LOW-CARBON BUILDINGS

A Method for Estimating Buildings GHG Emissions and Emissions Reduction Performance

2009 Edition

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Readers are welcome to send their comments and suggestions for improvement at: LCBMethod@hotmail.com.
Relevant comments will be considered in the next revision of this book.

While the author has used his best efforts when preparing this book, there still may be English spelling and grammatical errors here and there. The author asks for reader's indulgence in this matter.

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FOREWORDS

Accounting for 39% of all greenhouse gases (GHG) emissions[1], buildings are the largest contributors to Climate Change. But it is also the industrial sector whose emissions are the easiest and cheapest to reduce[2].

Regrettably, very few construction standards directly address this issue. Even modern "green buildings" achieve on average 25-30% emissions reduction which is far from what would make them "Climate neutral".

This book introduces the concept of "low-carbon" buildings (LCB), and proposes a method for:

- Estimating buildings lifetime GHG emissions.
- Estimating buildings GHG emissions reduction performance.

This method is intended for construction professionals without particular knowledge of GHG accounting. The method is:

- Simple: no need to run software or read complicated scientific literature.
- Quick: the whole emissions analysis can be done in a few hours.
- "Relatively" accurate (see last chapter).

It can be used as a tool by designers, builders, and owners to reduce the "Climate impact" of their buildings.

Ultimately, the author hopes that this method together with existing "green

[1] Emissions by end-use sectors, U.S. EPA, 2009 Draft U.S. GHG Inventory Report, 2009.
[2] IPCC, Climate Change 2007 Synthesis Report, 2007.

building" standards will contribute to the evolution of the building industry towards more sustainable practices.

GENERAL

1 CLIMATE CHANGE

Human activities (such as burning fossil fuels and deforestation) are responsible for the release in the atmosphere of considerable amount of GHG.

GHG concentrations in the atmosphere now stand at around 430 ppm CO_2-e compared with only 280 ppm CO_2-e before the industrial revolution. GHG concentrations are still increasing today at a rate of 2.7 ppm per year. In a possible "business as usual" scenario, they will reach 550 ppm CO_2-e in 2035.

GHG have the property of trapping solar heat. Their increasing concentrations in the atmosphere have for consequence an elevation in the average temperature of the Earth's near-surface air and oceans. Climate model projections indicate that global surface temperature will likely rise 1.1 to 6.4 °C during the twenty-first century.

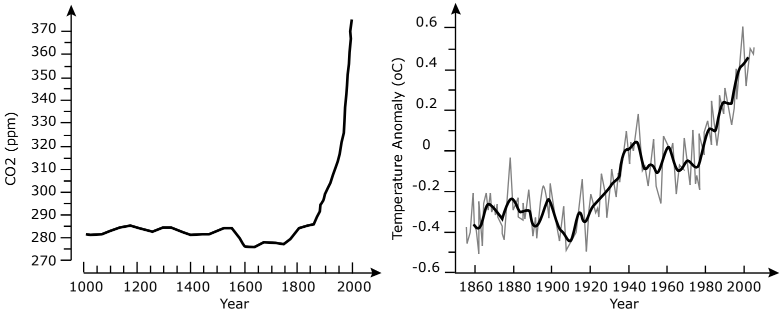


Fig. CO2 Concentration in the Atmosphere/
Temperature Anomalies Observed

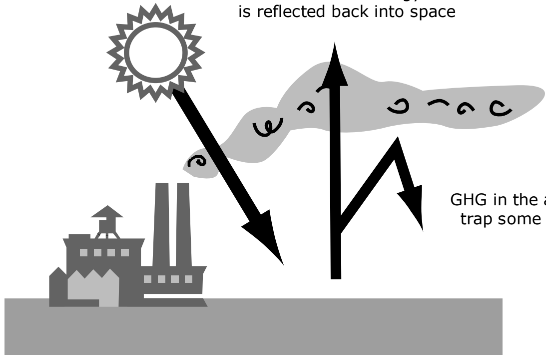
This elevation in temperature causes "changes" to the average weather of regions or the Earth as a whole ("Climate Change"). Average weather may include average temperature, precipitation and wind patterns.

WHAT ARE GHG?

Main greenhouse gases released by human activities are:

- Carbon dioxide: CO_2
- Methane: CH_4
- Nitrous oxide: N_2O
- And in smaller proportions: HFCs, SF_6, PFCs.

In the atmosphere, these gases form like a blanket over the Earth surface which traps solar radiations:



❧ WHAT IS "CO2-EQUIVALENT"? ❧

All GHG do not have the same ability to trap solar heat. One ton of CH4 for example has the same Global Warming effect (or Global Warming potential, GWP) than 21 tons of CO2 (1 tonCH4≈21 tonCO2-e).

For simplification, the Global Warming effect of all GHG is expressed in CO2-e using the following formula:

Emissions (in CO2-e) = Emissions x GWP

By convention the GWP of CO2 is 1. The GWP and atmospheric lifetime of other GHG are given below:

	GWP	**Atmospheric Lifetime** Yrs
CO2	1	50-200
CH4	21	9-12
N2O	310	120
HFCs	140-11,700	2-264
SF6	23,900	3,200
PCFs	6,500-9,200	3,200-50,000

2 BUILDINGS AND CLIMATE CHANGE

Buildings are the largest emitters of GHG. They are responsible for around 39% of all GHG emitted by human activities (not incl. land use changes)[3]:

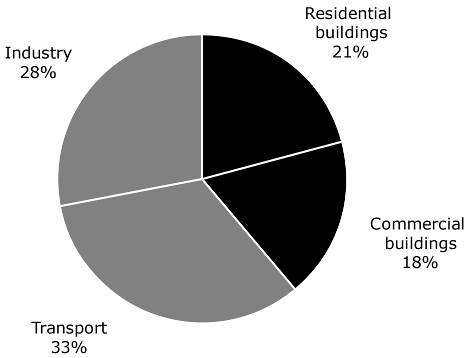


Fig. GHG Emissions by End-Use Sectors

A building emits GHG during its whole lifetime:

- Construction/Renovation: extraction of raw materials, manufacturing and transport of construction products, etc.
- Operation: generation of electricity, steam, etc. consumed by the building.
- Deconstruction: incineration of demolition wastes, decomposition in landfills, etc.

For reference, a traditional office building emits in the atmosphere approximately 8.5 tonCO2-e/m2 over 50 years:

[3] Emissions by end-use sectors, U.S. EPA, 2009 Draft U.S. GHG Inventory Report, 2009.

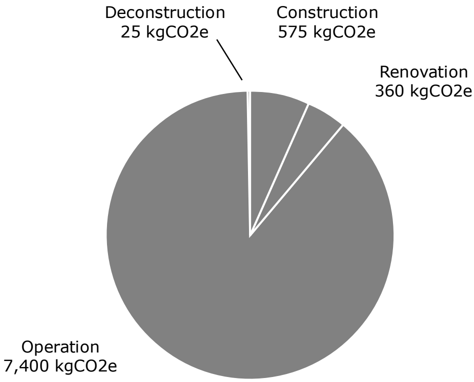


Fig. Office Buildings Lifetime Emissions per m2 (Average)

3 WHAT IS A LOW-CARBON BUILDING?

A “low-carbon” building (LCB) is a building which has been engineered to release significantly less GHG than a regular building (or “baseline”) over its lifetime.

Typically, a LCB will consume much less energy than a traditional building, and integrate distinctive technologies, such as renewable energy systems, which will reduce its GHG emissions.

Pushing the concept of low-carbon buildings further, “carbon-neutral” buildings are buildings which achieve zero GHG emissions.

LOW-CARBON BUILDINGS VS “GREEN BUILDINGS”

An important number of green buildings rating tools have emerged in recent years: LEED®, BREAM, CASBEE™, HQE®, etc.

These rating systems address a vast range of environmental issues such as land preservation, resources preservation, energy saving, etc. but very few of them directly address GHG emissions and Climate Change.

A recent study has shown for example that LEED certified buildings emit on average 34% less GHG than traditional buildings[4]. This is a significant emissions reduction performance but still far from what is needed to stabilize GHG concentrations in the atmosphere (see paragraph 7).

THE COST OF LCB

Depending on its emissions reduction performance, the initial cost of a LCB can be significantly higher than the one of a traditional building. The purchase of renewable energy systems (wind turbines, PV, etc.) accounts for most of this extra cost.

Under certain circumstances, in particular local financial incentives, these systems can have payback periods of 10-20 years. It means that in the end, a LCB can actually cheaper than a traditional building.

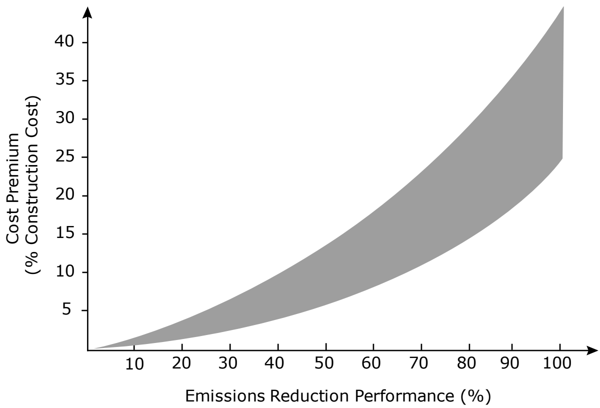


Fig. LCB Cost Premium

In the case of a large office building wishing to achieve 50% emissions reduction by using wind power, the theoretical simple payback period would

[4] Estimated from Kim M. Fowler, Emily M. Rauch, A Post Occupancy Evaluation of 12 GSA Buildings, 2008.

be[5]:

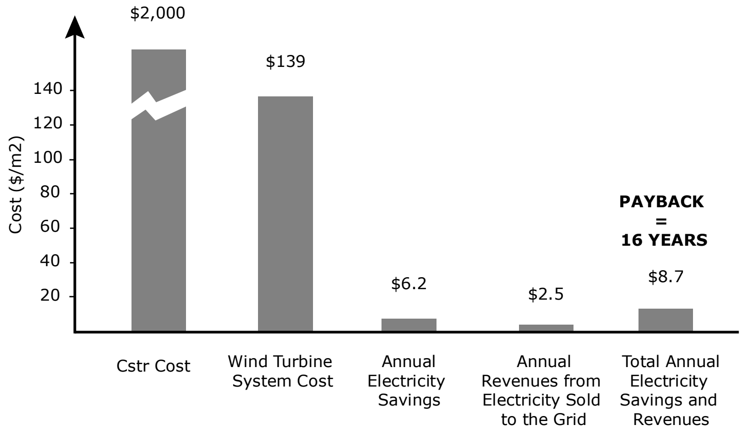


Fig. LCB Cost Savings per m2 (Example)

Note that when carbon emissions will be taxed (which is already the case in some regions), LCB will for sure become very cost attractive.

4 DEFINING A BASELINE

Accounting for GHG emissions reduction requires the definition of a "baseline": a building whose emissions are compared to the ones of the project building.

In this book, the baseline building, or baseline scenario is defined as follow:

The buildings which would most likely have been constructed if no particular GHG emissions reduction strategies had been considered.

5 Assumptions: wind power system cost=$1.9/W, electricity cost=$0.06/kWh, electricity sold to the grid=$0.02/kWh.

The LCB Method gives guidelines to determine a baseline scenario for:

- Building construction, renovation and demolition.
- Building operation.

☙ BASELINE AND "PERMANENCE" ❧

The built environment is changing very quickly. Regulations are updated on a regular basis requiring buildings to be each time more energy-efficient.

In this context, a baseline scenario is only valid for a limited period of time, usually not more than four years. It is therefore recommended when defining a baseline scenario to refer to the most recent standards and work practices (this includes the LCB Method).

5 ESTIMATING BUILDINGS LIFETIME EMISSIONS

The lifetime emission of a building E_{Lt} is the sum of its emissions from construction, operation, and deconstruction:

$$\mathbf{E_{Lt} = E_C + E_O + E_D} \quad \textbf{(eq. 1)}$$

E_C = construction emissions (incl. renovation)
E_O = operation emissions
E_D = deconstruction emissions

Guidelines to estimate E_C, E_O and E_D are given further in this book.

☙ EXCLUSIONS ❧

The LCB Method does not consider:

- Indirect emissions such as for example: employees commuting, wastes treatment during buildings operation, etc. Although they are often influenced by the building design, these emissions are ignored for simplification.

- Emissions from buildings maintenance (cleaning, repairs, etc.). These emissions are considered negligible, and only emissions related to buildings renovation are considered.

- Construction/deconstruction emissions offsetting. For simplification, the LCB method does not address the carbon offsetting of these activities. Carbon offsetting is only considered for building operation emissions.

CALCULATING GHG EMISSIONS

GHG emissions are usually calculated as follow:

GHG Emissions = Emission Factor x Activity Data

An emission factor (EF) is an average emission rate of CO2-e relative to the intensity of an activity (for example 0.240 kgCO2-e/km for a vehicle).

An "activity data" refers to an activity quantity such as a weight, volume, surface, distance, etc. (for example 2,000 km traveled for a vehicle).

Using the example above, the emissions associated with the travel made by the vehicle are: 0.240 x 2,000 = 480 kgCO2-e.

6 ESTIMATING EMISSIONS REDUCTION PERFORMANCE

The emissions reduction and emissions reduction performance of a building are calculated as follow:

$$\Delta E = E_p - E_b \quad \text{(eq. 2)}$$
$$\Delta E_{perf} = (E_p - E_b) \times 100 / E_b \quad \text{(eq. 3)}$$

E_p = project building emissions

E_b = baseline building emissions

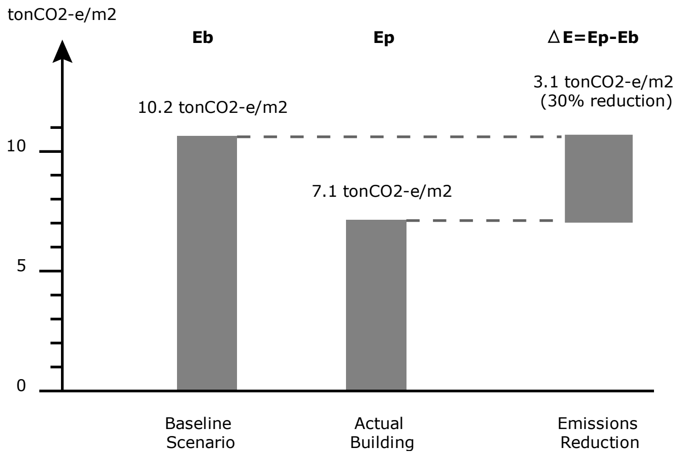


Fig. Estimation of Emissions Reduction (Example)

For buildings projects, emissions reductions are expressed in kgCO2e/m2 or tonCO2-e/m2 (building gross floor area). Emissions reduction performance is expressed in % emissions reduction compared to the baseline.

7 LOW-CARBON BUILDINGS CLASSIFICATION

Although a growing number of green buildings integrate fancy wind turbines, the concept of low-carbon buildings is still relatively new.

In fact, there is at the moment no internationally accepted emissions threshold under which a building would qualify as a LCB.

The LCB Method is referring to the latest scientific data on Climate Change[6]:

Change In Global GHG Emissions Compared to Current Levels	CO2-e Concentrations At Stabilization (At Or Below)	Peaking Year For CO2 Emissions
-30% to -60%	535 ppm	2009-2020
-50% to -85%	490 ppm	2009-2015
>-80%	~430 ppm	2009-2015

The 2006 Stern Review Report gives the additional precision: global GHG emissions would have to be reduced by 80% compared to current levels in order to balance the Earth's natural capacity to remove GHG from the atmosphere.

[6] Data in the table is derived from information in the 2006 Stern Review Report, and the IPCC Climate Change 2007 Synthesis Report.

Based on the figures on the previous page, the LCB Method 2009 proposes the following LCB classification:

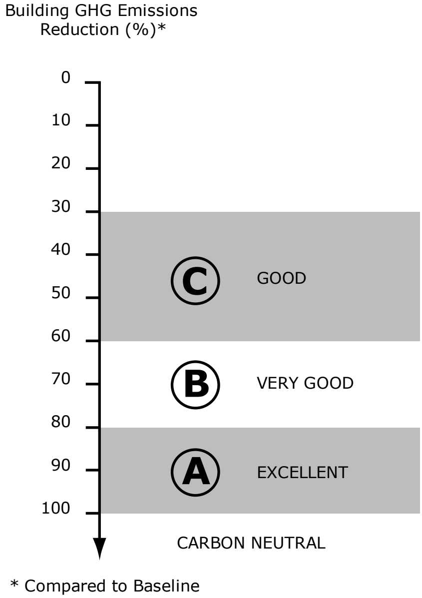


Fig. Low-Carbon Buildings-Proposed Classification

For example, if the lifetime emissions of the baseline building are 8 tonCO2-e/m2, the project has to achieve the following emissions performance in order to be recognized as a “low-carbon building”:

LCB Category	**Emissions Performance** tonCO2e/m2
Class C (Good)	3.2-5.6
Class B (Very Good)	1.6-3.2
Class A (Excellent)	0-1.6
Carbon-Neutral	0

Note that, in reference to the conclusions of the reports cited earlier, only carbon-neutral buildings and buildings in the "Excellent" category represent a "satisfactory" mitigation answer to Climate Change.

8 LOW-CARBON BUILDINGS: A STEP BY STEP APPROACH

Engineering a low-carbon building is a process that concerns all stages of the building life: construction, operation and deconstruction.

The LCB Method recommends the following approach for achieving the desired emissions reduction performance:

1

PHASE 1
Reduce Emissions during Construction, Renovation and Deconstruction

2

PHASE 2
Reduce Energy Consumption

3

PHASE 3
Produce Clean Electricity On-Site

4

PHASE 4
Buy Green Power

5

PHASE 5
Offset Remaining Emissions

The project team should focus in priority on PHASES 1 to 3 of the process for the reasons below:

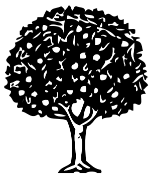
- As explained earlier ("The Cost of LCB"), PHASES 2 and 3 may ultimately generate long term money savings for building owners. PHASES 4 and 5 on contrary are pure spendings/expenses.

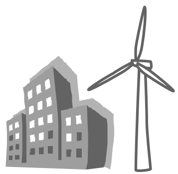
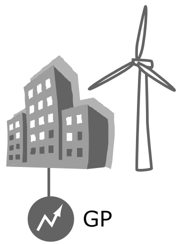
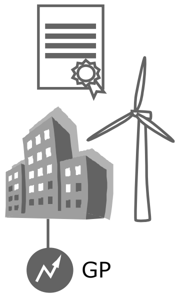
- In most GHG accounting standard (the GHG Protocol for example), RECs (see Chapter 4) and carbon offsets can not directly be deducted from the reporting Organization emissions.

- The quantity of green power and carbon offsets on the market might not be enough in the future to cover the needs of all LCB projects.

PHASES 4 and 5 should be considered only if PHASES 1 to 3 can not achieve the desired level of GHG emissions reduction.

More details and guidelines about each phases of the process are given in the following paragraphs. Notations used in these paragraphs are summarized on the illustration next page.



	PHASE 1	PHASE 2	PHASE 3	PHASE 4	PHASE 5
	Construction/ Renovation/ Deconstruction	Energy consumption	Clean electricity production on-site	Green power	Carbon offsets
Emissions Reductions	ΔE_C, ΔE_R, ΔE_D	ΔE_O	ΔE_{O3}	ΔE_{O4}	ΔE_{O5}
Building Emissions	E_C, E_R, E_D	E_O	E_{O3}	E_{O4}	E_{O5}
					

PHASE 1A-REDUCE CONSTRUCTION EMISSIONS

1 GENERAL

A building is made of an important quantity of materials and products: concrete, steel or wood for structure; carpet, ceramic tiles, plasterboard for building decoration, etc.

GHG are emitted during the following phases:

- Raw materials extraction
- Raw materials processing/transformation
- Construction products manufacturing
- Materials/products transport to site
- Site works
- Construction wastes treatment

EXAMPLE: CONCRETE

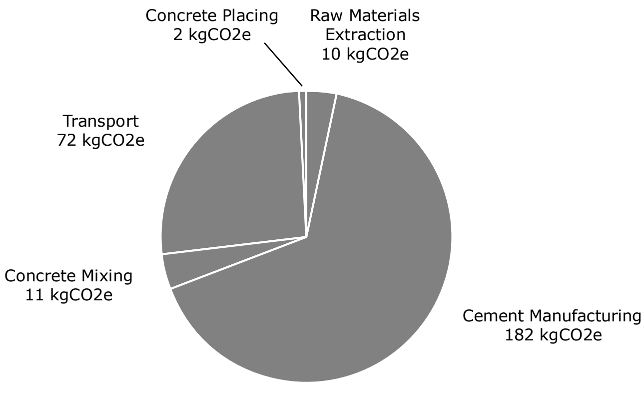
Concrete is a mix of sand, gravels, cement and water. GHG are emitted during:

- Raw materials extraction: extraction of sand, gravels and limestone in carries (limestone is the main constituent of cement).

- Raw materials processing: cement is made by heating limestone with small quantities of other materials (such as clay) to 1,450°C in a kiln.

- Concrete manufacturing: sand, gravels, cement and water are mixed together at the batching plant to make concrete.
- Raw materials and concrete transport to site: transport of limestone to the cement kiln. Transport of sand, gravels and cement to the batching plant. Transport of concrete from the batching plant to the site.
- Site works: placing of concrete in formworks.

Ultimately, the production of one cubic meter of concrete releases in the atmosphere around 277 kgCO2-e. Emissions for each phase are indicated below:



TOTAL = 277 kgCO2e/m3

2 ESTIMATING CONSTRUCTION EMISSIONS

The total emissions associated with the building construction are calculated as follow:

$$E_{c} = \sum E_{mat} + \sum E_{trans} + E_{site} + \sum E_{waste} \quad \text{(eq. 1)}$$

E_{mat} = emissions from material/product manufacturing

E_{trans} = emissions from material/product transport
E_{site} = emissions from site works
E_{waste} = emissions from construction wastes treatment

With, for each material/product:

$$E_{mat} = Q_{mat} \times EF_{mat} \quad \text{(eq. 2)}$$

Q_{mat} = material/product quantity (e.g. tons, m3, etc.)
EF_{mat} = emission factor associated with product manufacturing

$$E_{trans} = Q_{mat} \times (D_{e-m} \times EF_{veh} + D_{m-s} \times EF_{veh}) \quad \text{(eq. 3)}$$

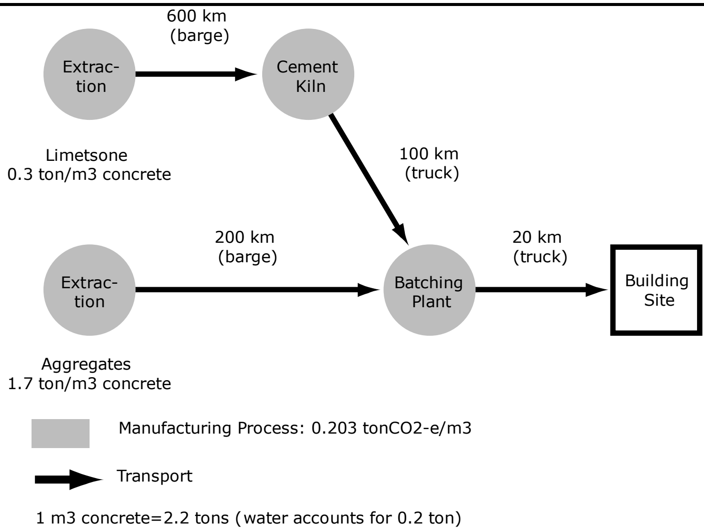
D_{e-m} = distance extraction-manufacturing
D_{m-s} = distance manufacturing-site
EF_{veh} = vehicle emission factor

EF_{veh} varies depending on the vehicle used (see paragraph 3.4).

For emissions related to construction wastes treatment, refer to Chapter 1C. For emissions related to site works (E_{site}), use the default values in paragraph 3.4.

EXAMPLE

A building is made of 2,000 m3 of concrete. The project team has collected the following information:



Using eq. 2, the project team starts to calculate manufacturing emissions:

E_{mat} = 2,000 x 0.203 = 406 tonCO2-e

Then the project team calculates emissions related to transport using eq. 3:

	EFveh	Weight ton	Dist. km	Emissions kgCO2e
Barge	0.03	0.3	600	5
Truck	0.186	0.3	100	6
Barge	0.03	1.7	200	10
Truck	0.186	2.2	20	8
			TOTAL	29

E_{trans} = 2,000 x 0.029 = 58 tonCO2e

The emissions associated with concrete manufacturing and transport for this project are calculated as follow: 406 + 58 = 464 tonCO2-e

The total building emissions can be estimated by summing the emissions associated with concrete (464 $tonCO_2$-e) with the emissions for all other materials using eq. 1.

Note: emissions from wastes treatment and site works have been ignored in this example.

3 ESTIMATING CONSTRUCTION EMISSIONS REDUCTION-PROPOSED METHOD

The proposed method for estimating construction emissions reduction is summarized below:

STEP 1: List assumptions for materials use reduction/substitution.
STEP 2: Collect actual EF from products manufacturing.
STEP 3: Collect km traveled for materials/products transport.
STEP 4: Estimate project emissions.
STEP 5: Estimate baseline emissions.
STEP 6: Estimate project emissions reduction.

3.1 STEP 1-LIST ASSUMPTIONS FOR MATERIALS USE REDUCTION/SUBSTITUTION

Reducing materials quantity and choosing more "climate-friendly" products are two effective ways of reducing the project emissions.

- ☑ List all materials whose quantities have been voluntary reduced.
- ☑ List all low-emitting materials which have been substituted for other materials.

All changes should be justified (see example below). The baseline scenario will consider materials type and quantity which are the usual practice in the region where the project is located.

EXAMPLE

On a new office building project, the design team decides to choose a wood structure. A study of the office buildings of identical size and function in the region shows that concrete is used in almost all the cases. The design team therefore decides to consider this change when defining the baseline scenario. The change is documented in a table as follow:

Item	Project	Baseline	Justification
Structure	Wood	Concrete	Based on a study of local construction practices

On the same project, in an effort to reduce materials use, the design team decides to use exposed concrete instead of carpet in all the open office spaces. The design team decides to consider exposed concrete for the building and carpet for the baseline.

Item	Project	Baseline	Justification
Floor Covering	Exposed concrete	Carpet	Based on a study of local construction practices

3.2 STEP 2-COLLECT ACTUAL EF FROM PRODUCTS MANUFACTURING

EF for a given product varies depending on the product specification and the manufacturer efficiency. For example, tufted carpet can be produced at 7 kgCO2e/m2 by supplier A, and 4 kgCO2-e/m2 by supplier B.

☑ Collect the actual EF related to manufacturing (EF_{mat}) for all materials/products used on the project.

EF_{mat} can be obtained by contacting directly the suppliers or by referring to the few existing products LCA programs such as:

- Environmental Profiles (BREEAM)
- INIES database, etc.

3.3 STEP 3-COLLECT KM TRAVELLED FOR MATERIALS/PRODUCTS TRANSPORT

Transport of materials from the extraction (carries, etc.) to the site contributes to a significant part of the project emissions.

☑ Collect the actual distance material extraction-manufacturing plant: D_{e-m}.

☑ Collect the actual distance manufacturing plant-project site: D_{m-s}.

These distances can be obtained by contacting the suppliers and contractors.

3.4 STEP 4-ESTIMATE PROJECT EMISSIONS

PRODUCTS MANUFACTURING

☑ Estimate the products manufacturing emissions using equation 2.

Use the project actual quantities and the EF collected in STEP 2. When EF are unknown, use the default values in Appendix A (emissions factors in Appendix A do not include transport).

TRANSPORT

☑ Estimate the project transport emissions using equation 3.

Consider the vehicles types which have actually been used on the project (truck, train, etc.). Use the actual distances collected in STEP 3. For EF_{veh}, and unless justified otherwise, use the default values in the table below:

Vehicles	Unit	EF_{veh}
		gCO_2-e
Medium And Heavy Trucks	Ton.km	186
Train	Ton.km	16
Barge And Boat	Ton.km	30
Plane	Ton.km	1,543

SITE WORKS

Unless justified otherwise, use the default value in the table below:

	E_{Site}
	$kgCO_2$-e/m2 developed
Site Works	4.5

CONSTRUCTION WASTES

Refer to Chapter 1D.

The project team should collect the project actual construction wastes quantities and identify the wastes actual diversion flows (landfill, incineration, recycling).

3.5 STEP 5-ESTIMATE BASELINE EMISSIONS

PRODUCTS MANUFACTURING

☑ Estimate the products manufacturing emissions using equation 2.

Use the project actual quantities and make the necessary adjustments to reflect the changes listed in STEP 1. If for example, the project has voluntary reduced the quantity of gypsum board from 1,000 m2 to 500 m2, the baseline case will consider 1,000 m2.

For EF_{mat}, refer to the default values in Appendix A. If the project team as voluntary decided to replace product A ($EF_{mat, A}$) by product B ($EF_{mat, B}$), and $EF_{mat, A} > EF_{mat, B}$, the baseline case will consider $EF_{mat, A}$. If for example, linoleum (2 kgCO2-e/m2) is used on the project instead of carpet (7 kgCO2-e/m2), the baseline calculations will be done with 7 kgCO2-e/m2.

TRANSPORT

☑ Estimate the project transport emissions using equation 3.

Consider the following default distances:

Product	D_{e-m} km	D_{m-s} km
Backfill Materials	100	NA
Concrete	300	30
Other Materials	600	400

For determining the vehicles types to consider in the baseline, refer to the practices of the region where the project is located. In a region with a dense railway system for example, assume that a significant proportion of materials are delivered by train.

Unless justified otherwise, use the EF_{veh} in the table in paragraph 3.4.

SITE WORKS

Use the default value in the table in the previous paragraph.

CONSTRUCTION WASTES

Refer to Chapter 1C.

The project team should use the following default wastes generation quantities:

Wastes	Qty
	% Construction Qty
Wood (formworks)	100%
Wood (structure)	7%
Concrete	3%
Steel	5%
Other Materials	5%

3.6 STEP 6-ESTIMATE EMISSIONS REDUCTION

☑ Estimate the construction emissions reduction as follow:

$$\Delta E_C = E_{C,p} - E_{C,b}$$

$E_{C,p}$ = project construction emissions
$E_{C,b}$ = baseline construction emissions

4 EMISSIONS REDUCTION OPPORTUNITIES

The most important GHG emissions during construction come from the materials used in the building structure (concrete and steel), and materials transport. The project team should therefore reduce in priority these emissions.

4.1 CHOOSE RECYCLED MATERIALS FOR THE STRUCTURE

FLY ASH CONCRETE

Fly ash is a fine, glass-like powder recovered from gases created by coal-fired electric power generation. Power plants produce huge quantity of fly ash, which is usually dumped in landfills. Fly ash can replace Portland cement used in concrete to an amount of 20-35%.

The GHG emissions of fly ash concrete are shown on the graph in Appendix B.

RECYCLED STEEL

Steel is one of the most widely recycled materials on Earth, in large part because it is economically advantageous to do so. Steel does not lose any of its inherent physical properties during the recycling process, and has drastically reduced energy requirements compared with refinement from iron ore. The proportion of used materials in steel construction elements can go from 0% to 100% if made with the electric arc furnace (EAF) process.

The GHG emissions of recycled steel are shown on the graphs in Appendix C.

WOOD FROM WELL-MANAGED FORESTS

Wood is a construction material widely used in countries like the U.S., Canada, etc. It is used in important quantities in residential buildings (structure, envelope, etc.). Wood has much lower lifecycle GHG emissions than concrete or steel when it comes from well-managed forests.

	GHG Emissions kgCO2-e/m3
Wood from non well-managed forests	~3,500[7]
Wood from well-managed forests	0[8]

FSC WOOD

The Forest Stewardship Council (FSC) is an international non-profit organization established in 1993 to promote responsible management of the world's forests. The FSC realize independent certification and labeling of forest products. FSC certified wood products are identified with the following logo:

[7] Estimated land "carbon removal ability" loss over a period of 50 years (default building lifetime) due to land use change (deforestation).
[8] Manufacturing emissions are ignored for simplification.

4.2 REDUCE QUANTITIES

A very effective way of reducing the project emissions is to optimize or reduce materials/products quantities during the design phase.

For example, a 5,000 m2 office that has an exposed concrete floor instead of carpet reduces its lifetime emissions by approximately 420 tonCO2-e.

4.3 SUBSTITUTE MATERIALS

Depending on the supplier, products can have very different emissions factors. A gypsum board supplier using 100% recaptured gypsum for example will have much lower EF than its competitors using 100% new gypsum.

To reduce the project emissions, the project team should therefore select products with the lowest emissions intensity for the specified quality and cost.

4.4 SOURCE LOCAL MATERIALS

The transport of construction materials from cradle to site represents approximately 30% of the total construction emissions.

Selecting materials extracted and manufactured regionally (within 800 km) helps reduce these emissions. For example, purchasing 10 ton of dimension stones 200 km closer from the site saves the equivalent of 400 kgCO2-e.

4.5 RECYCLE CONSTRUCTION WASTES

5 to 10% of the materials purchased on a project end up as wastes (wood from formwork, pieces of rebar, packaging, etc.).

As explained in the following paragraphs, construction wastes sent to landfills or incinerated release important quantities of GHG. Wastes sent to recycling are reused and therefore participate in emissions reduction.

4.6 REDUCE DEVELOPMENT AREA

Trees act as carbon sinks. Using photosynthesis, they transform the atmospheric carbon dioxide into biomass carbon. A forest for example has an average above-ground biomass of 150 tons dry matter per hectare, which is equivalent to a “stock” of 275 tons of CO_2.

Depending where the project is located, deforestation can be responsible for up to 10% of the construction emissions. The project team should therefore keep the site disturbances and the project development footprint to a minimum.

PHASE 1B-REDUCE RENOVATION EMISSIONS

1 GENERAL

Nearly all types of buildings require a major renovation every 25-30 years. It usually includes façade refurbishment, M&E system upgrade, new fit-out, etc.

Emissions associated with building renovation are not negligible. Cumulated over 50 years, they can represent up to 75% of construction emissions.

2 ESTIMATING RENOVATION EMISSIONS

The emissions associated with the replacement of each material/product are calculated as follow:

$$\mathbf{E_R = \sum(E_{mat} + E_{trans}) \times (L_t / R_t) \quad (eq.\ 1)}$$

E_{mat} = emissions from material/product manufacturing (calculated in PHASE 1)
E_{trans} = emissions from material/product transport (calculated in PHASE 1)
L_t = building lifetime
R_t = material/product lifetime (or replacement time)

The total renovation emissions are estimated by summing the emissions for each material/product.

The emissions from site works and construction wastes treatment are ignored for simplification.

3 ESTIMATING RENOVATION EMISSIONS REDUCTION-PROPOSED METHOD

STEP 1: Estimate materials/products lifetimes.
STEP 2: Estimate project emissions.
STEP 3: Estimate baseline emissions.
STEP 4: Estimate project emissions reduction.

3.1 STEP 1-ESTIMATE MATERIALS/PRODUCTS LIFETIME

☑ Estimate the lifetime of all materials and products used on the project building.

Materials and products lifetime can be obtained by contacting suppliers.

3.2 STEP 2-ESTIMATE PROJECT EMISSIONS

☑ Estimate the project renovation emissions using equation 1.

Use the products lifetime estimated in STEP 1. When products lifetime is unknown, use the default values in Appendix D.

Assume that the products are replaced by identical products (emissions from manufacturing and transport are similar to the ones in PHASE 1).

The building lifetime L_t is equal to the building structure design lifetime. If no design lifetime has been specified, use the default values below:

Building Type	L_t Years
Residential	50
Commercial	50
Industrial	40
Other	50

3.3 STEP 3-ESTIMATE BASELINE EMISSIONS

☑ Estimate the baseline renovation emissions using equation 1.

Proceed as for the project building but use the default products lifetime in Appendix D.

3.4 STEP 4-ESTIMATE PROJECT EMISSIONS REDUCTION

☑ Estimate the renovation emissions reduction as follow:

$$\Delta E_R = E_{R,p} - E_{R,b}$$

$E_{R,p}$ = project renovation emissions
$E_{R,b}$ = baseline renovation emissions

PHASE 1C-REDUCE DECONSTRUCTION EMISSIONS

1 GENERAL

There are three main wastes treatment methods:

- Disposal in landfills
- Incineration
- Recycling

Basic information regarding emissions associated with these different treatment methods is given below:

LANDFILLS

Organic wastes (mainly paper/cardboard and wood products) disposed in landfills decompose by biological process and release methane (CH_4). CH_4 is a gas with a global warming potential 21 times that of CO_2.

INCINERATION

When burned, the carbon content of solid wastes is transformed into carbon dioxide (CO_2):

$C+O_2->CO_2$.

The emissions factors given in paragraph 2 assume 100% oxidation and only consider the fossil carbon fraction of wastes (plastic is 100% fossil carbon, wood is 100% non-fossil carbon).

RECYCLING

Wastes sent to recycling are reused to manufacture new products. They account for 0 GHG emissions.

2 ESTIMATING DECONSTRUCTION EMISSIONS

The total emissions associated with the building deconstruction are calculated as follow:

$$E_D = \sum E_{waste} + \sum E_{trans} \quad \text{(eq. 1)}$$

E_{waste} = emissions from construction wastes treatment
E_{trans} = emissions from construction wastes transport

With, for each material:

$$E_{waste} = Q_{land} \times EF_{land} + Q_{inc} \times EF_{inc} \quad \text{(eq. 2)}$$

Q_{land} = qty diverted to landfill
Q_{inc} = qty incinerated
EF_{land} = emissions from landfill disposal
EF_{inc} = emissions from incineration

$$E_{trans} = Q_{land} \times D_{s-l} \times EF_{veh} + Q_{inc} \times D_{s-i} \times EF_{veh} + Q_{rec} \times D_{s-r} \times EF_{veh} \quad \text{(eq. 3)}$$

Q_{rec} = qty recycled
D_{s-l} = distance site-landfill
D_{s-i} = distance site-incineration
D_{s-r} = distance site-recycling

EF_{veh} varies depending on the vehicle used (see Chapter 1A).

Default EF_{land} and EF_{inc} are given below:

Wastes	**Unit**	**EF_{land}** kgCO2-e	**EF_{inc}** kgCO2-e
Non-FSC Wood/Paper/Cardb.	Ton	7,207	1,833
FSC Wood	Ton	7,207	0[9]
Plastics	Ton	0	2,750
Inert Wastes	Ton	0	0

Inert wastes include: concrete, metals, glass, etc.

3 ESTIMATING DECONSTRUCTION EMISSIONS REDUCTION-PROPOSED METHOD

STEP 1: Collect wastes quantities and diversion flows.
STEP 2: Estimate project emissions.
STEP 3: Estimate baseline emissions.
STEP 4: Estimate project emissions reduction.

3.1 STEP 1-COLLECT WASTES QUANTITIES AND DIVERSION FLOWS

☑ Collect the total quantity of wastes generated by the project. Identify the wastes diversion flows as in the example below:

[9] When incinerated, the carbon captured by the wood is released in the atmosphere. By convention, for FSC wood, the LC GHG emissions are considered = 0 (note: this is not true anymore when FSC wood is diverted to landfill).

Wastes	**Total Qty**	**Q_{land}**	**Q_{inc}**	**Q_{rec}**
	Tons	Tons	Tons	Tons
Paper/Cardboard	10	0	0	10
Wood	20	10	10	0
Plastics	15	5	10	0
Concrete	200	150	0	50
Metals	50	0	0	50
Glass	10	0	0	10
Other	20	20	0	0

☑ Collect the actual distances between the project site and landfill, incineration plant and recycling site.

3.2 STEP 2-ESTIMATE PROJECT EMISSIONS

☑ Estimate the project deconstruction emissions using equation 1.

Use the data collected in STEP 1. Unless justified otherwise, use the default emissions factors in the table in paragraph 2.

3.3 STEP 3-ESTIMATE BASELINE EMISSIONS

☑ Estimate the baseline deconstruction emissions using equation 1.

Assume that wastes are treated as follow:

Wastes Disposal	**Rate** (Weight)
Landfill	50%
Incinerated	15%
Recycled	35%

The corresponding EF are:

Wastes	Unit	EF kgCO2-e
Non-FSC Wood/Paper/Cardboard	Ton	3,879
FSC Wood	Ton	3,604
Plastics	Ton	413
Inert Wastes	Ton	0

For calculating transport emissions, assume that all construction wastes are transported by trucks to treatment facilities situated at the following distances from the project site:

	Distance km
Landfill	100
Incineration Plant	100
Recycling Plant	100

3.4 STEP 4-ESTIMATE PROJECT EMISSIONS REDUCTION

☑ Estimate the deconstruction emissions reduction as follow:

$$\Delta E_{D} = E_{D,p} - E_{D,b}$$

$E_{D,p}$ = project deconstruction emissions
$E_{D,b}$ = baseline deconstruction emissions

PHASE 2-REDUCE ENERGY CONSUMPTION

1 GENERAL

After construction, a building has an "operational life" of approximately 50 years. This is when it will release the largest amount of GHG.

A typical concrete office building emits more than 7 $tonCO_2$-e/m^2 during this period.

GHG are emitted as a consequence of the energy used by the building for lighting, artificial heating and cooling, etc.

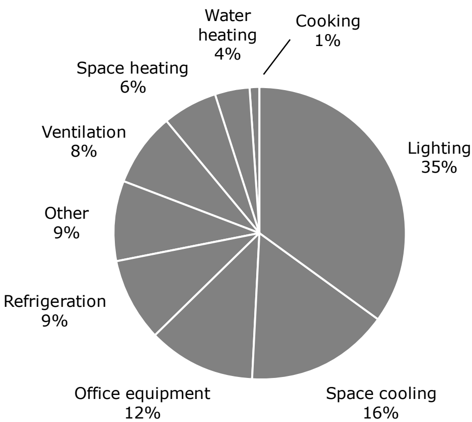


Fig. Energy Use in a Typical Building

Most of the time, this energy is generated by the burning of fossil fuels such as coal, oil, gas, etc. The combustion of these fuels releases in the atmosphere huge quantities of GHG.

In the U.S. the production and distribution of 1 kWh of electricity release approximately 0.7 kgCO2-e. It means for example that using a small residential heating unit for just one night is responsible for the emission in the atmosphere of more than 10 kgCO2-e.

2 ESTIMATING OPERATION EMISSIONS

The total annual emissions $E_{O,a}$ associated with the building operation are calculated as follow:

$$E_{O,a} = E_{elec,a} + E_{gas,a} + E_{steam,a} + \sum E_{fuel,a} \quad \text{(eq. 1)}$$

$E_{elec,a}$ = emissions related to annual electricity consumption
$E_{gas,a}$ = emissions related to annual gas consumption
$E_{steam,a}$ = emissions related to annual steam consumption
$E_{fuel,a}$ = emissions related to annual other fossil fuels consumption

With for electricity:

$$E_{elec,a} = C_{elec,a} \times EF_{grid} \quad \text{(eq. 2)}$$

$C_{elec,a}$ = annual electricity consumption
EF_{grid} = emission factor associated with electricity production and distribution

Emissions for gas, steam and other fossil fuels are calculated in the same manner.

The total lifecycle emissions E_O associated with the building operation can be quickly estimated as follow:

$$E_O = E_{O,a} \times L_t \quad \text{(eq. 3)}$$

L_t = building lifetime

Note that this equation does not take into account the evolution of utility emissions factors in time, in particular the one corresponding to electricity production and distribution (see below).

Equation 2 shows that emissions related to buildings energy use depend on:

- The actual energy consumed by the building
- The emissions factors of the energy purchased

There are consequently two ways to reduce the emissions of a building during operation:

1- To install energy-efficient systems (for example energy-efficient lighting, energy-efficient chillers, etc.).

2- To produce on-site or purchase renewable energy, in particular clean electricity (for example wind, small-hydro power, etc.).

This chapter only concerns buildings energy use reduction (1-). The production on-site or purchase of renewable energy (2-) is addressed in the following paragraphs.

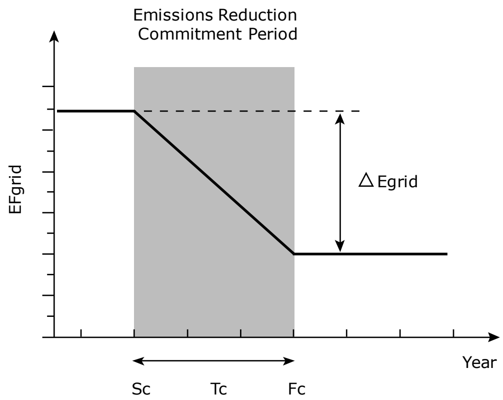
ACCOUNTING FOR CHANGE IN EF_{grid}

Predicting the evolution of EF_{grid} is a difficult task. Recently, many regions have adopted policies aiming at increasing the proportion of renewable energy in their energy portfolio. EF_{grid} in these regions should consequently decrease significantly in the years to come.

To anticipate the evolution of EF_{grid} for their project, the project team should define:

- If clean energy policies have been or will be adopted in the region where the project is located.
- The policy emissions reduction target (ΔE_{grid}) and commitment period (T_c).

The project team will assume that EF_{grid} varies as indicated below:

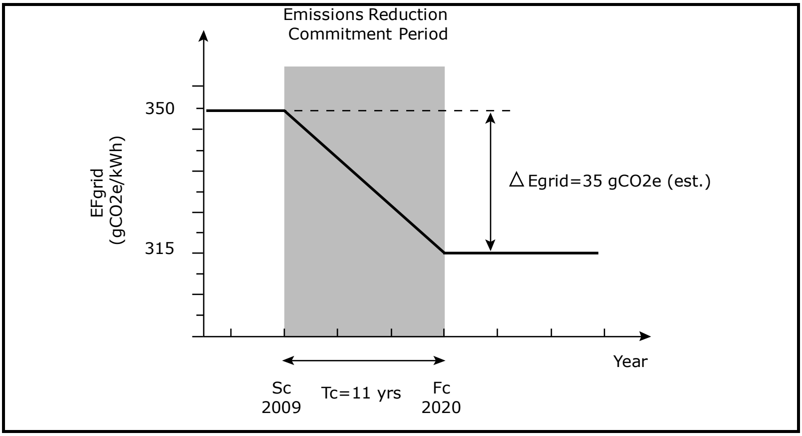


- Stable before S_c
- Linear evolution during T_c with an annual reduction=ΔE_{grid} /T_c
- Stable after F_c

In regions which have not adopted clean energy policies, the project team will assume that EF_{grid} remains stable.

Example: California has set a target of 33% renewable energy by 2020, 10% above current level. The current EF_{grid} in this region is 350 gCO2-e/kWh.

Based on these information, the project team estimates that EF_{grid} will vary as shown below:



3 ESTIMATING OPERATION EMISSIONS REDUCTION-PROPOSED METHOD

STEP 1: Collect building energy systems parameters.

STEP 2: Gather local utilities EF.

STEP 3: Estimate project emissions.

STEP 4: Estimate baseline emissions.

STEP 5: Estimate project operation emissions reduction.

3.1 STEP 1-COLLECT ENERGY SYSTEMS PARAMETERS

☑ Collect the technical parameters of the project building energy systems. It includes all systems related to:

- Lighting
- Artificial cooling, heating and refrigeration (chillers, AHU, etc.)
- Domestic hot water
- Process equipments (elevators, plug loads, etc.), etc.

Collect also data about all other building features which influence its energy performance:

- Building dimensions
- Building orientation
- Opaque envelope performance (insulation, etc.)
- Fenestration performance, etc.

3.2 STEP 2-GATHER LOCAL UTILITIES EF

☑ Collect the emissions factors associated to all utilities used on the project (electricity, gas, etc.).

Data can be obtained by contacting the project utilities providers. Default EF_{grid} for most countries are given in Appendix E.

3.3 STEP 3-ESTIMATE PROJECT EMISSIONS

☑ Use an energy modeling software (see list below) to estimate the project building annual energy consumption.

Input the energy systems parameters collected in STEP 1. Run the software to determine the building annual consumption for each utility:

- Electricity: $C_{elec, a}$
- Gas: $C_{gas, a}$
- Steam: $C_{steam, a}$
- Other fossil fuels

The building emissions are calculated by multiplying the consumption of each utility by the corresponding emission factor as explained in paragraph 2.

When modeling the project building and calculating GHG emissions, assume that:

- The project building does not produce clean electricity on-site.
- The project is not purchasing electricity from renewable energy sources

(green power).

- 100% of the electricity is coming from the local grid.

The purpose of PHASE 2 is to estimate the GHG emissions reduction of the project building resulting from its improved energy efficiency. Emissions reductions coming from the purchase of green power and the production of clean electricity on-site are addressed in PHASES 3 and 4.

Note: projects pursuing a LEED NC certification can use the results of the energy modeling required under EA credit 1 (design case).

ENERGY MODELING SOFTWARES

Building simulation is a powerful tool that Architects and Engineers use to estimate the building energy consumption. The accuracy of the modeling results is usually ±10%.

Most widely used software include: eQUEST, Trace 700, HAP, DOE-2, EnergyPlus, EnergyPro, ENER-WIN, VisualDOE, ECOTEC, System Analyser, Energy 10, etc.

EXAMPLE

The project team estimates that the annual energy consumption of their new building will be:

- $C_{elec, a}$ = 130,000 kWh
- $C_{gas, a}$ = 6,500 therms

The region where is located the project has the following utility EF:

- EF_{elec}: 0.8 tonCO2-e/MWh
- EF_{gas}: 0.005 tonCO2-e/therm

The project team calculates that the annual operation emissions are equal to:

$E_{O,a}$ = 130 x 0.8 + 6,500 x 0.005 = 137 tonCO2-e.

3.4 STEP 3-ESTIMATE BASELINE EMISSIONS

To determine the baseline energy use, the project team has the choice of using one of the two methods below:

METHOD 1: when no local standards/guidelines exist for defining parameters for the baseline building energy systems:

☑ Use the default energy intensity values in Appendix F.

OR

☑ Use an energy modeling software to estimate the annual energy use of the baseline building. The performances of the baseline building energy systems should be based on local construction standards prescriptive requirements and local engineering practices at the time of the project. All assumptions made by the project team should be justified.

METHOD 2: when local standards/guidelines exist for defining the parameters of the baseline building energy systems:

☑ Use an energy modeling software to estimate the annual energy use of the baseline building. The performance of the baseline building energy systems should be defined as explained in the standards/guidelines.

In the U.S., the project team should refer to the ASHRAE 90.1 2007, Appendix G-Performance Method for defining the parameters of the baseline building energy systems.

Note 1: the ASHRAE 90.1-2007 standard can also be used outside of the U.S. once the climate zone of the region has been identified.

Note 2: projects pursuing a LEED NC certification can use the results of the energy modeling required under EA credit 1 (baseline case).

The utility EF to consider when calculating the baseline building emission should be the same as for the project building.

3.5 STEP 4-ESTIMATE PROJECT OPERATION EMISSIONS REDUCTION

Estimate the project operation emissions reduction as follow:

$$\mathbf{\Delta E_O = E_{O,\,p} - E_{O,\,p}}$$

$E_{O,\,p}$ = project operation emissions
$E_{O,\,b}$ = baseline operation emissions

4 EMISSIONS REDUCTION OPPORTUNITIES

A lot of design strategies exist for reducing the energy consumption of buildings (efficient lighting controls, natural ventilation, demand-controlled ventilation, etc.).

A detailed description of all these strategies would be beyond the scope of this book.

Readers are kindly advised to refer to existing design guides such as:

- ASHRAE 90.1-2007-Energy Standard for Buildings
- ASHRAE Advanced Design Guide for Small Office Buildings
- ASHRAE Advanced Design Guide for K-12 School Buildings
- ASHRAE Advanced Design Guide for Small Retail Buildings

- ASHRAE Advanced Design Guide for Small Warehouses and Self-Storage Buildings
- California 2005 Building Energy Standard

PHASE 3: PRODUCE CLEAN ELECTRICITY ON-SITE

1 GENERAL

Renewable energy is energy generated from natural resources such as wind, sunlight, rain, biomass, tides and geothermal heat, which are renewable (naturally replenished).

As shown below, renewable energy resources (especially solar) far exceed the energy we use:

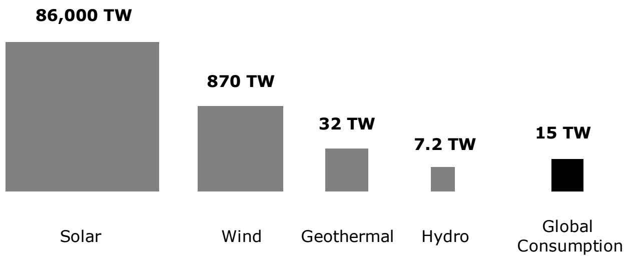


Fig. Primary Renewable Energy Resources (2004)

Renewable energy sources can provide part to in theory all the energy of a building. "Zero-energy" buildings (ZEB) are buildings which produce 100% of the energy they consume on-site. "Energy-plus" buildings produce more energy than they consume. Usually, the electricity surplus is sold to the grid.

2 GHG EMISSIONS FROM RENEWABLE ENERGY

If embodied emissions are excluded, the electricity produced from renewable energy is considered to be emissions free, and the associated emission factor is:

$EF_{renewable}$ = 0 gCO2-e/kWh

Embodied emissions are emissions related to the systems fabrication, installation, maintenance, deconstruction (e.g. wind turbines fabrication, dam construction, etc.).

The figure below shows the actual electricity EF from different sources of energy when embodied emissions are included:

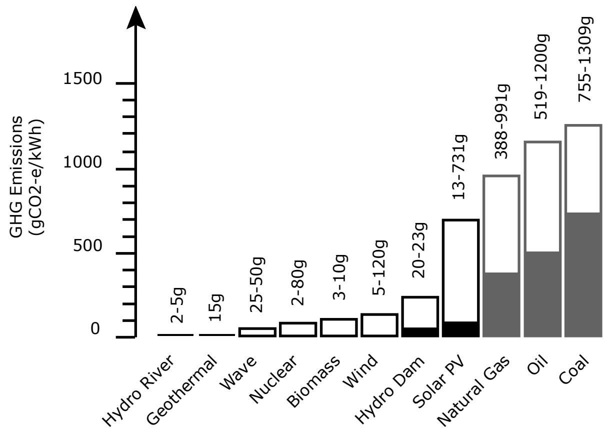


Fig. Electricity Emissions Factors (gCO2-e/kWh)

❧ EXCLUSIONS ☙

- In the LCB method, the systems embodied emissions are excluded from PHASE 2 calculations and are reported with PHASE 1 emissions. It means for example that if small-hydro is used on the project, the emission associated with the construction of the dam, the fabrication of the mechanical systems, cabling, etc. are part of PHASE 1 emissions.

- This section only concerns on-site electricity generation from renewable energy sources. If renewable energy is used to produce heat or hot water thus reducing the building overall energy consumption (e.g. solar HW), it should be reflected into PHASE 2 calculations.

  If for example the project team decides to use a wood boiler which produces combined heat and power (CHP). The emissions and emissions reductions should be reported as follow:

Emission Source	PHASE
Boiler Fabrication	1
Emissions Reduction from Heat Produced On-Site	2
Emissions Reduction from Clean Electricity Produced On-Site	3

3 ESTIMATING EMISSIONS REDUCTION-PROPOSED METHOD

STEP 1: Calculate electricity generated on-site from renewable energy.
STEP 2: Estimate corresponding project emissions reduction.

3.1 STEP 1-CALCULATE ELECTRICITY GENERATED ON-SITE FROM RENEWABLE ENERGY

☑ Use hand calculation or an energy modeling software to estimate:

- The annual amount of clean electricity produced on-site and actually consumed by the project building: $C_{renew.\ cons.,\ a}$.

- The annual amount of clean electricity produced on-site and sold to the grid: $C_{renew.\ sold,\ a}$.

"Clean electricity" refers to the electricity produced on-site from eligible renewable energy sources (see list in paragraph 4).

ACCOUNTING FOR ELECTRICITY SOLD TO THE GRID

Projects under a net-metering contract with the local electricity provider can sell the extra electricity produced on-site to the grid (often at a very attractive price).

The indirect emissions reduction resulting from this operation can not be deducted from the building operation emissions as it is used outside of the site. However, the emissions reduction can be calculated and reported under a separate section called "additional information" in the building final assessment report (see example below).

3.2 STEP 2-ESTIMATE CORRESPONDING PROJECT EMISSIONS REDUCTION

☑ Calculate the corresponding project emissions reduction as follow:

$\Delta E_{O3} = C_{renew.\ cons.,\ a} \times EF_{grid} \times L_t$ (eq. 1)

EF_{grid}: electricity emission factor from the local grid (same as the one used in PHASE 2 calculations)
L_t: building lifetime

☑ Adjust the lifetime operation emissions of the project building:

$E_{O3,\ p} = E_{O,\ p} - \Delta E_{O3}$ (eq. 2)

The operation emissions of the baseline remain unchanged: $E_{O,\ b}$. The baseline scenario assumes that the entire electricity consumed by the baseline building is provided by the local grid.

EXAMPLE

The project team decides to install on the project site a 500 kW wind turbine and estimates that this turbine will supply to the building approximately 500 MWh per year (another 1,000 MWh will be sold to the grid). The project operation emissions calculated in PHASE 2 are 16,000 tonCO2-e. The local EF_{grid} is 0.4 tonCO2-e/MW.

The GHG emissions that can be deducted from the project building operation emissions calculated in PHASE 2 are (assuming L_t=50 years):

ΔE_{O3} = 500 x 0.4 x 50 = 10,000 tonCO2-e.

The project building operation emissions become:

$E_{O3,\ p}$ = 16,000 – 10,000 = 6,000 tonCO2-e.

The indirect emissions reduction corresponding to the selling of the extra electricity to the grid is:

$\Delta E_{renew.\ sold.}$ = 1,000 x 0.4 x 50 = 20,000 tonCO2-e.

This amount should be indicated as "additional info" in the project assessment report:

Project Building Operation Emissions	EO, p	16,000 tonCO2-e
Emissions Reduction from Clean Electricity Produced On-Site	Δ EO3	– 10,000 tonCO2-e
Adjusted Project Building Operation Emissions	EO3, p	6,000 tonCO2-e
Additional Information:		
Indirect Emissions Reduction from Clean Electricity Sold to the Grid		20,000 tonCO2-e

4 SOURCES OF RENEWABLE ENERGY

Eligible on-site renewable energy systems include:

- Wind power systems
- Photovoltaic power systems
- Low-impact hydro electrical systems
- Biofuels based electrical systems (second generation biofuels not including food part of crops)
- Geothermal electrical systems
- Wave and tidal power systems

The following paragraphs give a short description and basic facts about each of the systems listed above (except tidal power systems which have little development potential for buildings on-site electricity production).

Note that payback periods indicated in the tables below may vary depending on the renewable energy incentives where the project is located. These periods are for grid-connected systems only. Most systems not connected to the grid will actually not pay back.

4.1 WIND POWER

Lifetime	20 years
Capacity Factor	20-40% of nameplate capacity installed
GHG Emissions	0 gCO2-e/kWh
GHG Emissions when considering embodied emissions	5-120 gCO2-e/kWh
Cost	Small-scale: around $60,000 for a 10 kW turbine Utility-scale: $1.2-2.6 million per

	MW nameplate capacity installed
Payback (grid-connected systems)	10 to 15 years

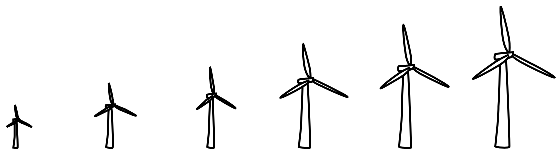
SYSTEM DESCRIPTION

Wind power is the conversion of wind energy into electricity using wind turbines. Today it represents 1% of worldwide electricity production (19% in Denmark, 9% in Spain).

Wind speed is a crucial element in projecting a turbine performance. Generally, an annual average wind speed of 4 m/s is required for small wind turbines and 6 m/s for utility scale wind turbines.

For buildings applications, the nominal capacity of wind turbines ranges from:

Building Type	Capacity Range
Residential	10-50 kW (small-scale turbine)
Commercial	50-700 kW
Industrial	700 kW-2.5 MW



Rotor (m)	10	17	27	40	50	71
Rating (kW)	25	100	225	550	750	1,650
Annual (MWh)	45	220	550	1,480	2,200	5,600

Fig. Wind Turbines Dimension and Annual Electricity Generation

Modern wind turbines have a capacity factors around 30%. It means that the turbine produces over its lifetime 30% of what it would have produced if it would have run at full capacity. However it does not mean that the turbine is running only one-third of the time. Usually a turbine is able to produce power 65-90% of the time.

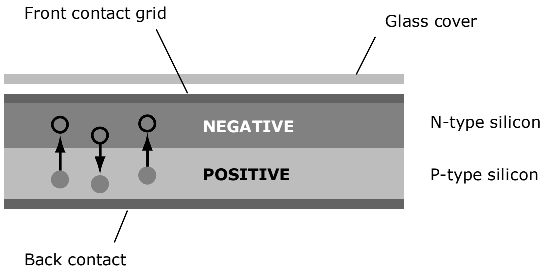
For example a turbine with a nameplate capacity of 1 MW will produce annually approximately: 1 x 365 x 24 x 30% = 2,628 MWh of electricity.

4.2 SOLAR POWER

Lifetime	20 to 30 years
Capacity Factor	12-18% (PV) [1]
GHG Emissions	0 gCO2-e/kWh
GHG Emissions when considering embodied emissions	20-45 gCO2-e/kWh
Cost	Around $5 per installed Watt (panels only). Around $7.50 to $9.50 per installed Watt (incl. panels, inverters, mounts, and electrical items).
Payback (grid-connected systems)	14-20 years

SYSTEM DESCRIPTION

Solar panels are made of solar cells which transform solar light into electricity. Most of solar cells on the market today are made of silicon.



N-type silicon has free electrons.
P-type silicon has free holes. When N-type and P-type come into contact, an electric field forms within the cell.

Fig. Solar Cell (Section)

Building-integrated photovoltaics (BIPV) are increasingly incorporated into new domestic and industrial buildings as a principal or ancillary source of electrical power.

Panels are able to produce around 100 W/m2. It means that a typical 8,000 m2 office building would have to install just above 4,000 m2 panels to completely cover its electricity consumption.

BATERIES

Lead-acid (Pb-acid) and nickel/cadmium (Ni/Cd) batteries are most often used in buildings applications. Pb-acid batteries are cheaper and best suited for small PV systems. Ni/Cd batteries are of a higher cost but have longer life and work at higher efficiencies if they are not fully charged.

The size of the battery bank depends on the storage capacity required. Ideally, the battery bank should be sized to be able to store power for 5 days of autonomy during cloudy weather. If the battery bank is smaller, it is going to cycle deeply on a regular basis and the battery will have a shorter life.

4.3 SMALL-HYDRO

Lifetime	50 years or more
Efficiency	About 75%
GHG Emissions	0 gCO2-e/kWh
GHG Emissions when considering embodied emissions (dam construction, etc.)	2-5 gCO2-e/kWh
Cost	Turbine-generator unit cost: around $3,000 per kW
Payback (grid-connected systems)	Around 10 years

SYSTEM DESCRIPTION

Small-hydro generally refers to hydroelectric power installations that produce less than 1,000 kW of power.

Small-hydro is frequently accomplished with:

- A Pelton wheel for high head, low flow water supply. The installation is often just a small dammed pool, at the top of a waterfall, with several hundred meters of pipes leading to a small generator housing.

- A Banki turbine, a pressurized self-cleaning crossflow waterwheel, is often preferred for low-head micro-hydro power systems.

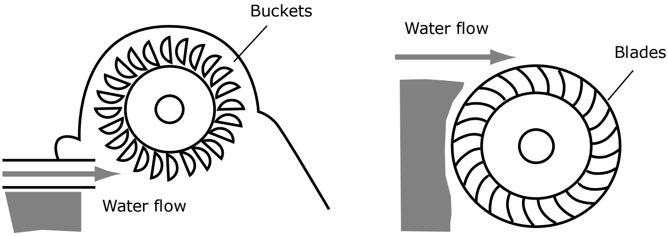


Fig. Pelton Wheel (Left)/Bianki Turbine (Right)

Hydro systems capacity ranges from:

Hydro Systems	Capacity
Pico-Hydro	Under 5 kW
Micro-Hydro	Up to 100 kW
Small-Hydro	Up to 1,000 kW

4.4 BIOFUELS/WOOD BURNING BOILERS

Lifetime	Around 20 years
Efficiency	Up to 40% (electricity-only mode), 85-90% (CHP mode)
GHG Emissions	By convention 0 gCO2-e/kWh
GHG Emissions when considering embodied emissions	3-10 gCO2-e/kWh
Cost	$1,500 to $4,000 per kW
Payback (grid-connected systems)	As low as 2 years for co-firing systems

SYSTEM DESCRIPTION

Biomass heating systems burn plants or other organic matter, such as wood chips, agricultural residues or even municipal waste, to generate heat and power.

For buildings applications, the fuel usually takes the form of wood pellets, wood chips and wood logs. Systems can be biomass-dedicated (use of biomass only), or mixed (co-firing with other fuels). Power systems often exceed 1 MW capacity and are most of the time operated in CHP mode.

Other processes include gasification and anaerobic digestion. Biomass is converted into biogas. Biogas is used in combustion engines (10 kW to 100 MW).

4.5 GEOTHERMAL

Lifetime	50 years or more
Availability	Up to 90% in practice
GHG Emissions	0 gCO2-e/kWh
GHG Emissions when considering embodied emissions	15 gCO2-e/kWh
Cost	The initial cost for the field and power plant is around $2,500 per installed kW in the U.S., and around $3,000 to $5,000/kW for a small (<1MW) power plant (see detailed cost below).
Payback (grid-connected systems)	Around 15 years

SYSTEM DESCRIPTION

Geothermal energy from deep beneath the Earth's surface is used to heat water and make steam to turn generator turbines and make electricity. Today, countries like the Philippines and Iceland produce more than 15% of their electricity with geothermal plants.

Geothermal power requires high temperature (150 to 370 oC) hydrothermal resources that may come from either dry steam wells or hot water wells.

These resources can be accessed by drilling wells into the earth and piping the steam or hot water to the surface. Geothermal wells are 1.5 to 3 km deep.

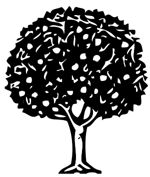
Geothermal plants can be as small as 100 kW up to 1-5 MW for buildings applications.

Small Plants (<5 MW)-$/kW Installed Capacity		
	High Quality Resource	**Medium Quality Resource**
Exploration	$400-800	$400-1,000
Steam Field	$100-200	$300-600
Power Plant	$1,100-1,300	$1,100-1,400
Total	**$1,600-2,300**	**$1,800-3,000**

GROUND WATER HEAT PUMPS (GWHP)

GWHP is often confused with geothermal. GWHP use the Earth's constant temperatures in the upper 10 feet of its surface to heat and cool buildings. GWHP transfer heat from the ground (or water) into buildings in winter and reverse the process in summer.

GWHP do not obtain significant quantities of deep-earth heat to turn generator turbines and make electricity. They belong to energy-efficient systems and therefore should be considered under PHASE 2 of the LCB Method.



PHASE 4: BUY GREEN POWER

1 GENERAL

Green power is grid-power from renewable sources. Most green power Programs, such as Green-e® in the U.S., consider as eligible renewable sources:

- Wind power
- Photovoltaic power
- Low-impact hydro power
- Biofuels based power (under certain conditions)
- Geothermal power
- Wave and tidal power

Nuclear power is excluded from green power products.

Organizations which want to purchase green power can do it:

1- By directly selecting a green power provider where the project is located.
2- Buy buying tradable Renewable Energy Certificates (RECs) (read note below).

Today, green power costs a few extra cents per kWh. For residential customers, this usually means $5 to $10 a month extra.

❧ RENEWABLE ENERGY CERTIFICATES ☙

Renewable Energy Certificates (RECs) are tradable certificates which represent proof that 1 MWh of electricity was renewable. The owner of 1,000 RECs for example can claim to have purchased 1,000 MWh of clean electricity.

It is important to understand that the electricity associated with a REC is sold separately and is used by another party. The consumer of a REC receives only a certificate. In 2008, RECs price ranges from $5 to $90 per MWh, median around $20.

❧ ABOUT THE GREEN-E® PROGRAM ☙

The Green-e® Program is a voluntary certification and verification program for green electricity products (such as RECs). To be certified, the products must meet certain criteria, in particular concerning the type of renewable sources. Eligible sources of renewable energy are: wind, solar, low-hydro, biomass, geothermal an tidal. Nuclear power is excluded. Green-e electricity products are identified by this logo:

❧ WHAT ABOUT NUCLEAR POWER? ☙

Mitigating Global Warming by developing nuclear power at a large scale is actively debated but has still not reached a consensus.

On the pros side, nuclear power emits very little CO_2 (only 35 gCO_2-e/kWh when embodied emissions are included). In this respect, it can be compared with renewables.

On the cons side, the disposal of nuclear wastes is still unresolved, and uranium which is used in nuclear reactors is only available on Earth in limited quantities.

For these reasons, green power certification bodies do not consider nuclear power as "sustainable", and do not include it among eligible clean energy sources.

2 GHG EMISSIONS FROM GREEN POWER

Green power is considered to be emissions free, and the associated emission factor is:

EF_{gpower} = 0 gCO2-e/kWh

For simplification, and because RECs can be made of a complex mix of renewables, the embodied emissions associated with green power products are ignored.

3 ESTIMATING EMISSIONS REDUCTION-PROPOSED METHOD

STEP 1: Purchase green power.
STEP 2: Estimate the corresponding project emissions reduction.

3.1 STEP 1-PURCHASE GREEN POWER

Choose one of the two options below:

OPTION 1

☑ Select a green-e® or equivalent certified power provider. Secure a contract for an annual quantity of electricity: $C_{gpower, a}$.

In regions with a closed electrical market, but where a local green-e® or equivalent accredited Program exists:

☑ Enroll in the Program for a certain annual quantity of electricity: $C_{gpower, a}$.

OPTION 2

In regions where it is not possible to directly purchase green power:

☑ Buy Renewable Energy Certificates (RECs) corresponding to an annual quantity of electricity: $C_{gpower, a}$.

3.2 STEP 2-ESTIMATE THE CORRESPONDING PROJECT EMISSIONS REDUCTION

☑ Calculate the project lifetime GHG emissions reduction as follow:

$$\Delta E_{O4} = C_{gpower, a} \times EF_{grid} \times L_t \quad \text{(eq. 1)}$$

L_t: lifetime of the building
EF_{grid}: electricity emission factor from the local grid (same as the one used in PHASES 2 and 3 calculations).

☑ Adjust the operation emissions of the project building:

$$E_{O4, p} = E_{O3, p} - \Delta E_{O4} \quad \text{(eq. 2)}$$

The operation emissions of the baseline remain unchanged: $E_{O, b}$. The baseline scenario assumes no purchase of green power.

❧ EXAMPLE ❧

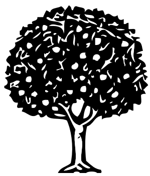
The project is situated in a region with no green power providers. The local electricity provider does not have green-e® accredited utility program. The project building owner commits himself to buy 100 RECs every year. The project operation emissions calculated in PHASE 3 are 10,000 tonCO_2-e. The building lifetime is assumed to be 60 years. The local grid average EF over this period is 0.4 tonCO_2-e/MW.

The GHG emissions that can be deducted from the project building operation emissions calculated in PHASE 3 are:

ΔE_{O4} = 100 x 0.4 x 60 = 2,400 tonCO_2-e.

The project building operation emissions become:

$E_{O4,\,p}$ = 10,000 – 2,400 = 7,600 tonCO_2-e.



PHASE 5: OFFSET EMISSIONS

1 GENERAL

“Carbon offsetting” consists in purchasing emissions savings elsewhere to compensate or balance its own emissions.

Emissions savings are sold as “carbon offsets” and are measured in tons of CO2-e. One carbon offset represents the reduction of one ton of CO2-e.

Emissions reduction projects mainly include:

- Renewable energy
- Methane collection and combustion
- Energy-efficiency
- Land-use, land-use change and forestry

Organizations can purchase carbon offsets to offsets providers. In 2009, the price of carbon offsets is around $15 per offset.

Offsetting GHG emissions should only be considered by the project team if it has failed to achieve its emissions reduction target by other means (PHASES 1 to 4).

Note that generally, companies buy carbon offsets to balance their annual global emissions from different sources, not only building operations.

These other sources can be: employees commuting, business travels, wastes treatment, etc.

❧ CARBON OFFSET QUALITY ☙

The quality of carbon offsets varies a lot depending on the offset provider and the offset project. Good offset projects should in particular demonstrate "additionality". "Additionality" means that the project would not have been done for reasons other than emissions reductions.

Standards have been developed for ensuring carbon offsets quality. One of the most widely used is the "Gold Standard".

❧ RECS VS CARBON OFFSETS ☙

Building owners may wonder if it is best to buy RECs or carbon offsets?

From a pure carbon accounting point of view, RECs are different from carbon offsets for the reason that the additionality of RECs projects is most of the time not verified nor guaranteed.

So by buying RECs, a company may buy "emissions reductions" elsewhere which do not genuinely exist. On contrary, a company which buys good quality carbon offsets is certain to buy real emissions reductions.

2 ESTIMATING EMISSIONS REDUCTION-PROPOSED METHOD

STEP 1: Purchase carbon offsets.
STEP 2: Estimate corresponding project emissions reduction.

2.1 STEP 1-PURCHASE CARBON OFFSETS

☑ Select one or more carbon offset provider(s). Select offset projects. Purchase carbon offsets corresponding to an annual amount of $\Delta E_{O5,\ a}$

tonCO2-e.

2.2 STEP 2-ESTIMATE THE CORRESPONDING PROJECT EMISSIONS REDUCTION

☑ Calculate the project lifetime GHG emissions reduction as follow:

$\Delta E_{O5} = \Delta E_{O5,\,a} \times L_t$ (eq. 1)

L_t: building lifetime

Adjust the operation emissions of the project building:

$E_{O5,\,p} = E_{O4,\,p} - \Delta E_{O5}$ (eq. 2)

The operation emissions of the baseline remain unchanged: $E_{O,\,b}$. The baseline scenario assumes that no emissions are offset.

Note: For carbon-neutral buildings: $E_{O5,\,p} = 0$.

EXAMPLE

The project owner decides to purchase every year 300 carbon offsets (corresponding to 300 tonCO2-e). The project operation emissions calculated in PHASE 4 are 30,000 tonCO2-e. The building lifetime is assumed to be 60 years.

The GHG emissions that can be deducted from the project building operation emissions calculated in PHASE 4 are:

ΔE_{O5} = 300 x 60 = 18,000 tonCO2-e.

The project building operation emissions become:

$E_{O5,\ p} = 30{,}000 - 18{,}000 = 12{,}000$ tonCO_2-e.

REPORTING BUILDING EMISSIONS

1 ESTIMATING BUILDINGS LIFETIME EMISSIONS-SUMMARY

As explained in Chapter 1, the project building lifetime emissions are:

$$\mathbf{E_{Lt,\,p} = E_{C,\,p} + E_{R,\,p} + E_{D,\,p} + E_{O5,\,p}}$$

The baseline building lifetime emissions are:

$$\mathbf{E_{Lt,\,b} = E_{C,\,b} + E_{R,\,b} + E_{D,\,b} + E_{O,\,b}}$$

The project building lifetime emissions reduction is:

$$\mathbf{\Delta E_{Lt} = E_{Lt,\,p} - E_{Lt,\,b}}$$

The project building lifetime emissions reduction performance is:

$$\mathbf{\Delta E_{Lt\ perf} = (E_{Lt,\,p} - E_{Lt,\,b}) \times 100 / E_{Lt,\,b}}$$

2 LIFETIME EMISSIONS REPORTING

Project teams are free to use the format they want to report buildings emissions, but for clarity, it is recommended to summarize emissions and emissions reductions calculated with the LCB Method in a table as shown below:

		Project	Baseline
Construction Emissions	E_C	$E_{C, p}$	$E_{C, b}$
Renovation Emissions	E_R	$E_{R, p}$	$E_{R, b}$
Deconstruction Emissions	E_D	$E_{D, p}$	$E_{D, b}$
Lifetime Operation Emissions (not considering electricity produced on-site, green power, carbon offsets)	E_O	$E_{O, p}$	$E_{O, b}$
Emissions Reduction from Electricity Produced On-Site	ΔE_{O3}	$\Delta E_{O3, p}$	0
Emissions Reduction from Green Power Purchase	ΔE_{O4}	$\Delta E_{O4, p}$	0
Emissions Reduction from Carbon Offsets Purchase	ΔE_{O5}	$\Delta E_{O5, p}$	0
Lifetime Operation Emissions	E_{O5}	$E_{O5, p}$	$E_{O5, b} = E_{O, b}$
Lifetime Emissions	E_{Lt}	$E_{Lt, p}$	$E_{Lt, b}$
Lifetime Emissions Reduction	ΔE_{Lt}	$E_{Lt, p} - E_{Lt, b}$	
Lifetime Emissions Reduction Performance	$\Delta E_{Lt\ perf}$	$(E_{Lt, p} - E_{Lt, b}) \times 100 / E_{Lt, b}$	
LCB Category	NA	☐ Carbon-Neutral ☐ A-Excellent ☐ B-Very Good ☐ C-Good	

To support the results in the summary table, assessment reports should also include details concerning:

- The date of the project
- The building lifetime considered
- The building energy consumption
- The quantity of electricity produced on-site

- The assumptions concerning the evolution of EF_{grid}
- The quantity of green power and carbon offsets purchased, etc.

3 CORPORATE REPORTING

Two main standards are used by Organizations as the basis for their GHG accounting and reporting systems:

- The GHG Protocol
- ISO 14064-1

To help delimitate direct and indirect emissions, these standards have defined three “scopes”:

SCOPE 1: Direct GHG emissions
SCOPE 2: Electricity indirect GHG emissions
SCOPE 3: Other indirect GHG emissions

For building owners, emissions related to their buildings should be reported as follow:

Emissions Sources	Scope
Construction/Renovation/ Deconstruction	
Construction	3
Renovation	3
Deconstruction	3
Operation	
Electricity Purchase	2
Fossil Fuels Burned On-Site (e.g. gas, etc.)	1
Green Power	
Green Power Purchase	Add. Information
Carbon Offsets	
Carbon Offset Purchase	Add. Information

As shown above and as explained at the beginning of this book, emissions reductions from the purchase of green power and carbon offsets have no impact the reporting Entity's direct emissions.

To reduce their direct emissions, the project team should therefore focus their efforts on the reduction of the building energy consumption and the production of clean electricity on-site.

4 ACCURACY

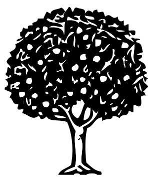
Carbon accounting is still a relatively new science and most emissions data (either emissions factors or activity data) are riddled with significant uncertainty:

Uncertainty	Uncertainty Range
Very Low	0 to 5%
Low	5 to 10%
High	10 to 20%
Very High	More than 20%

EF/Activity Data	Uncertainty*	Sources of Information
PHASE 1A		
Q_{mat}	Very Low	Quantities can be found in the project bill of quantities.
EF_{mat}	High	Suppliers.
D_{e-m}, D_{m-s}	Low	Contractors, Suppliers, Transporters.
EF_{veh}	High	Contractors, Suppliers, Transporters.
E_{site}	High	
E_{waste}	Very High	

PHASE 1B		
L_t	High	Owner, Designer.
R_t	High	Suppliers.
PHASE 1C		
Q_{land}, Q_{inc}	Low	Contractors.
EF_{land}	Very High	
EF_{inc}	Very High	
PHASE 2		
C_{elec}, C_{gas}, etc.	Low	Energy simulations generally return results with a ±10% accuracy.
EF_{grid}, EF_{gas}, etc.	Low	Utilities providers.
PHASE 3		
C_{renew}	Low	Renewable energy systems Suppliers.
PHASE 4		
C_{gpower}	Nil	The exact amount of green power purchased is indicated on the green power provider contract.
PHASE 5		
ΔE_{O5}	Variable	Depends on carbon offsets projects.

* Based on Expert judgment.



THE FUTURE OF LOW-CARBON BUILDINGS

In supermarkets today, fluorescent light bulbs occupy an area much bigger than incandescent bulbs. And it is probable that in five years, incandescent bulbs will have completely disappeared.

The same will probably happen with buildings: before long, low-carbon buildings will be the norm.

Everybody is pushing for it:

Governments: the newly elected U.S. Administration has proposed a goal of carbon-neutrality for all new buildings by 2030.

People and Organizations: the square footage of sustainable and "green buildings" in the U.S. has increased more than height fold in the last five years.

Building professionals: more and more projects integrate renewable energy systems, and "going to zero (GHG emissions)" is the main topic of an increasing number of conferences.

For all these reasons, low-carbon buildings will probably develop very rapidly in the next 2-3 years, and will play a central role in the "green economy" which is emerging.

Those who doubt it can have a look to the lighting section of their supermarket next time they go shopping…

LIST OF APPENDIX

APPENDIX A

MATERIALS/PRODUCTS MANUFACTURING-DEFAULT EMISSIONS FACTORS

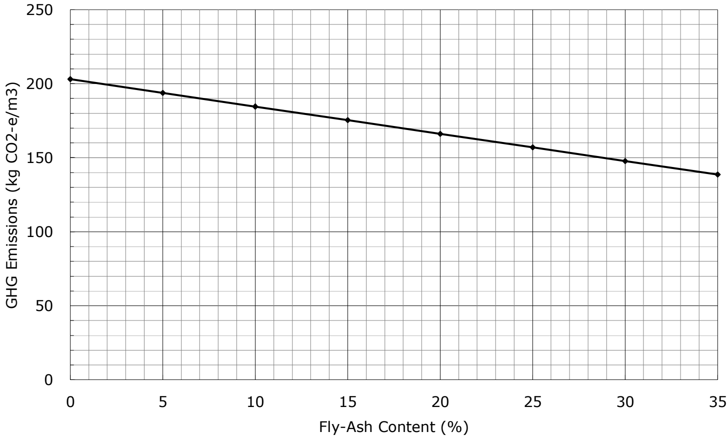
Item	**Unit**	**EF_{mat}** kgCO2-e
Land Use Change		
Grassland	M2 developed area	1.5
Mixed Vegetation	M2 developed area	32
Forest	M2 developed area	62
Excavation/Backfilling		
Excavation/Backfilling (Soil/Sand)	M3	1
Backfilling (Stones)	M3	5
Piling		
Piles 400x400	M	74
PHC Piles Dia. 400	M	50
Sprayed Piles Dia. 500	M	40
Structure		
Concrete	M3	203
Rebar	Ton	1,720
Structural Steel	Ton	1,891
Structural Wood (Non-FSC)	M3	3,500
Dimension Stone	M3	140
Envelope		
Rockwool Insulation	M2 (50 mm th.)	2
Glasswool Insulation	M2 (50 mm th.)	1.5

EPS Insulation	M2 (50 mm th.)	2.5
SBS Waterproofing Membrane	M2	11
CMU	M2	49
ALC	M2 (200 mm th.)	48
Brick Masonry	M2 (100 mm th.)	38
Plastering	M2	5
Steel Cladding	M2 (0.6 mm th.)	14
Aluminum Cladding	M2 (4 mm th.)	59
Stone Cladding	M2	19
Clay Roof Tiles	M2	23
Doors And Windows		
Glazing	M2 (incl. frame)	13
Door	Pc	70
Floor And Wall Finishing		
Carpet	M2	7
Wood Parquet/Wood Wall Covering	M2	6
Linoleum	M2	2
PVC Tiles	M2	5
Ceramic Tiles	M2	9.5
Stone Tiles (Granite, etc.)	M2	9.5
Ceiling Tiles	M2	4.5
Gypsum Board	M2	3.5
Glass Partition	M2	5.5
Plywood/OSB/MDF	M2	6
Paint	M2 (simple coat)	0.5
Wallpaper	M2	Negligible

Plumbing		
Plumbing Fixtures (Toilets, Faucets, etc.) -Use a factor of 0.45 to estimate equipment price from construction price-	$US	1
M&E		
M&E Equipments -Use a factor of 0.45 to estimate equipment price from construction price-	$US	0.15
Wind Turbine	kW Installed (nominal value)	250
PV Panel	M2 Panels	300
Landscaping/Outdoor Works		
Paving Blocks (Concrete)	M2	8
Asphalt Road	M2	10
Concrete Road	M2 (200 mm th.)	41
Other		
Office Furnitures	$US	0.1

APPENDIX B

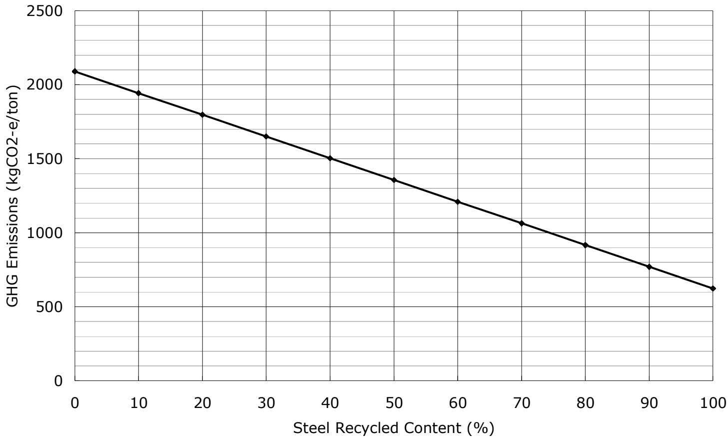
FLY-ASH CONCRETE EMISSION FACTOR



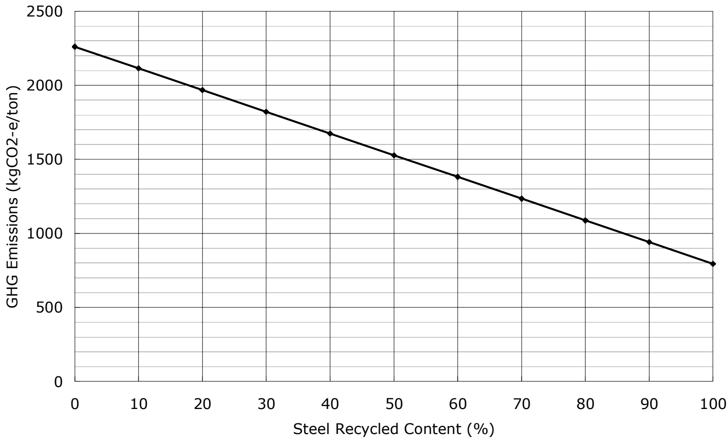
APPENDIX C

RECYCLED STEEL EMISSION FACTOR

REBAR



STRUCTURAL STEEL



APPENDIX D

RENOVATION-MATERIALS/PRODUCTS LIFETIME

Products	R_t Yrs
Envelope	
Rockwool Insulation	20
Glasswool Insulation	20
EPS Insulation	20
SBS Waterproofing Membrane	20
CMU	30
ALC	30
Brick Masonry	30
Plastering	15
Steel Cladding	15
Aluminum Cladding	25
Stone Cladding	30
Clay Roof Tiles	20
Doors And Windows	
Glazing	15
Door	20
Floor And Wall Finishing	
Carpet	5
Wood Parquet/Panels	20
Linoleum	8
PVC Tiles	8
Ceramic Tiles	15
Stone Tiles	15
Ceiling Tiles	15
Gypsum Board	15

Glass Partition	15
Paint	5
Plumbing	
Toilet Fixtures	20
M&E	
M&E Equipments	20
Wind Turbine	20
PV Panel	30
Landscaping/Outdoor Works	
Paving Blocks (Concrete)	20
Asphalt	15
Other	
Office Furnitures	10

APPENDIX E

DEFAULT EF_{grid} BY COUNTRY[10]

Country	EF_{grid} gCO2-e/kWh
Argentina	0.317
Australia	0.924
Austria	0.197
Belgium	0.289
Brazil	0.093
Canada	0.223
China (not incl. HK)	0.898
Denmark	0.358
Germany	0.539
EU (25)	0.387
Finland	0.239
France	0.083
Greece	0.887
India	0.999
Indonesia	0.722
Ireland	0.699
Italy	0.525
Japan	0.417
Korea	0.493
Mexico	0.593
Netherlands (The)	0.479
Poland	0.730
Portugal	0.511
Russia	0.351
Saudi Arabia	0.816
South Africa	0.911

[10] U.S. Department of Energy, EIA (2007).

Spain	0.443
Sweden	0.048
Turkey	0.584
UK	0.475
Ukraine	0.345
U.S.	0.676

APPENDIX F

DEFAULT ENERGY USE BY BUILDING TYPE[11]

Building Type	Electricity kWh/m2-yr	Energy* kBtu/m2-yr
Education	99	505
Food Sales	533	345
Food Services	416	1,362
Health Care	133	891
Lodging	132	555
Retail (Other than Mall)	104	234
Enclosed and Strip Malls	244	278
Office	128	377
Public Assembly	57	369
Public Order and Safety	88	377
Religious Worship	39	296
Service	70	381
Warehouse and Storage	34	155
Other	79	556

* Not incl. electricity.

[11] EIA 2003 Commercial Building Energy Consumption.

With 39% of our greenhouse gases (GHG) emissions, buildings are the largest contributors to Climate Change. But it is also the industrial sector whose GHG emissions are the easiest and cheapest to reduce.

Despite this fact, very few construction standards directly address this issue. Even modern “green buildings” achieve on average 25-30% GHG emissions reduction, which is far from what is needed to significantly mitigate Climate Change.

This book introduces the concept of “low-carbon buildings” and proposes an easy-to-implement method for:

- Estimating buildings lifetime emissions
- Estimating buildings emissions reduction perfor mance

It also gives a step-by-step approach to help building owners, designers and builders achieving significant emissions reduction, and complete their “low-carbon buildings” projects successfully.

GUILLAUME FABRE, has been working for more than ten years on construction projects worldwide. Today, he is working in China on the design, construction and certification of green buildings.