

Supplementary Materials

Table S1: Developed and non-developed land-use categories used in the LULC model.

Code	Category name	Summary
HI	Developed – High Intensity	80–100% imperviousness. Represents dense urban-core development, including high-rise buildings and very limited green space.
MI	Developed – Medium Intensity	50–79% imperviousness. Represents moderately dense residential development, including single-family detached homes and duplex-type housing with smaller yards and compressed property lines, often near urban centers.
LI	Developed – Low Intensity	20–49% imperviousness. Represents lower-density residential development, typically single-family detached homes with larger yards, generally farther from urban centers.
OS	Developed – Open Space	Less than 20% imperviousness. Represents developed areas with substantial vegetation or open space, often including low-density residential development.
ND	Non-developed	Includes all natural land-cover types. May include rural residences on large parcels, often associated with agricultural or open land.

Embodied emissions intensity of Texas buildings

In order to assess the overall embodied emissions in Texas now and in future decades, intensities per building type and height were informed from the available values in literature. However, no comprehensive data for Texas specifically exists, and the heterogeneity of the building stock, coupled with a lack of data on building age and material type means a broad, order-of-magnitude approach is appropriate. For this paper, product stage (A1-A3) is focused on in line analyses in this space [1]. Benke et al. produced a detailed dataset of North American embodied carbon [2], showing a wide range of values and the absence of a relationship with building height remains a challenge for assessments in this space [3, 4]. Gursel et al. found that material efficiency improves with height in office buildings [5]. For most building types, we assume a slight material efficiency improvement with height in the move between low-rise to mid-rise, and then a reducing benefit as buildings become very tall and require more reinforcement. It is further assumed that there will be not meaningful change in embodied emissions intensity through 2050.

Table S2: Embodied GHG emissions intensity values assigned by building type and height category.

Building type	Height category	Story range	Embodied emissions (tCO ₂ e m ⁻²)	GHG	Notes for interpretation
Agricultural	Low-rise	1-3	0.10		Barns, sheds, greenhouses, and livestock buildings.
Agricultural	Mid-rise	4-8	0.20		Specialized agricultural facilities, including some processing or storage buildings.
Agricultural	High-rise	9+	0.30		Very rare; mainly relevant for vertical farming or atypical storage structures.
Commercial	Low-rise	1-3	0.40		Retail, small offices, and low-rise mixed commercial stock.
Commercial	Mid-rise	4-8	0.30		Larger offices and hotels.
Commercial	High-rise	9+	0.50		Office towers and other tall commercial buildings.
Industrial	Low-rise	1-3	0.40		Most factories, warehouses, and logistics buildings.
Industrial	Mid-rise	4-8	0.30		Multi-story industrial or laboratory-type buildings.
Industrial	High-rise	9+	0.25		Uncommon; may include vertically stacked industrial programs.
Public	Low-rise	1-3	0.40		Schools, libraries, small civic buildings, and community facilities.
Public	Mid-rise	4-8	0.30		Larger institutional buildings, hospitals, and administrative buildings.
Public	High-rise	9+	0.50		Tall institutional or civic buildings, especially in dense urban settings.
Residential	Low-rise	1-3	0.20		Detached, semi-detached, row-home, and small apartment forms.
Residential	Mid-rise	4-8	0.50		Apartment buildings and multi-unit dwellings.
Residential	High-rise	9+	0.60		Typical residential towers.
Vacant or unknown	Low-rise	1-3	0.20		Interpreted as likely residential.
Vacant or unknown	Mid-rise	4-8	0.30		Interpreted as likely commercial.
Vacant or unknown	High-rise	9+	0.50		Interpreted as likely commercial.

Notes: Values represent embodied greenhouse gas emissions intensity assumptions assigned by building type and height category. Story ranges are used to classify buildings into low-, mid-, and high-rise categories.

Table S3: Carbon stock, sequestration, and soil carbon values assigned to natural land-cover classes.

Land type	Aboveground C stock (t C ha ⁻¹)	Soil C stock (t C ha ⁻¹)	Sequestration rate (t C ha ⁻¹ yr ⁻¹)
Open Water	0.00	0.00	0.00
Barren Land	0.00	0.00	0.00
Deciduous Forest	96.00	100.00	2.60
Evergreen Forest	179.00	80.00	2.60
Mixed Forest	180.00	100.00	2.60
Shrub/Scrub	2.99	75.16	0.00
Grassland/Herbaceous	30.00	73.90	0.50
Pasture/Hay	7.84	88.00	1.50
Cultivated Crops	0.00	15.00	0.30
Woody Wetlands	0.00	0.00	0.00
Emergent Herbaceous Wetlands	0.00	0.00	0.00

Notes: Aboveground C stock represents the estimated initial aboveground carbon loss associated with conversion to developed land. Soil C stock represents the estimated soil organic carbon pool used for land-conversion accounting. Forest values were informed by Lal [6], Prentice et al. [7], Lewandrowski et al. [8], Nowak et al. [9], and Pregitzer et al. [10]. Shrub/scrub values were based primarily on shrubland vegetation and soil carbon estimates from Li et al. [11]. Grassland values were informed by NatureScot [12] and grassland management estimates from Conant et al. [13]. Pasture/hay values were informed by Orefice et al. [14] and Lewandrowski et al. [8]. Cropland sequestration values were informed by Lewandrowski et al. [8] and Poeplau and Don [15]. Water, barren land, and wetlands were assigned zero values in this implementation because those pools were excluded from the terrestrial carbon accounting framework.

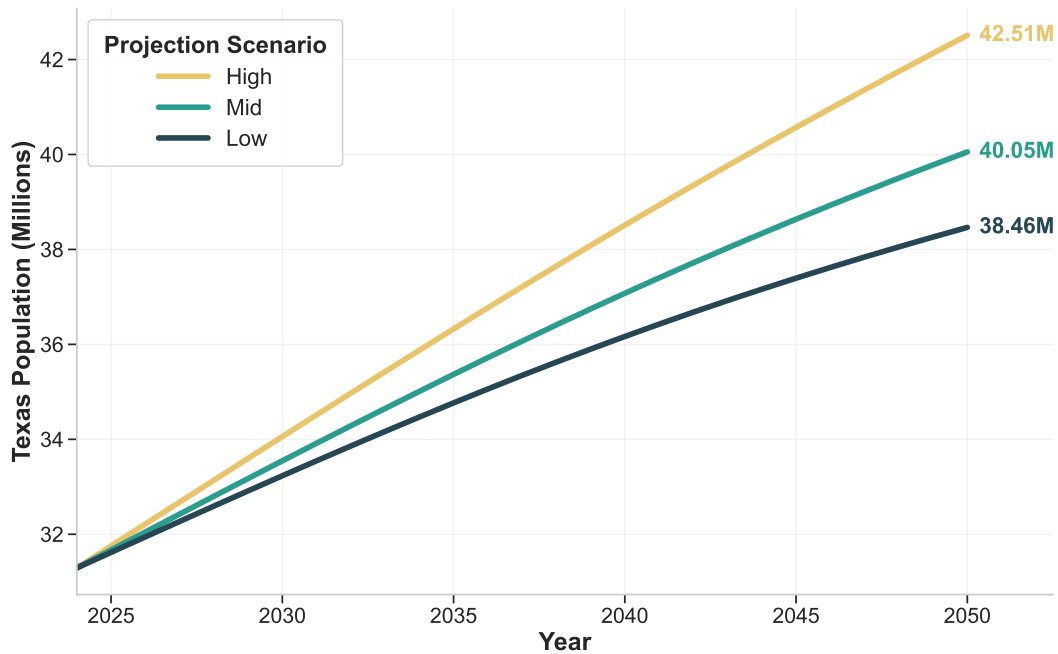


Figure S1: Three population growth pathways provided by the Texas Demographic Center

Table S4: Floor area per capita (FAC) by NLCD development category and building type for Texas in 2021. Values are reported in $\text{m}^2 \text{ person}^{-1}$.

Development category	Residential	Commercial	Industrial	Public	Agricultural	Vacant or unknown	Total FAC
Non-Developed	116.3	6.8	1.7	3.1	53.2	24.2	205.4
Developed – Open Space	106.8	4.8	0.8	2.5	9.7	11.1	135.6
Developed – Low Intensity	93.3	4.9	0.9	2.6	3.1	5.6	110.3
Developed – Medium Intensity	85.8	18.9	5.6	9.2	1.9	7.5	128.8
Developed – High Intensity	51.1	212.5	127.6	64.8	9.5	41.7	507.3

Supplementary Methods: Land-Use/Land-Cover Change and Land-Carbon Accounting

This section describes the land-use/land-cover change (LULCC) and land-carbon accounting methods used to project future development across Texas. The model begins from a 2024 National Land Cover Database (NLCD) baseline raster and projects land-cover change in five-year increments through 2050. County-level population growth is converted to demand for new developed land, allocated spatially on a 30 m raster grid, and used to estimate initial land-carbon loss and foregone sequestration from converted land.

Spatial basis and land-cover classes

NLCD land-cover classes are used as the base land-use classification [16]. Original NLCD class codes are preserved as integer raster values. All rasters are clipped to Texas, reprojected to EPSG:3083 for area calculations, and aligned to a 30 m grid. Each raster cell has an area of:

$$900 \text{ m}^2 = 0.0009 \text{ km}^2 = 0.09 \text{ ha}.$$

The model includes NLCD classes 11, 12, 21–24, 31, 41–43, 52, 71, 81, 82, 90, and 95. Classes 21–24 are treated as developed classes: Developed Open Space, Low Intensity, Medium Intensity, and High Intensity. All invalid or nodata cells are excluded from area, allocation, and carbon calculations. Water, perennial ice/snow, and wetlands are retained for reporting but excluded from active conversion in the scenario allocation.

Scenario design

The scenario framework combines three county-level population-growth assumptions (Low, Mid, and High) with three development-form assumptions (Sprawl, BAU, and Built-Up), producing nine total scenarios. County population projections are taken from the Texas Demographic Center [17]. For each county and projection period, population growth is calculated as:

$$\Delta P_{i,t} = P_{i,t} - P_{i,t-1},$$

where $P_{i,t}$ is the projected population of county i in benchmark year t . Negative increments are set to zero, so projected population decline does not remove existing developed land.

County development profiles

County development profiles relate population to developed land-cover classes. Profiles are estimated by overlaying county boundaries, NLCD land-cover classes, and population density from the TWDB buildings dataset [18]. For each county and category, the overlay estimates land area, associated population, population density, and population share. The categories

include Non-Developed land and the four developed NLCD classes. The Non-Developed category allows some projected population growth to be absorbed without requiring additional land conversion.

For each developed class c , category-specific population density is defined as:

$$\rho_{i,c} = \frac{P_{i,c}}{A_{i,c}},$$

where $P_{i,c}$ is the population associated with class c in county i , and $A_{i,c}$ is the area of that class in km^2 .

Dynamic development shares and densities

Development patterns vary with county population density. Using the 2021 NLCD/TWDB overlay, counties are binned by total population density, and median values are calculated within each bin for: (1) the share of county population associated with each land-use category and (2) the population density within each developed class. These binned relationships are smoothed in log-density space and evaluated for each county and projection year and are shown in S2.

Development-form scenarios are implemented by modifying the category-share curves prior to allocation. Sprawl increases the relative share of Developed Open Space and Low Intensity development and reduces the share of Medium and High Intensity development. BAU preserves the observed density-share relationship. Built-Up increases the relative share of Medium and High Intensity development and reduces the share of Open Space and Low Intensity development. After scenario multipliers are applied, category shares are normalized to sum to one.

Population-to-land-demand conversion

For each county, projection year, and target developed class, allocated population growth is converted to required developed land area:

$$A_{i,c,t}^{\text{new}} = \frac{\Delta P_{i,c,t}}{\rho_{i,c,t}},$$

where $\Delta P_{i,c,t}$ is the population allocated to developed class c , and $\rho_{i,c,t}$ is the projected population density for that class. Required area is then converted to 30 m pixels:

$$N_{i,c,t}^{\text{new}} = \left\lceil \frac{A_{i,c,t}^{\text{new}}}{0.0009} \right\rceil.$$

Developed classes are allocated from highest to lowest intensity: High, Medium, Low, and Open Space. This order permits intensification, so higher-intensity development can replace lower-intensity developed classes. When intensification occurs, replacement demand is tracked so that displaced lower-intensity development can be recreated elsewhere if required by the scenario.

Spatial allocation and transition weights

Development is allocated within each county using a source-quota-constrained cellular automata procedure with reproducible random tie-breaking. Candidate pixels must be valid raster cells, lie within the county being allocated, belong to an allowed source class for the target developed class, and have a suitability value greater than zero. Allocation favors pixels adjacent to existing or newly selected developed land. If no adjacent frontier cells are available, the model uses the broader eligible candidate pool.

Allowed source classes vary by target intensity. Developed Open Space can only be allocated from non-developed source classes. Low Intensity development can be allocated from non-developed classes or Developed Open Space. Medium Intensity development can be allocated from non-developed classes, Developed Open Space, or Low Intensity development. High Intensity development can be allocated from non-developed classes or any lower developed class.

Fixed statewide source shares are derived from observed NLCD transitions during 2000–2005, 2005–2010, 2010–2015, 2015–2021, and 2021–2024. Historical transition counts are pooled across these periods and converted to relative shares separately for each target developed class:

$$W_{s,c} = \frac{H_{s \rightarrow c}}{\sum_s H_{s \rightarrow c}},$$

where $H_{s \rightarrow c}$ is the statewide number of historical pixels transitioning from source class s to target developed class c . For each county, projection period, and target class, the required number of pixels is divided among eligible source classes according to these fixed shares:

$$Q_{i,t,s,c} = D_{i,t,c} W_{s,c},$$

where $D_{i,t,c}$ is the total pixel demand for target class c in county i and period t , and $Q_{i,t,s,c}$ is the corresponding source-class quota. Quotas are rounded to integer pixels while preserving the total requested allocation.

Within each source-class quota, candidate pixels receive a suitability score:

$$S_x = N_x U_x,$$

where N_x is the neighborhood effect and U_x is the suitability value. The neighborhood effect is defined as:

$$N_x = 1 + \frac{n_x}{8},$$

where n_x is the number of developed cells in the eight-cell Moore neighborhood. This term favors compact growth adjacent to existing development. Pixels are selected in descending score order until the source quota is filled. Pixels tied at the selection threshold are selected randomly using a fixed random seed.

If a source quota cannot be filled because too few eligible pixels remain, its shortfall spills over to the remaining eligible source classes. During spillover, remaining pixels are ranked using the historical source share, neighborhood effect, and suitability value:

$$S_x^{\text{spill}} = W_{s,c} N_x U_x.$$

The fixed statewide source shares used in the allocation are shown in Table S5.

Table S5: Fixed statewide source-class shares used to allocate land transitions into each developed class. Values were derived from a study of annual NLCD maps from 2000-2024.

Source Class	Developed - Open Space	Developed - Low Intensity	Developed - Medium Intensity	Developed - High Intensity
Barren Land	0.0014	0.0061	0.0091	0.0049
Deciduous Forest	0.0146	0.0115	0.0104	0.0082
Evergreen Forest	0.0719	0.0479	0.0405	0.0291
Mixed Forest	0.0328	0.0186	0.0150	0.0123
Shrub/Scrub	0.3360	0.1723	0.0988	0.0517
Grassland/Herbaceous	0.1785	0.1536	0.1541	0.1298
Pasture/Hay	0.2218	0.1154	0.1095	0.0815
Cultivated Crops	0.1431	0.1093	0.1102	0.1048
Developed - Open Space	0.0000	0.3652	0.1490	0.1607
Developed - Low Intensity	0.0000	0.0000	0.3033	0.1836
Developed - Medium Intensity	0.0000	0.0000	0.0000	0.2334

Zero values indicate source-to-target transitions that are not allowed for a given target developed class.

Suitability constraints

A suitability raster is aligned to the 30 m land-cover grid and used to restrict or discourage conversion. Suitability is derived from protected-area and spatial-constraint data [19]. GAP status 1 and 2 areas are blocked, GAP status 3 areas are strongly discouraged but not fully blocked, and GAP status 4 areas are blocked. Numerically, blocked areas are assigned 0.0, strongly discouraged areas are assigned 0.01, and generally available areas are assigned 1.0. Suitability affects where growth is allocated but does not change county-level population growth or initial land demand. However, spatial constraints may prevent the model from filling all requested development when insufficient eligible land remains.

Land-use area and change metrics

After each projection year, land-cover area is calculated from class-specific pixel counts:

$$A_{c,t} = N_{c,t} \times 0.0009.$$

Land-use change is measured relative to the 2024 baseline:

$$\Delta A_{c,t} = A_{c,t}^{\text{scenario}} - A_c^{\text{baseline}}.$$

These metrics are calculated for each land-cover class, projection year, and scenario.

Initial land-carbon loss

Initial land-carbon loss is estimated when a non-developed source pixel is converted to developed land. Developed-to-developed intensification changes land-cover class but is not assigned additional land-carbon loss. Initial carbon loss includes aboveground carbon loss and soil carbon loss. Soil carbon loss is represented as a fixed fraction of source-class soil carbon stock:

$$F_{\text{soil},s} = C_{\text{soil},s} \times f_{\text{soil}},$$

where $C_{\text{soil},s}$ is the source-class soil carbon stock and $f_{\text{soil}} = 0.30$ is the soil carbon loss fraction. Total initial loss factor is:

$$F_{\text{initial},s} = F_{\text{above},s} + F_{\text{soil},s}.$$

For each conversion event:

$$C_{\text{initial}} = A_{\text{converted}} \times F_{\text{initial},s},$$

where $A_{\text{converted}}$ is converted area in hectares. Carbon coefficients are shown in Table S3. Aboveground and soil carbon values were informed by forest, shrubland, grassland, pasture, and cropland carbon estimates from the literature.

Foregone sequestration

Foregone sequestration represents carbon uptake that converted land would have provided if it had remained in its source class. The model tracks cumulative converted area by source class. For each projection period:

$$C_{\text{foregone},s,t} = A_{\text{converted},s,t}^{\text{cumulative}} \times r_s \times \Delta t,$$

where $A_{\text{converted},s,t}^{\text{cumulative}}$ is cumulative converted area in hectares, r_s is the source-class sequestration rate in $\text{tC ha}^{-1} \text{ yr}^{-1}$, and Δt is the length of the projection period in years. Because converted area is tracked cumulatively, land converted in earlier periods continues to contribute foregone sequestration in later periods. Annual sequestration rates are shown in Table S3.

Carbon unit conversion and aggregation

The scenario engine stores land-carbon values in metric tons of carbon (tC). Results are converted to CO_2 -equivalent using:

$$\text{tCO}_2\text{e} = \text{tC} \times 3.67,$$

and summarized in MtCO_2e as:

$$\text{MtCO}_2\text{e} = \frac{\text{tCO}_2\text{e}}{1,000,000}.$$

The land-carbon components reported in the scenario summaries are cumulative initial land-carbon loss and cumulative foregone sequestration. When combined with the building-materials workflow, total carbon impact includes cumulative new building embodied emissions, cumulative initial land-carbon loss, and cumulative foregone sequestration.

Assumptions and limitations

This model is designed for scenario comparison rather than parcel-level prediction. The strongest interpretation is comparative: how Sprawl, BAU, and Built-Up development forms affect land conversion and land-carbon impacts under Low, Mid, and High population-growth futures. Key assumptions include:

- County population growth drives new developed land demand.
- Population decline does not remove existing developed land.
- Development allocation is deterministic and score-ranked.
- Existing developed land can intensify to higher developed classes.
- Initial land-carbon loss is applied only to non-developed source classes.
- Water, perennial ice/snow, and wetlands are excluded from conversion.
- Suitability constraints approximate protected-area and spatial restrictions but do not capture all legal, market, infrastructure, ownership, or local planning constraints.
- Development shares and densities are inferred from observed county relationships and modified by scenario assumptions.
- Soil carbon loss is represented as a fixed fraction of source-class soil stock.
- Foregone sequestration is calculated from cumulative converted area and fixed source-class sequestration rates.
- The 30 m grid improves spatial detail but does not eliminate uncertainty in population allocation, land-cover classification, or future development behavior.

Sensitivity and Uncertainty Analysis

Table S6: Sensitivity of cumulative combined upfront carbon impacts in 2050 to the assumed fraction of soil carbon stock lost following development.

Population pathway	Urban form	15%	Baseline (30%)	45%
		Combined upfront carbon impact (MtCO ₂ e)		
Low	Sprawl	501.32	556.58	611.84
Low	BAU	473.33	515.96	558.58
Low	Built-Up	629.44	662.80	696.15
Mid	Sprawl	582.85	643.56	704.26
Mid	BAU	555.27	602.84	650.41
Mid	Built-Up	746.67	784.08	821.49
High	Sprawl	700.84	768.94	837.04
High	BAU	682.27	737.21	792.15
High	Built-Up	925.50	968.50	1011.49

Note: Combined upfront carbon impact includes cumulative embodied building carbon, initial above-ground and soil carbon loss, and foregone carbon sequestration through 2050. The sensitivity cases vary only the fraction of soil carbon stock lost following conversion to developed land. Population, development, gross floor area, embodied carbon, aboveground carbon loss, and foregone sequestration remain unchanged.

Table S7: Sensitivity of cumulative combined upfront carbon impacts in 2050 to reductions in embodied emissions coefficients of buildings. Land-carbon loss and foregone sequestration coefficients remain unchanged.

Population pathway	Urban form	Baseline (100%)	80%	60%
		Combined upfront carbon impact (MtCO ₂ e)		
Low	Sprawl	556.58	512.13	467.68
Low	BAU	515.96	463.41	410.87
Low	Built-Up	662.80	570.42	478.04
Mid	Sprawl	643.56	590.04	536.52
Mid	BAU	602.84	539.49	476.14
Mid	Built-Up	784.08	672.68	561.29
High	Sprawl	768.94	701.17	633.40
High	BAU	737.21	656.90	576.59
High	Built-Up	968.50	827.24	685.99

Note: Combined upfront carbon impact includes cumulative embodied building carbon, initial land-carbon loss, and foregone carbon sequestration through 2050. The sensitivity cases scale only the embodied building coefficients; population, development, gross floor area, and land-carbon effects are unchanged.

Cadastral Calibration and Uncertainty Analysis for Single-Family Detached Buildings

We calibrated single-family detached (SFD) gross floor area (GFA) from the Texas Water Development Board (TWDB) against parcel-level records from the Travis Central Appraisal District (TCAD). Using a matched sample of one qualifying pre-2022 TCAD SFD improvement and one TWDB building per parcel, and excluding 11 nonpositive-area records, the final sample was 209,065 parcels. The TCAD reference area includes house floor-like area, garages, and porches, but excludes noncomparable records (paving, pools, HVAC equipment, fences, storage). No valid observations were removed by error magnitude.

The correction factor is the ratio of aggregate areas:

$$C_{\text{SFD}} = \frac{\sum_{i=1}^n A_i^{\text{TCAD}}}{\sum_{i=1}^n A_i^{\text{TWDB}}}, \quad (\text{S1})$$

where A_i^{TCAD} and A_i^{TWDB} are the TCAD clean SFD and TWDB GFA for parcel i . Aggregate TWDB GFA was 1.37 times the TCAD area, giving $C_{\text{SFD}} = 0.73$; thus multiplying TWDB SFD GFA by 0.73 reduces the aggregate by 27.3% to match the TCAD reference. The median signed parcel-level TWDB error was +14.28%, describing typical pre-correction error rather than uncertainty in the aggregate factor.

We estimated spatial uncertainty via a whole-cell block bootstrap: parcels were assigned to 125 occupied 5-km grid cells, and complete cells resampled with replacement over 10,000 replicates, yielding a 95% interval of $0.69 \leq C_{\text{SFD}} \leq 0.76$. This interval reflects only neighborhood-level variation within the matched Travis County SFD population. It excludes cadastral, TWDB-measurement, temporal-mismatch, classification, matching, and detection-coverage uncertainty, and does not address transferability to counties with different appraisal methods. It should therefore be read as a narrow Travis County SFD calibration, not a statewide factor or a comprehensive TWDB uncertainty estimate.

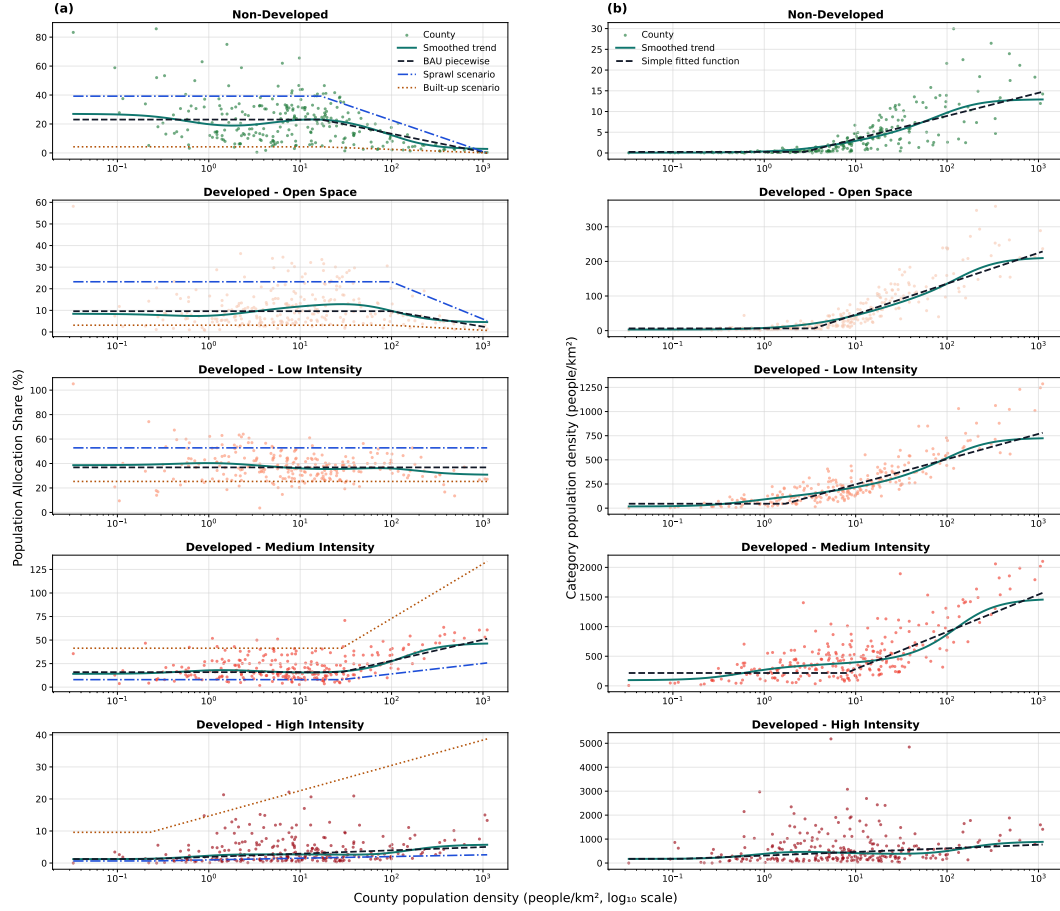


Figure S2: Empirical relationships used for county-level land apportionment, derived from 2021 baseline data. (a) Population allocation share as a function of county population density under baseline (BAU), low-density, and high-density scenarios. (b) Category population density as a function of county population density. Points represent county-level observations; solid lines indicate smoothed trends; dashed lines denote simplified fitted functions used in the model.

Table S8: Numerical values underlying Figure 6 - Cumulative upfront carbon impact of all nine scenarios by 2050. Values are reported in MtCO₂e, with each component's percentage of total scenario carbon impact shown in parentheses.

Population pathway	Density scenario	New Building Embodied Emissions	Initial Land Carbon Loss	Foregone Carbon Sequestration	Total Upfront Carbon Impact
Low	Sprawl	222.2 (39.9%)	258.3 (46.4%)	76.0 (13.7%)	556.6 (100.0%)
Low	BAU	262.7 (50.9%)	194.2 (37.6%)	59.0 (11.4%)	516.0 (100.0%)
Low	Built-Up	461.9 (69.7%)	153.8 (23.2%)	47.1 (7.1%)	662.8 (100.0%)
Mid	Sprawl	267.6 (41.6%)	291.4 (45.3%)	84.6 (13.1%)	643.6 (100.0%)
Mid	BAU	316.7 (52.5%)	219.9 (36.5%)	66.2 (11.0%)	602.8 (100.0%)
Mid	Built-Up	557.0 (71.0%)	173.8 (22.2%)	53.3 (6.8%)	784.1 (100.0%)
High	Sprawl	338.9 (44.1%)	334.0 (43.4%)	96.1 (12.5%)	768.9 (100.0%)
High	BAU	401.6 (54.5%)	259.5 (35.2%)	76.1 (10.3%)	737.2 (100.0%)
High	Built-Up	706.3 (72.9%)	201.0 (20.8%)	61.2 (6.3%)	968.5 (100.0%)

Note: Percentages represent each component's share of total carbon impact within each scenario. Values may not sum exactly to totals due to rounding.

Table S9: Numerical values underlying Figure 8 - Total cumulative embodied emissions of projected Texas building stock through 2050. Values are reported in MtCO₂e, with each building type's percentage of total new building embodied emissions shown in parentheses.

Building Type	Low Sprawl	Low BAU	Low Built-Up	Mid Sprawl	Mid BAU	Mid Built-Up	High Sprawl	High BAU	High Built-Up
Residential	138.5 (62.3%)	134.7 (51.3%)	127.3 (27.6%)	166.6 (62.3%)	162.0 (51.1%)	153.2 (27.5%)	210.7 (62.2%)	204.9 (51.0%)	193.9 (27.5%)
Commercial	36.9 (16.6%)	60.3 (23.0%)	165.1 (35.8%)	44.7 (16.7%)	73.1 (23.1%)	199.3 (35.8%)	57.0 (16.8%)	93.1 (23.2%)	252.9 (35.8%)
Industrial	13.7 (6.2%)	25.1 (9.6%)	83.8 (18.1%)	16.6 (6.2%)	30.4 (9.6%)	101.1 (18.2%)	21.2 (6.3%)	38.8 (9.7%)	128.3 (18.2%)
Public	15.5 (7.0%)	24.0 (9.1%)	56.3 (12.2%)	18.8 (7.0%)	29.1 (9.2%)	68.0 (12.2%)	24.0 (7.1%)	37.0 (9.2%)	86.2 (12.2%)
Vacant or Unknown	13.0 (5.8%)	14.6 (5.6%)	25.4 (5.5%)	15.5 (5.8%)	17.6 (5.5%)	30.7 (5.5%)	19.5 (5.7%)	22.2 (5.5%)	38.9 (5.5%)
Agricultural	4.6 (2.1%)	3.9 (1.5%)	3.9 (0.8%)	5.4 (2.0%)	4.6 (1.4%)	4.7 (0.8%)	6.6 (1.9%)	5.6 (1.4%)	5.9 (0.8%)

Note: Percentages represent each building type's share of total new building embodied emissions within each scenario. Values may not sum exactly to totals due to rounding.

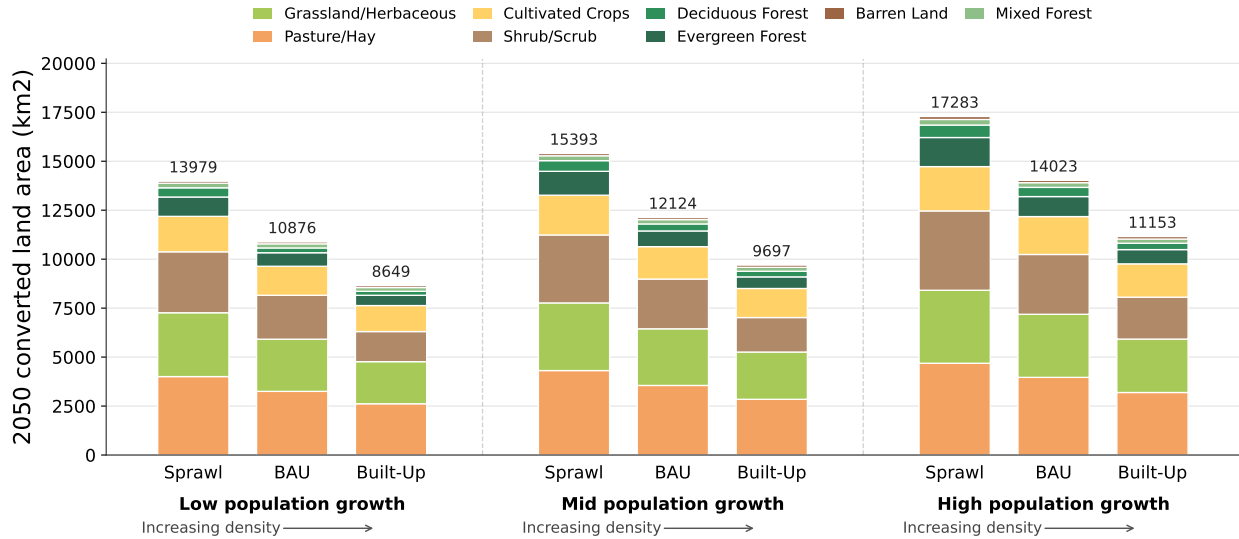


Figure S3: Projected cumulative land area converted to development, 2024–2050, for all natural land-cover archetypes by scenario. Values are rounded; see Supplementary Table S10 for full precision.

Table S10: Numerical values underlying Supplementary Figure S3. Each cell reports converted area in km², with the percentage of total natural land converted in that scenario shown in parentheses.

Land use	L-Sp	L-BAU	L-BU	M-Sp	M-BAU	M-BU	H-Sp	H-BAU	H-BU
Barren Land	99 (0.7%)	92 (0.8%)	99 (1.1%)	114 (0.7%)	104 (0.9%)	112 (1.2%)	150 (0.9%)	118 (0.8%)	125 (1.1%)
Deciduous Forest	470 (3.4%)	245 (2.3%)	205 (2.4%)	544 (3.5%)	358 (3.0%)	290 (3.0%)	637 (3.7%)	469 (3.3%)	324 (2.9%)
Evergreen Forest	986 (7.1%)	689 (6.3%)	523 (6.0%)	1,219 (7.9%)	801 (6.6%)	592 (6.1%)	1,485 (8.6%)	1,020 (7.3%)	727 (6.5%)
Mixed Forest	237 (1.7%)	210 (1.9%)	190 (2.2%)	249 (1.6%)	221 (1.8%)	200 (2.1%)	285 (1.6%)	240 (1.7%)	216 (1.9%)
Shrub/Scrub	3,111 (22.3%)	2,241 (20.6%)	1,536 (17.8%)	3,469 (22.5%)	2,540 (21.0%)	1,760 (18.2%)	4,050 (23.4%)	3,052 (21.8%)	2,139 (19.2%)
Grassland/Herbaceous	3,258 (23.3%)	2,665 (24.5%)	2,150 (24.9%)	3,453 (22.4%)	2,892 (23.9%)	2,413 (24.9%)	3,727 (21.6%)	3,222 (23.0%)	2,728 (24.5%)
Pasture/Hay	4,006 (28.7%)	3,250 (29.9%)	2,617 (30.3%)	4,313 (28.0%)	3,553 (29.3%)	2,845 (29.3%)	4,686 (27.1%)	3,965 (28.3%)	3,192 (28.6%)
Cultivated Crops	1,812 (13.0%)	1,483 (13.6%)	1,329 (15.4%)	2,031 (13.2%)	1,654 (13.6%)	1,484 (15.3%)	2,263 (13.1%)	1,936 (13.8%)	1,702 (15.3%)
Total natural land converted	13,979	10,875	8,649	15,392	12,123	9,696	17,283	14,022	11,153

Note: L = Low population growth, M = Mid population growth, H = High population growth; Sp = Sprawl, BAU = business-as-usual, and BU = Built-Up.

Table S11: Numerical values underlying Figure 9 - Carbon stock loss through 2050 by scenario and natural land type. Values are reported in MtCO₂e, with each land-cover class's percentage of total initial land carbon loss shown in parentheses.

Land Use	Low Sprawl	Low BAU	Low Built- Up	Mid Sprawl	Mid BAU	Mid Built- Up	High Sprawl	High BAU	High Built- Up
Barren Land	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
Cultivated Crops	3.0 (1.2%)	2.4 (1.3%)	2.2 (1.4%)	3.4 (1.2%)	2.7 (1.2%)	2.5 (1.4%)	3.7 (1.1%)	3.2 (1.2%)	2.8 (1.4%)
Deciduous Forest	21.8 (8.4%)	11.3 (5.8%)	9.5 (6.2%)	25.2 (8.6%)	16.5 (7.5%)	13.4 (7.7%)	29.5 (8.8%)	21.7 (8.4%)	15.0 (7.5%)
Evergreen Forest	73.5 (28.4%)	51.3 (26.4%)	39.0 (25.4%)	90.8 (31.2%)	59.7 (27.2%)	44.1 (25.4%)	110.6 (33.1%)	76.0 (29.3%)	54.2 (26.9%)
Grassland/Herbaceous	62.4 (24.1%)	51.0 (26.3%)	41.2 (26.8%)	66.1 (22.7%)	55.4 (25.2%)	46.2 (26.6%)	71.4 (21.4%)	61.7 (23.8%)	52.2 (26.0%)
Mixed Forest	18.2 (7.1%)	16.2 (8.4%)	14.7 (9.5%)	19.2 (6.6%)	17.1 (7.8%)	15.4 (8.9%)	22.0 (6.6%)	18.5 (7.1%)	16.6 (8.3%)
Pasture/Hay	50.3 (19.5%)	40.8 (21.0%)	32.9 (21.4%)	54.2 (18.6%)	44.6 (20.3%)	35.8 (20.6%)	58.9 (17.6%)	49.8 (19.2%)	40.1 (20.0%)
Shrub/Scrub	29.2 (11.3%)	21.0 (10.8%)	14.4 (9.4%)	32.5 (11.2%)	23.8 (10.8%)	16.5 (9.5%)	38.0 (11.4%)	28.6 (11.0%)	20.0 (10.0%)

Note: Percentages represent each land-cover class's share of total initial land carbon loss within each scenario. Values may not sum exactly to totals due to rounding.

Table S12: Numerical values underlying Figure 10 - Foregone potential for carbon sequestration through 2050 by scenario and natural land type. Values are reported in MtCO₂e, with each land-cover class's percentage of total foregone carbon sequestration shown in parentheses.

Land Use	Low Sprawl	Low BAU	Low Built- Up	Mid Sprawl	Mid BAU	Mid Built- Up	High Sprawl	High BAU	High Built- Up
Barren Land	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
Cultivated Crops	3.3 (4.4%)	2.7 (4.6%)	2.4 (5.1%)	3.7 (4.3%)	3.0 (4.6%)	2.7 (5.0%)	4.2 (4.4%)	3.5 (4.6%)	3.1 (5.0%)
Deciduous Forest	6.3 (8.3%)	3.9 (6.5%)	3.0 (6.4%)	7.7 (9.1%)	5.5 (8.2%)	4.2 (7.8%)	9.2 (9.6%)	6.7 (8.9%)	5.3 (8.6%)
Emergent Herbaceous Wetlands	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
Evergreen Forest	14.1 (18.5%)	10.4 (17.6%)	8.0 (17.0%)	16.4 (19.4%)	11.7 (17.7%)	9.1 (17.1%)	20.2 (21.1%)	14.1 (18.5%)	10.7 (17.5%)
Grassland/Herbaceous	10.0 (13.2%)	8.0 (13.6%)	6.4 (13.5%)	10.9 (12.9%)	8.8 (13.3%)	7.2 (13.5%)	11.9 (12.4%)	9.9 (13.0%)	8.2 (13.4%)
Mixed Forest	4.3 (5.6%)	3.7 (6.3%)	3.2 (6.8%)	4.6 (5.5%)	4.0 (6.1%)	3.6 (6.7%)	5.0 (5.2%)	4.5 (5.9%)	4.0 (6.5%)
Open Water	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
Pasture/Hay	38.0 (50.0%)	30.3 (51.4%)	24.1 (51.2%)	41.3 (48.8%)	33.2 (50.2%)	26.6 (49.9%)	45.5 (47.3%)	37.5 (49.2%)	30.0 (49.0%)
Shrub/Scrub	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
Woody Wetlands	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)

Note: Percentages represent each land-cover class's share of total foregone carbon sequestration within each scenario. Values may not sum exactly to totals due to rounding.

References

- [1] M. Röck, A. Sorensen, M. Balouktsi, *et al.*, “Global Buildings Database Seed on Whole Life Carbon Emissions, Energy Performance, and Material Intensity (GBDB CarbEnMats),” 2024.
- [2] B. Benke, M. Chafart, Y. Shen, M. Ashtiani, S. Carlisle, and K. Simonen, “A Harmonized Dataset of High-Resolution Embodied Life Cycle Assessment Results for Buildings in North America,” *Scientific Data*, vol. 12, p. 1085, July 2025.
- [3] A. Hoffer, E. Bentz, and S. Saxe, “Just one more storey? The embodied greenhouse gas impacts of adding height, slab thickness, building code and design tranches,” *Resources, Conservation and Recycling*, vol. 227, p. 108753, 2026.
- [4] K. H. Rankin, A. Arceo, K. Isin, and S. Saxe, “Embodied GHG of missing middle: Residential building form and strategies for more efficient housing,” *Journal of Industrial Ecology*, vol. 28, pp. 455–468, 2024.
- [5] A. P. Gursel, A. Shehabi, and A. Horvath, “Embodied energy and greenhouse gas emission trends from major construction materials of U.S. office buildings constructed after the mid-1940s,” *Building and Environment*, vol. 234, p. 110196, 2023.
- [6] R. Lal, “Forest soils and carbon sequestration,” *Forest Ecology and Management*, vol. 220, pp. 242–258, Dec. 2005.
- [7] I. C. Prentice, G. D. Farquhar, M. J. R. Fasham, M. L. Goulden, and e. a. Heimann, “The carbon cycle and atmospheric carbon dioxide,” in *Climate Change 2001: The Scientific Basis* (J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson, eds.), Cambridge University Press, 2001.
- [8] J. Lewandrowski, M. Peters, C. Jones, R. House, M. Sperow, M. Eve, and K. Paustian, “Economics of sequestering carbon in the u.s. agricultural sector,” Technical Bulletin 1909, U.S. Department of Agriculture, Economic Research Service, Washington, DC, 2004.
- [9] D. J. Nowak, E. J. Greenfield, R. E. Hoehn, and E. Lapoint, “Carbon storage and sequestration by trees in urban and community areas of the United States,” *Environmental Pollution*, vol. 178, pp. 229–236, July 2013.
- [10] C. C. Pregitzer, C. Hanna, S. Charlop-Powers, and M. A. Bradford, “Estimating carbon storage in urban forests of New York City,” *Urban Ecosystems*, vol. 25, pp. 617–631, Apr. 2022.
- [11] M. Li, P. H. Verburg, and J. van Vliet, “Global trends and local variations in land take per person,” *Landscape and Urban Planning*, vol. 218, p. 104308, Feb. 2022.
- [12] NatureScot, “Guidance: Evidence on carbon and nature,” n.d. Retrieved May 5, 2026.
- [13] R. T. Conant, K. Paustian, and E. T. Elliott, “Grassland Management and Conversion into Grassland: Effects on Soil Carbon,” *Ecological Applications*, vol. 11, no. 2, pp. 343–355, 2001. [_eprint: https://esajournals.onlinelibrary.wiley.com/doi/pdf/10.1890/1051-0761%282001%29011%5B0343%3AGMACIG%5D2.0.CO%3B2](https://esajournals.onlinelibrary.wiley.com/doi/pdf/10.1890/1051-0761%282001%29011%5B0343%3AGMACIG%5D2.0.CO%3B2).
- [14] J. Orefice, M. M. Smith, W. C. Weinberg, and M. Batcheler, “Carbon dynamics of silvopasture systems in the Northeastern United States,” *Scientific Reports*, vol. 15, p. 6995, Feb. 2025.

- [15] C. Poeplau and A. Don, “Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis,” *Agriculture, Ecosystems & Environment*, vol. 200, pp. 33–41, Feb. 2015.
- [16] U.S. Geological Survey, “Annual nlcd collection 1 science products.” USGS Data Release, 2024.
- [17] Texas Demographic Center, “Vintage 2024 Population Projections for Texas Counties, 2020–2060.” Texas Population Projections Program dataset, 2025. Accessed 2026-05-13.
- [18] Texas Water Development Board, “2025 Buildings with Population Datasets.” Flood Planning Data Hub, ArcGIS Hub dataset, 2025. Accessed 2026-05-13.
- [19] U.S. Geological Survey (USGS) Gap Analysis Project, “Protected Areas Database of the United States (PAD-US) 4.1.” U.S. Geological Survey data release, 2024. Accessed 2026-05-13.