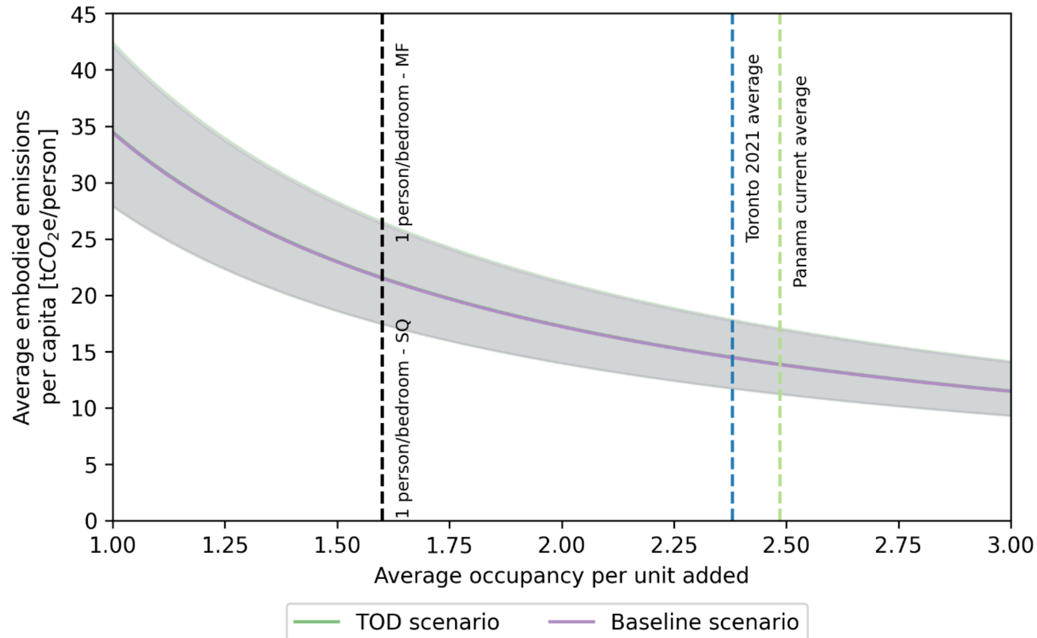

Figure 19. Sensitivity analysis for the embodied GHG per capita vs. average unit occupancy of newly built units for the baseline and TOD scenarios. Average embodied GHG per capita for each scenario are shown with solid lines, 95 per cent confidence intervals are shown in surrounding shaded areas, and reference occupancy values are shown in dashed lines. (SQ = Status Quo unit mix, or 1.6 people/unit; MF = Multi-Family unit mix, or 1.6 people/unit)

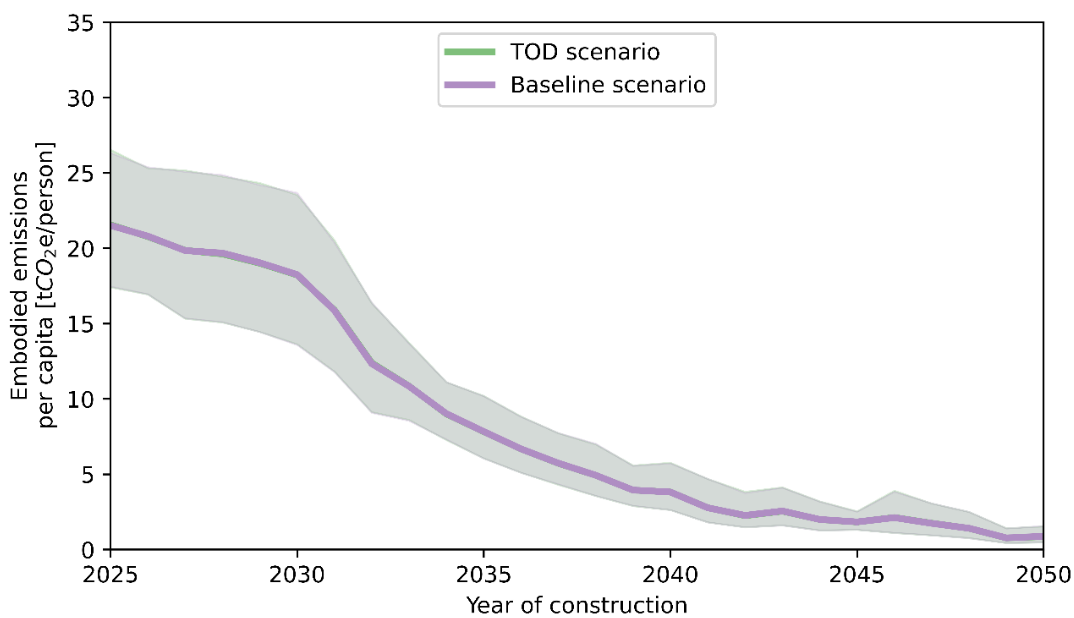

Figure 20. Sensitivity analysis for the embodied GHG per capita vs. year of construction accounting for future reductions in the GHG intensity of material manufacturing for the baseline and TOD scenarios. Average embodied GHG per capita for each scenario are shown with solid lines, while 95 per cent confidence intervals are shown in surrounding shaded areas.

8. Key design takeaways

The analysis indicates that TOD scenarios generally result in lower or comparable total embodied GHG emissions and per capita relative to baseline scenarios, depending on unit size and occupancy levels. A critical factor influencing per capita embodied GHG is the mix of unit types and bedroom counts. Units designed to accommodate more people, particularly those with higher average occupancy rates, contribute significantly reduce embodied GHG emissions per capita. The per capita results are highly sensitive to the number of people living in a unit.

Important considerations over time for controlling embodied GHG will be the improvement (or not) in material manufacturing. Critically, past research has shown that building design is a critical lever for reducing embodied GHG emissions. This is shown here within the sensitivity analysis, with lower embodied GHG design pathways producing the lower end of the calculated ranges. To achieve lower embodied GHG in buildings of a set type, key design choices included:

- **The amount of underground parking:** The more underground construction, the higher the embodied GHG footprint. Avoiding underground parking construction is the most powerful opportunity to reduce building embodied GHG emissions in mid/high rise buildings specifically (Arceo, MacLean and Saxe, 2023; Rankin *et al.*, 2024).
- **Slab design and transfer slabs**: After underground parking, slabs have the highest embodied GHG in most buildings. Aligning columns and choosing thinner slabs presents a large opportunity for reduced embodied GHG in buildings (Hoffer, Bentz and Saxe, 2025).
- **Choosing low GHG insulation**: After concrete, insulation is usually the 2nd largest contribution to embodied GHG emissions in a building (Arceo, MacLean and Saxe, 2023; Rankin *et al.*, 2024). In particular, design choices to avoid the need for fossil fuel derived such as extruded polystyrene (XPS), expanded polystyrene (EPS) can help reduce embodied GHG from insulation (KPMB Lab *et al.*, 2021). This is a readily available opportunity for embodied GHG emission reductions, as low embodied GHG insulation is already on the market; examples include traditional inorganic insulation materials such as glass wool or stone wool, or emerging super-insulating materials like aerogel (Grazieschi, Asdrubali, and Thomas, 2021).
- **Floor plate efficiency.** Low utility floor space (e.g. hallways) requires materials and embodied GHG the same as high utility floor space. Efficient floor plate design and use have the potential to reduce the materials needed in relation to the housing function provided.

Working together, low-carbon design choices can reduce the embodied GHG in a building by 50 per cent or more.

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