Normative Appendix A – *ADORB Cost* Calculation Method

Informative note: The convention in this appendix is that equals signs “=” indicate calculation formulas and the words “is / are” indicate definitions of the symbols in the formulas.

ADORB = PV/N, where
N is the analysis period [years]. # Per section 6.4.1.1. See also ytt below.
PV is the overall present value [$].

PV = sum over i of PV_i,
where the cost_component i is one of
{dirEnr, # direct energy cost
opCarb, # cost of carbon (operating)
dirMR, # direct maintenance / refit cost
emCarb, # cost of carbon (embodied)
eTran} # cost of energy transition

PV_i = sum over y from 1 to N of C_i_y / (1+k_i)^y , where
C_i is the cost, of cost_component i [$].
k_i is the discount rate for cost_component i [fraction 0 to 1].
k_dirEnr = 0.02
k_opCarb = 0
k_dirMR = 0.02
k_emCarb = 0
k_sysTran = 0.02
y is the year, counting from the current year = 1, that is, the future calendar year minus the previous calendar year.

And, for yearly time resolution:

C_dirEnr_y = Eg_y * Pg_y + Ee_y * Pe_y, where

Eg_y is the Annual gas energy use [therm/yr] in year y.
Ee_y is the Annual site electrical energy use [kWh/yr] in year y.
Pg_y is the Gas price [$/therm] in year y
Pe_y is the Electricity price [$/kWh] in year y

C_opCarb_y = Pc * M_op_y, where

Pc is the Carbon price [$/kg].
Pc = $0.25/kg # [Direct air capture]

M_op_y is the Annual operating emissions [kg] in year y.
M_op_y = Mg_op_y + Me_op_y
Mg_op_y is the gas emission [kg] in year y.
Me_op_y is the elec emission [kg] in year y.

Mg_op_y = Eg_y * Fg
Me_op_y = Ee_y * Fe_y
Eg_y is the gas energy consumption [therms] in year y.
Ee_y is the electrical energy consumption [kWh] in year y.

Fg is the gas emission factor, taken to be constant
Fg = 12.7 kg/therm # Energy Star Portfolio Manager Technical Reference

Fe_y is the electrical emission factor [kg/kWh] in year y.
For national average electrical emission factor:
if y=1 then
    Fe_1 = 0.433 kg/kWh # Energy Star Portfolio Manager Technical Reference
else # y>1
    Fe_y = max(0,Fe_(y-1) - Fe_1/(grid decarb year - this year)) # Linear glide path

For hourly time resolution:

Me_op_y = sum over the hour from 1 to 8760 of Ee_hour * Fe_hour_region_y

hour is the hour of the year.
region is the NREL Cambium GEA region in which the building is located.
Ee_hour is the electrical energy consumption for the hour [kWh].

Fe_hour_region_y is a long-run marginal emission factor from the NREL Cambium workbook (LRMER) for GEA regions (Gagnon et al 2022), with the following settings:
        Emission - CO2e
        Emission stage - Combined
        Start year - 2023+y
        Evaluation period - 1 years
        Discount rate (real) - 0
        Scenario - 95% decarb by 2050
        Global Warming Potentials - 100-year (AR5)
        Location - End-use
(See Levelized LRMER tab, row 350+, check units and convert to kg/kWh if necessary.)

C_dirMR_y is the cost of all the maintenance or retrofit items occurring in year y.
C_dirMR_y = sum over individual cost items in these categories:

C_dirMR_y =

+ ENV_y # Envelope
+ HVAC_y # HVAC
+ DHW_y # Hot water
+ APL_y # Major appliances, builder-installed.
+ LITE_y # Lighting
+ … continues below

Alternate: It is recommended that the more detailed breakdown of the five hard costs above follows the structure of NREL's Residential Efficiency Measures Database. Its high-level categories are as follows:

AirLeakage
MechanicalVentilation
AppliancesFixtures
CeilingsRoofs
FoundationFloors
Lighting
SpaceConditioning
Walls
WaterHeating
WindowsDoorsSkylights

+ …
+ GEN_y # PV/Battery/Generation

+ CX_y # *Commissioning*, Testing, Inspection
+ PERF_y # Other performance-related
+ IAQ_y # Indoor air quality related
+ HAZ_y # Hazard mitigation related
+ IN_y # Other in-scope
+ OUT_y # Other out-of-scope

+ INC_y # Incentives
+ TAX_y # Tax credits

For items that do not have a replacement interval,

C_dirMR_item_y = Cinitial_item
Cinitial_item is the initial cost of the item [$].

For items that have a replacement interval,
C_dirMR_item_y = Cinitial_item*Flag, where
If (y + repIntv_item - remLife_item) modulo repIntv_item < 1 then
Flag = 1 else Flag = 0

repIntv_item is the replacement interval of the item [years].
remLife_item is the presently remaining life of the item [years].

Note: setting remLife_item to 1 (not zero) in this formula will make the cost happen in year 1.

For Level 1 embodied carbon calc (national emissions intensity based):

Right now there is no decarbonization glide path applied to embodied emissions (i.e. of recurring equipment replacements).

C_emCarb_y = (emMat_y + emLbr_y)*Pc
emMat_y is the embodied emissions due to the material items in year y [kg]
emLbr_y is the embodied emissions due to domestic / installation labor of the items in year y [kg]

emMat_y = sum, over the project retrofit and maintenance items, of emMat_item_y
emMat_item_y is the embodied emissions of the material item [kg].

emMat_item_y = C_dirMR_item_y * (1-LF_item_y) * EF(CoO_item_y)
LF_item_y is the fraction of install labor in C_dirMR_item_y [fraction 0 to 1].
EF(country) is the national emission factor of a country [kg/$].
CoO_item_y is the country of origin for the item occurring in year y.

EF(country) = CO2_country / GDP_country * 1000
CO2_country is the annual CO2e emissions from the country [Megatons].
GDP_country is the annual gross domestic product of the country [USD millions].

EF, CO2 and GDP data for the top 15 US trading partners is shown in Table 1.

emLbr_y = sum, over the project retrofit and maintenance items, of emLbr_item_y
emLbr_item_y is the embodied emissions due to labor, of the item occurring in year y.

emLbr_item_y = C_dirMR_item_y * LF_item_y * EF(COPL)
COPL is the country of the project location / building site.

Table 1. Annual CO2 emissions and GDP of US and top trading partners.

Country	US trading rank	GDP [USD millions]	CO2 [MT]	EF [kg/$]
USA	-	20,936,600.00	4900	0.234
Canada	3	1,643,407.98	565.2	0.344

Country	US trading rank	GDP [USD millions]	CO2 [MT]	EF [kg/$]
China	1	14,722,730.70	9500	0.645
France	15	2,603,004.40	303.5	0.117
Germany	5	3,806,060.14	696.1	0.183
India	10	2,622,983.73	2300	0.877
Ireland	8	418,621.82	35.3	0.084
Italy	12	1,886,445.27	317.1	0.168
Japan	4	5,064,872.88	1100	0.217
Korea, South	7	1,630,525.01	605.8	0.372
Malaysia	13	336,664.44	228	0.677
Mexico	2	1,076,163.32	448.5	0.417
Switzerland	11	747,968.64	35.7	0.048
Taiwan	9	668,510.00	276.7	0.414
United Kingdom	14	2,707,743.78	352.4	0.130
Vietnam	6	271,158.44	226.5	0.835

For level 2 embodied carbon calc (itemized carbon reduction credits)

The formula for C_emCarb changes to:
C_emCarb_y = (emMat_y + emLbr_y - L2mC_y)*Pc,
where L2mC_y is the Level 2 embodied carbon credits for year y [kg]. That is, the Level 2 calc is an adjustment to the Level 1 calc rather than a replacement for it.

L2mC_y = L2mCbizMat_y + L2mCperson_y
L2mCbizMat_y is the embodied carbon credit from Business Process and Materials choices in year y. [kg]
L2mCperson_y is the embodied carbon credit from Personal choices in year y. [kg]

L2mCbizMat_y = sum over g of the carbon credit items L2mCbizMat_g_y
L2mCperson_y = sum over persons p of the carbon credit items L2mCperson_p_y

L2mCbizmat_g_y is an embodied carbon credit item g in year y. [kg]
L2mCperson_p_y is an embodied carbon credit from person p in year y. [kg]

L2mCbizmat_g_y = BAUintens_g_y * BAUqty_g_y - PROJintens_g_y * PROJqty_g_y

BAUintens_g_y and PROJintens_g_y are the business-as-usual and project-chosen carbon intensities respectively, for item g. [units vary but are of the form kg per quantity].
BAUqty_g_y and PROJqty_g_y are the corresponding quantities. [units vary among the items g].

L2mCperson_p_y = IncomeFrac_p_y * Tons_p_y * 1000 * %better_p_y

IncomeFrac_p_y is the fraction of person p's annual income that comes from the project in year y.
Tons_p_y is the tons of CO2e per year, and %better_p_y is the percent better than average, for person p, according to the Berkeley CoolClimate calculator.

C_eTran_y = TCF_y * PkPwr_y * 1000, where
TCF_y is the transition cost factor for year y. [$/Watt.yr]
PkPwr_y is the peak electrical power used by the building in year y. [kVA]

if y > ytt, then
    TCF_y = 0
else
    TCF_y = NTCF / ytt   #linear transition

ytt is the number of years to transition. Use 2050 minus the current year.
NTCF is the national transition cost factor [$/W]

NTCF = NTC / (NNCI * 1e9)

NTC is the national transition cost [$].
NNCI is the required national nameplate capacity increase (of carbon-free generation) [GW].

For the US,
NTC = $4.5e12
NNCI = 1600 GW

pkPwr_y is calculated by detailed hourly simulation, or by the following simplified method:

Simplified method for baseline cases:

basePkPwr_y = Pavg * PAM_tmy3

Pavg is the current average power consumption [kW].

PAM_tmy3 is a peak over average multiplier for the TMY3 location appropriate for the project location, according to the Open Energy Data Initiative (OEDI).

Simplified method for post retrofit cases:

postPkPwr_y = basePkPwr_y * Elif
Elif is an electrification multiplier [dimensionless]

Elif = (oldCkts + newCkts)/oldCkts
oldCkts is a power rating based on the existing electrical circuits in the building with diversity factors applied. [kVA]
newCkts is a power rating for new electrical circuits with diversity factors applied. [kVA]

oldCkts = sum over k of ckt_k
k is the number of existing circuits.
ckt_k = Voltage_k * Amperage_k * div_k / 1000
Voltage_k is the nominal circuit voltage e.g. 120, 240 [V].
Amperage_k is the circuit breaker / fuse rating of the circuit, e.g. 15, 30 [A].

div_k is the diversity factor according to circuit function, see Table 2. Set the factor to zero for any existing circuits that will be removed.

Table 2. Suggested load diversity factors by circuit function.

Circuit function	Diversity factor
Range	1
Dryer	1
Furnace	0, because removed
Kitchen	0.2
Lights	0.9
Plugs	0.2
Bath	0.2
Storage	0.01
Heat pump	0.8
Heat pump water heater	0.8