GTI's Energy Planning Analysis Tool (EPAT) – Version 2.1

Released May 7, 2021

The **Energy Planning Analysis Tool (EPAT)** is a screening tool to evaluate the potential implications of electricity and fuel use (natural gas, renewable natural gas, propane, and renewable propane) choices in residential applications on end use economics and site/source energy use and emissions. The use of fuel burning equipment or electric equipment influences energy, environmental, and economic outcomes for space conditioning, water heating, cooking, and clothes dryers. Direct site use of fuels in these applications has demonstrated savings in source energy use and GHG emissions, as well as reductions in annual energy costs with favorable paybacks for end users. The tool enables comparison of the economic, energy use, and environmental impacts of residential energy use based on an annual snapshot or over a life cycle of up to 30 years. The life cycle analysis provides alternative electric grid source energy mix scenarios with increasing utilization of renewable energy. Both analysis approaches are described in further detail below.

Annual Snapshot

The annual snapshot comparison is the default analysis in the EPAT tool, accessed either at the Residential City or State Level Comparison pages. The user selects the residence location and appliances for a base case and alternative home for comparison.

Building Data

EPAT allows the user to evaluate the impacts of switching to direct fuel use at the state level for all-electric residences as identified by EIA 2009 Residential Energy Consumption Survey (RECS 2009).[3,4] State populations and average floor space (square footage) were defined for the following five types of residential buildings: Mobile Home, Single-Family Detached, Single-Family Attached, Apartment Buildings with 2 - 4 Units, and Apartment Buildings with 5+ Units. The user has the option of evaluating each building type separately or grouping some or all building types to create custom target population.

For the state level comparison, checkboxes allow "user specified" data to be entered for number of units, average floor space, and average number of occupants. For the city level comparison[5], the default number of all-electric buildings are estimated based on city populations as reported in the 2010 U.S. Census. "User specified" options allow users to change the population input for the city or state, residential fuel prices, and input building data to calculate the total energy, environmental and cost benefits.

Energy Prices

Regional electricity and natural gas residential prices are based on state-level EIA 2019 annual average prices (https://www.eia.gov/). Regional propane prices are based on PADD average annual 2019 EIA data. The U.S. average propane price is used as the default for states with unavailable data. EIA average energy

[3] Houses identified in RECS 2009 as electric heat pump heated were eliminated from population of likely targets for fuel switching

[4] Data in RECS 2009 census region database including multiple states was disaggregated to states level using population density.

[5] Available for cities included in NREL TMY2 weather database.

prices are based on total costs, including fixed costs such as customer charge, divided by total energy consumption. Marginal energy prices are the incremental cost per energy use. In some cases, such as time of use rate structures, marginal prices may be higher than the average. EPAT defaults use marginal electricity prices developed and published by U.S. DOE, and marginal natural gas prices developed and published by AGA. The user has the option to modify any default energy prices.

Installed Equipment Costs

Installed equipment costs are based on NREL's National Residential Efficiency Measures Database v.3.1.0 which is the data source for the NREL/Building America installed cost database used in the Building Energy Optimization software (BEopt) (https://beopt.nrel.gov/). Cost data are supplemented by EIA published data or manufacturer information as necessary.

According to the website[6], the purpose of this database is to *provide a national unified database of residential building retrofit measures and associated costs.*

> *This database provides full cost estimates for many different retrofit measures. For each measure, the database provides a range of costs, as the cost data for a measure can vary widely across regions, houses, and contractors. Climate, construction, home features, local economy, and geographic location all affect the actual cost to perform any of these measures*
>
> *Some measures have multiple costs that must be added together to obtain total cost for the measure. For example, air conditioner measures have a fixed cost ($) and a normalized cost ($/kBtuh) that must be combined to get the total cost for the measure.*
>
> *The cost data represents the total cost to implement the retrofit measure. For example, a new air conditioning unit that just meets code may cost $5,000. In addition to a measure that just meets code, the database may also include a measure to install a more energy-efficient air conditioner that costs $5,700. In this case, the cost listed in the database represents the full cost of the air conditioner ($5,700), and not the incremental cost ($700) to improve the unit from code.*
>
> *This database is not intended to provide specific cost estimates for a specific project. The cost estimates do not include any rebates or tax incentives that may be available for the measures. Rather, it is meant to help determine which measures may be more cost-effective. NREL makes every effort to ensure accuracy of the data; however, NREL does not assume any legal liability or responsibility for the accuracy or completeness of the information*

More detailed information on assumptions for each measure can be found at: https://remdb.nrel.gov/about.php

Actual installation costs for retrofits can vary widely based on equipment costs, local wages, and the specifics of the installation. The user has the option to modify any default total installed equipment costs. A national total cost range is provided for guidance. These ranges were derived from various websites that collect homeowner and contractor installation and equipment costs for actual retrofit projects, as well as from EIA, EERE and manufacturer information as necessary.

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[6] NREL's National Residential Efficiency Measures Database https://remdb.nrel.gov/

Energy Consumption

Annual site consumption is calculated based on user-selected inputs for fuel type, equipment specifications, location, building square footage and occupancy. The default base case building configuration selects standard minimum efficiency electric equipment and the default alternative case building configuration selects standard minimum efficiency natural gas equipment. The user can adjust the equipment selections by efficiency and energy source.

Details of particular equipment of interest are further explained below and more details on the residential buildings energy use module is found in the tool description for GTI's Source Energy and Emissions Analysis Tool (http://seeatcalc.gastechnology.org/HelpPages/ToolDescription.pdf).

- **Air-Source Heat Pumps (ASHP)**

  ASHP performance is very dependent on ambient temperatures. In cooling mode, ASHP moves heat from inside the home to the outdoor condensing unit. In heating mode, ASHP extracts heat from the outdoor air, transferring that heat to an indoor fan coil. ASHP heating efficiency and capacity is reduced at lower ambient temperatures when less heat can be extracted from the surrounding air. To maintain performance at low ambient temperatures, ASHPs typically switch to electric resistance heating mode.

  Heating Seasonal Performance Factor (HSPF), used to describe ASHP heating efficiency, is defined by the annual space heating required in Btu, divided by the total electrical energy consumed in watt-hours. EPAT uses an adjusted HSPF for the selected location based on a formula developed by Fairey et al[7] that estimates seasonal field HSPF as a function of the local winter outdoor design temperature. This formula includes use of backup electric resistance heat during cold periods when the heat pump cannot provide enough heat. This analysis also assumes a ducted ASHP [8].

  ASHP cooling seasonal efficiency is indicated by its SEER rating, which is also used for central air conditioning systems. SEER is defined by the average cooling delivered in Btu, relative to every watt-hour of electricity consumed over a cooling season. The Energy Planning Analysis Tool calculates ASHP cooling energy use based on climate-adjusted SEER factors using DOE2.1e algorithms.

- **Gas Absorption Heat Pump (GAHP) (Prototype)**

  A gas heat pump is a heat pump that is driven by the onsite combustion of natural gas. An absorption heat pump uses the heat of combustion to separate the refrigerant from the sorbent in the desorber. Low temperature heat is added to the system in the evaporator. Heat is removed from the system in the refrigerant condenser, the absorber (where the refrigerant and sorbent are combined), and the condensing combusted gas heat exchanger. The source energy COP of this system is greater than one, including combustion losses and electricity inputs. Performance is affected by ambient temperature, load fraction, and hydronic return temperatures when used for space heating.

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[7] Fairey, P., D.S. Parker, B. Wilcox and M. Lombardi, "Climate Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air Source Heat Pumps." ASHRAE Transactions, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, June 2004.

[8] Nadel, S. and C. Kallakuri, Opportunities for Energy and Economic Savings by Replacing Electric Resistance Heat with Higher-Efficiency Heat Pumps, ACEEE Report A1603, May 2016.

EPAT calculates the fuel use for the gas absorption heat pump based on reduced order correlations derived from manufacturer data and field testing of prototype GAHPs. These correlations take into account the effect of the regional design temperature on seasonal performance to predict the yearly energy use.

Distributed Generation

Two options for residential distributed generation are provided in the EPAT tool: Rooftop Solar Photovoltaics (PV) and micro-Combined Heat and Power (mCHP).

- **Rooftop Solar Photovoltaic Panels**

Rooftop solar photovoltaic panels can be included on the home, enabling evaluation of cost and value of on-site PV to approach or reach zero net energy performance. The PV array size must be within a minimum reasonable size based on the annual electricity consumption of the home and not exceed a maximum based on the physical limits of the home's rooftop. A warning will appear if the user selects a size outside the recommended range. An option for an integrated battery is also included, with minimum and maximum size limits determined by both physical and electric load-based limits.

Excess energy produced by the panels that flows back into the grid can be valued in two ways:

- Net Metering: Electricity sent to the grid is credited back to the homeowner at the full retail rate of electricity up to, but not exceeding, the annual electricity use of the home.
- Feed-in-Tariff: Electricity sent to the grid is credited to the homeowner based on the retail electric rate and a user-entered multiplier that can be less than or greater than one. In this case, the possibility exists to be reimbursed beyond the annual electricity consumption of the home.

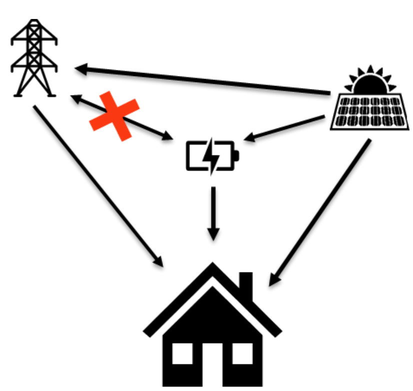

Figure 1. Energy Flows for EPAT PV Module

The PV model in EPAT was developed using various resources, including NREL's PV Watts[9] and the *Solar and Battery Calculator* tool developed by Solar Choice based in Australia[10]. The model developed provides the percentage of the home's annual electricity use that is directly offset by PV, and directly offset by the battery, if applicable, based on the total annual electricity use of the home, the percent of that electricity use that is devoted to space heating, the size of the PV array and battery, and the regional capacity factor[11] of the PV array. The model works under the assumption that the first path for PV generated electricity is to the home. In the case of excess generation, the battery is charged, and any further excess electricity is sent to the grid. In the case that the panels do not meet the electric load of the home, the battery is discharged, and any further demand

[9] PVWatts® Calculator Version 6.1.3 https://pvwatts.nrel.gov/
[10] Solar choice™ Solar & Battery Calculator. www.solarchoice.net.au. Tool accessed May 2020. https://www.solarchoice.net.au/blog/solar-pv-battery-storage-sizing-payback-calculator#fullcalc
[11] Capacity factor is the ratio of the actual generation output of the PV array over the maximum possible generation output of the PV array.

is met by the grid. The battery is never charged by the grid in this model. Since EPAT analyzes annual rather than hourly loads, there is no peak shaving or time of use controls over the battery charge or discharge timing.

Table 1. Photovoltaic Array and Battery Specifications

PV Array System	
Module Type	Standard Crystalline Silicon, 15% Nominal Efficiency
Array Type	Fixed Roof-Mounted (4/12 pitch), 180 degree Azimuth
System Losses	14.08%
DC to AC Size Ratio	1.2
Inverter Efficiency	96%
Battery System	
Battery System Setup	AC-coupled
Battery Type	Lithium-ion, 80% Depth of Discharge
Battery Round-Trip Efficiency	84%
Grid-Charging of Battery	No
Discharge Pattern	Whenever Possible

Limitations of the PV model in EPAT need to be recognized. The tool bases all calculations on annual energy consumption and production with a single grid emission factor applied. Therefore, the economic and emissions value of the energy displaced by the PV/battery in summer vs. winter is not accounted for.

- **Residential micro-CHP**

Three types of combined heat and power are available in the model. Each mCHP option is available in a thermal load following or electric load following control scheme. With the selection of electric load following, the mCHP will not generate electricity in excess of the immediate requirements of the home. In thermal load following mode, the mCHP may generate excess electricity that is sent to the grid. The mCHP options available are:

  - Natural Gas (NG) Engine
  - Proton Exchange Membrane (PEM) Fuel Cell
  - Solid Oxide (SO) Fuel Cell

Emission and Source Energy Factors

The source energy and emissions are based on GTI's Source Energy and Emissions Analysis Tool (SEEAT) (http://seeatcalc.gastechnology.org), corresponding to the total annual site energy use of electricity, natural gas, or propane. SEEAT uses government published and publicly available data sources to estimate source energy and related air emissions for selected fossil fuels and electric energy consumed at a site. However, default values for nearly all parameters can be changed by the user. Users have the option of using the eGRID2019 database at the state or plant level, screened to verify and align fuel plant classification with primary input fuel. The user must select the Geographic Area corresponding to the region in which their analysis is being performed. Default values for emission factors and source energy factors in the latest version of SEEAT use the following sources, and a full overview of the methodology is on the SEEAT Tool Description:

- **Source Energy Factors**
  - Source energy factors for fossil fuels pre-combustion energy consumption are calculated using the National Renewable Energy laboratory (NREL) U.S. Life-Cycle Inventory (LCI) database and GREET 2012 data. The NREL LCI database provides data needed to calculate source energy conversion factors for the three major types of coal (bituminous, subbituminous, and lignite) used in US power plants. Related supplemental data are provided in NREL report TP-550-38617 "Source Energy and Emission Factors for Energy Use in Buildings". (www.nrel.gov/docs/fy07osti/38617.pdf) That report also provides data needed to calculate the percentage of coal fuel mix 2 March 19, 2010 (bituminous, subbituminous, and lignite) used in electric power generation at state, regional, and national levels. (http://www.nrel.gov/lci/)
  - Source energy factors for fossil fuels on-site combustion are assumed to be 100% (i.e., complete combustion).
  - Source energy factors for fossil fuels combustion at power plants for conversion to electricity are calculated using EPA eGRID2019 data.
  - Hydroelectric plant conversion efficiency is estimated at 90%. [1a]
  - Solar power generation conversion efficiency is estimated at 12%. [1b]
  - Wind power generation conversion efficiency is estimated at 26%. [1c]
  - Geothermal power generation conversion efficiency is estimated at 16%. [1d]
  - Nuclear power generation conversion efficiency is a national average value based on 2018 DOE EIA data at 32.6%. [2]
  - Biomass power generation conversion efficiency is based on eGRID2019 data.

- **Greenhouse Gas and Criteria Pollutant Emission Factors**
  - Fossil fuels pre-combustion emissions are calculated using data from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model version released by Argonne National Laboratory in 2012. GREET references current US EIA and EPA data sources as well as a database of information developed by Argonne National Laboratory during the past 15 years. The GREET program (https://greet.es.anl.gov/index.php), sponsored by the U.S. DOE Office of Energy Efficiency and Renewable Energy (EERE), is being used by DOE for modeling emissions and energy use in transportation.
  - Fossil fuels on-site combustion emissions are calculated using GREET 2012 data.
  - Fossil fuels combustion emissions for conversion to electricity are calculated using the EPA 2019 Emissions & Generation Resources Integrated Database (eGRID2019). EPA 2021 eGRID2019 provides detailed and aggregate data on electric power plant generation and emissions for the year 2019. Data is available for nearly all US power plants and aggregated at state, National Electric Reliability Council (NERC) sub-region, NERC region, and national levels. Relevant emissions data includes CO_2, NOx, SO_2, Hg, CH_4, and N_2O emissions. In addition, the database includes the percentage of power supplied by coal, oil, natural gas, hydro, nuclear, and other renewable sources. This generation mix data is useful to estimate source energy conversion factors at state, regional, and national levels. Heat rates for electricity generation using fossil fuels like coal, natural gas, and oil as well as electricity transmission and distribution (T&D) losses are also available from eGRID2019. (https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid)

- CO_2e emission factors are calculated using global warming potential (GWP) values for three of the greenhouse gases. Calculations are based on GWP values for pollutants' 100 years lifetime as per 2013 Intergovernmental Panel on Climate Change (AR5 p714): Carbon Dioxide (CO_2) GWP = 1; Methane (CH_4) GWP = 28 ; Nitrous Oxide (N_2O) GWP = 265.

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[1] U.S. Energy Information Administration - Annual Energy Review 2011, Appendix F
Alternatives for Estimating Energy Consumption, Table F1. Conversion Efficiencies of Noncombustible Renewable Energy Sources. http://www.eia.gov/totalenergy/data/annual/pdf/sec17.pdf

Sources cited by U.S. EIA:

> **[1a]** Conventional Hydroelectric: Based on published estimates for the efficiency of large-scale hydroelectric plants. See http://www.usbr.gov/power/edu/pamphlet.pdf.
>
> **[1b]** Solar Photovoltaic: Based on the average rated efficiency for a sample of commercially available modules. Rated efficiency is the conversion efficiency under standard test conditions, which represents a fixed, controlled operating point for the equipment; efficiency can vary with temperature and the strength of incident sunlight. Rated efficiencies are based on the direct current (DC) output of the module; since grid-tied applications require alternating current (AC) output, efficiencies are adjusted to account for a 20 percent reduction in output when converting from DC to AC.
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> **[1c]** Wind: Based on the average efficiency at rated wind speed for a sample of commercially available wind turbines. The rated wind speed is the minimum wind speed at which a turbine achieves its nameplate rated output under standard atmospheric conditions. Efficiency is calculated by dividing the nameplate rated power by the power available from the wind stream intercepted by the rotor disc at the rated wind speed.
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> **[1d]** Geothermal: Estimated by EIA on the basis of an informal survey of relevant plants.

[2] The nuclear average heat rate is the weighted average tested heat rate for nuclear units as reported on the Form EIA-860; https://www.eia.gov/electricity/annual/html/epa_08_01.html

Output

EPAT Annual Snapshot output reports the following calculations for each baseline and alternative options:

- Annual site and source energy consumption
- Annual CO_2, SOx, NOx, CH_4, N_2O, and GHG full fuel cycle emissions
- Annual energy costs
- Estimated installed equipment costs
- Potential cost savings and simple payback for alternative technology options

Frequently Asked Questions (FAQ)

1. How is state-level annual energy use determined?

A. Annual energy use is calculated based on city-level weather data and then rolled up to state-level using a population weighted average.

- Space conditioning energy use is estimated based on location and the home square footage.
- Water heating energy use is based on number of occupants, and also includes hot water use for dishwashers and clothes washers. Annual energy use for heat pump water heaters is also dependent on the location. If options for dishwasher or clothes washer are selected and set to zero, the resulting increased water use is reflected in increased energy use for water heating.
- Estimated energy use for water heating and other appliances is based on number of occupants.

2. Why is 2009 RECS data used instead of the more current 2015 RECS?

A. EPAT continues to use 2009 RECS database because no state level estimates were available for the 2015 RECS due to a smaller sample size. (See below)

Reference:
Residential Energy Consumption Survey (RECS) 2015 Technical Documentation Summary: *A return to the traditional number of respondents after an increase in the previous RECS. The total number of responding households is 5,686 in the 2015 RECS compared to 12,083 in the 2009 RECS. Due to the smaller sample size, no state level estimates are available for the 2015 RECS.*
https://www.eia.gov/consumption/residential/reports/2015/methodology/index.php
https://www.eia.gov/consumption/residential/data/2015/pdf/microdata.pdf

3. Why is the EPAT total state energy consumption lower than total residential consumption reported elsewhere?

A. Default housing data is from the RECS database which only includes homes that are a primary residence. This does not include secondary homes, any vacant units, military barracks or common areas. (See below)

Reference:
Residential Energy Consumption Survey (RECS) 2015 Technical Documentation Summary: *The scope and purpose of RECS differ slightly from similar EIA products that report residential energy*

data. RECS samples homes occupied as a primary residence, which excludes secondary homes, vacant units, military barracks, and common areas in apartment buildings. As a result, RECS estimates do not represent sector-level estimates, but they are best suited for comparison across different characteristics of homes within the residential sector.
https://www.eia.gov/consumption/residential/reports/2015/methodology/index.php
https://www.eia.gov/consumption/residential/data/2015/pdf/microdata.pdf

Life Cycle Analysis

The life cycle analysis comparison is accessed from the annual snapshot pages of EPAT after entering in the base case and alternate house configurations. The analysis approach is based on government life cycle methodology, primarily NIST Handbook 135. Information including location and house base year initial equipment configuration are pulled into the life cycle page from the default annual analysis.

The data flow diagram below gives the basic outline of the inputs, data sources, processes and outputs of the life cycle analysis.

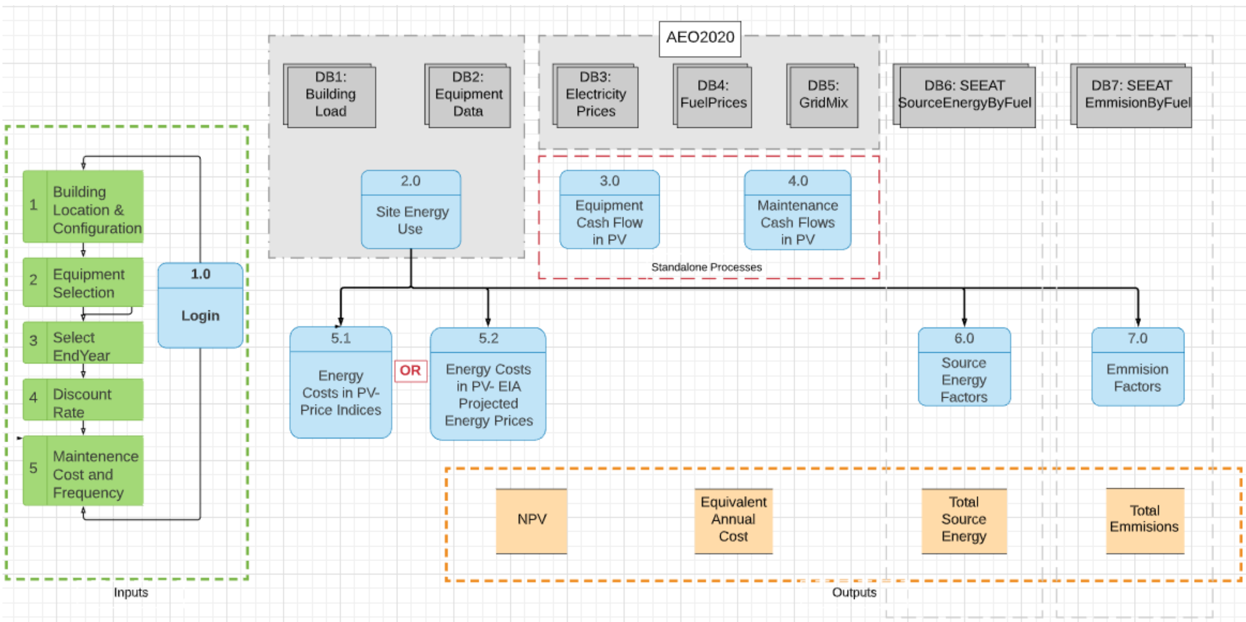

Figure 2. Life Cycle Analysis Data Flow Diagram

Life Cycle Analysis Inputs

The study period of the life cycle analysis always begins with a base date of 2020 and continues through the end year defined by the user, up to 2050. The analysis assumes all initial equipment and installations costs are made in 2020 and energy consumption starts the first day of 2021 (service date).

The EPAT LCA module performs all calculations on a constant-dollar basis, expressing all capital, maintenance, and energy costs as 2020 constant dollars ($2020) when presented on an annual basis. The default discount rate for the LCA is 3%, which can be adjusted by the user. This is used to discount costs occurring at different points in time to their present value as of the base date. Because the calculations are performed on a constant-dollar basis this is a real discount rate, net of general inflation. The DOE published 2020 real discount rate is 3.0%.[12]

[12] 2020 Discount Rates. U.S. Department of Energy. March 3, 2020. https://www.energy.gov/sites/prod/files/2020/04/f74/2020discountrates.pdf

Building Data

The building data used in the life cycle analysis is identical to that in the annual snapshot and is carried over to the life cycle page.

Energy Prices

Regional residential electricity, natural gas, and propane price projections from 2020 through 2050 are based on the Reference Case and the Low Renewable Cost case from the EIA Annual Energy Outlook 2020[13]. Energy prices are all brought back to real 2020 dollars from the 2019 values reported in the Annual Energy Outlook using the 2019 to 2020 modeled real inflation rate. The regional price projections were used to also produce regional price indices. These indices relate future prices back to the base year energy prices. Using price indices allows the user to define the starting energy costs, which are then adjusted through the end of the life cycle based on regional price indices. The user has the option to modify the price projection or price indices. This should be done carefully, understanding that the default values are related to the electrical grid mix and economy-wide energy use inherent in the Annual Energy Outlook Case they are associated with.

Price projections are not available for renewable natural gas and renewable propane from EIA. If these are included by the user in future delivered fuel mixes, then user-entered price projections must be entered as well.

Installed Equipment Costs and Average Life

Installed equipment costs are based on the same sources as for the annual snapshot. All prices are brought back to real $2020 (i.e. constant-dollar amounts) and no difference is projected for the real installed price of initial vs replacement equipment of the same type.

An additional recurring cost can be incurred over the lifetime if the user inputs maintenance costs for major equipment types, specifically HVAC, water heating, and distributed generation equipment. These are incurred on a set interval as specified by the user.

Typical equipment life expectancy in years is used to analyze the equipment cash flow as equipment is replaced. The tool provides the flexibility to the user to input equipment life from 5 to 30 years. The following table shows the list of equipment types and life expectancies from a variety of resources including the U.S. Energy Information Administration (EIA) Updated Building Sector Appliance and Equipment Technology Forecast Updates[14, 15], National Renewable Energy Laboratory (NREL)[16,17], and The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) life expectancy chart,

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[13] EIA Annual Energy Outlook 2020. Accessed September 2020. https://www.eia.gov/outlooks/aeo/data/browser/

[14] EIA Updated Buildings Sector Appliance and Equipment Costs and Efficiency. Appendix A – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case. June 2018. https://www.eia.gov/analysis/studies/buildings/equipcosts/

[15] EIA Residential Demand Module. January 2020. https://www.eia.gov/outlooks/aeo/assumptions/pdf/residential.pdf

[16] National Residential Efficiency Measures Database. NREL. Version 3.1.0. https://remdb.nrel.gov/

[17] National Renewable Energy Laboratory, Sandia National Laboratory, SunSpec Alliance, and the SunShot National Laboratory Multiyear Partnership (SuNLaMP) PV O&M Best Practices Working Group. 2018. Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems; 3rd Edition. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-73822. https://www.nrel.gov/docs/fy19osti/73822.pdf.

among others. Default average lifetimes in the tool were developed from these resources. In the event that equipment requires replacement more than once during the life cycle selected, the specified Replacement Equipment will be installed a second time. Equipment that has remaining useful life at the end of the life cycle is evaluated for residual value based on linearly prorating the total initial installed equipment cost.

Table 2. Equipment Average Life

Equipment Type	Fuel	Equipment Life in Years				
		EIA	NREL	ASHRAE	Other	Default
Furnace	Electricity	15-30	20	15	*	**20**
	Natural Gas/Propane	16-27	20	18	15-25 [a]	**20**
Air Source Heat Pump	Electricity	9-22	15	15	10-15 [a]	**15**
Absorption Heat Pump	Natural Gas/Propane	12-18	*	*	up to 20 [b]	**18**
Engine Heat Pump	Natural Gas/Propane	*	*	*	10-15 [b]	**10**
Central Air Conditioner	Electricity	11-25	16	15	7-15 [a]	**16**
Storage Water Heater	Electricity	6-20	13	*	6-12 [a], 15 [c,d]	**13**
	Natural Gas/Propane	6-20	13	*	6-12 [a], 15 [c,d]	**13**
Tankless Water Heater	Natural Gas/Propane	8-30	20	*	10 [a], 20 [c]	**20**
Heat Pump Water Heater	Electricity	6-20	12	*	10 [c,d,f]	**12**
	Natural Gas/Propane	*	*	*	*	**12**
Range	Electricity	10-20	13	*	13-20 (16) [e]	**13**
	Natural Gas/Propane	9-15	15	*	15-23 (19) [e]	**15**
Dryer	Electricity	8-18	13	*	11-18 (14) [e]	**13**
	Natural Gas/Propane	8-18	13	*	11-16 (13) [e]	**13**
Solar PV Array	-	*	25+	*	20-30 [a]	**30**
Lithium Ion Battery	-	*	10-20	*	3-12 [a]	**10**
mCHP Natural Gas Engine	Natural Gas	10-15	*	*	10 [b]	**10**
mCHP PEM Fuel Cell	Natural Gas	10	*	*	5-7 [b]	**7**
mCHP SO Fuel Cell	Natural Gas	10	*	*	5 [b]	**5**

* Data is not available from this resource

(a) InterNACHI's Standard Estimated Life Expectancy Chart for Homes. International Association of Certified Home Inspectors. Accessed Dec 2020. https://www.nachi.org/life-expectancy.htm

(b) Manufacturer or SME feedback

(c) New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs - Residential, Multi-Family, and Commercial/Industrial Measures. Technical Reference Manual Version 7. April 15, 2019. New York State Joint Utilities.

(d) Wong, Tony and Jonathan Leber. 1996 ACEEE Proceedings. Analysis of Various Water Heating Systems. https://www.aceee.org/files/proceedings/1996/data/papers/SS96_Panel1_Paper26.pdf

(e) Appliance Life Expectancy. Accessed Dec 2020. Data from 23rd Annual Portrait of the U.S. Appliance Industry Saturation. https://www.mrappliance.com/expert-tips/appliance-life-guide/

Energy Consumption

The annual site energy consumption is calculated as for the annual snapshot based on user-selected inputs for fuel type, equipment specifications, location, building square footage and occupancy. The site energy consumption is calculated on an annual basis, accounting for changes in site energy use as equipment is retired or replaced.

Distributed Generation

The same distributed generation options are available for life cycle analysis as for the annual snapshot — rooftop solar photovoltaics and micro-combined heat and power. However, replacement equipment options are restricted based on the initial equipment selection, i.e. the user cannot replace PV with mCHP or vice versa.

Manufacturer warranties of solar arrays are often 20 to 25 years. However, the arrays continue to function beyond this time at lower output. The median degradation rate for solar array performance is about 0.5% per year, and this is the default annual DC degradation rate applied in the EPAT life cycle module[18]. The contribution of solar to the energy consumption of the home is calculated each year of the life cycle based on the adjusted PV performance. Likewise, an annual absolute capacity decrease of 2% is applied to the battery, resulting in 80% of the nameplate capacity after 10 years. When reliability is important, a battery whose capacity had dropped to 80% would most likely be replaced, but for many applications, effective capacities down to 60% of initial capacity are acceptable[19]. The actual degradation rate is highly dependent on the operation and installation conditions of the battery. The user has the option to modify the default PV and battery degradation rates.

Grid Mix Projections, Emission and Source Energy Factors

Regional electrical grid mix projections by fuel type from 2020 through 2050 are based on the Reference Case and the Low Renewable Cost case from the EIA Annual Energy Outlook 2020[20]. The AEO Reference Case assumes that existing laws and regulations remain as enacted throughout the projection period, including when laws or policies are scheduled to sunset. The Low Renewable Cost adds the projection of forty percent reduction in the cost of renewable energy generation by 2050, resulting in increased renewable generation compared to the Reference Case. Projections of energy generation by fuel for the electricity power sector are available at the Electricity Market Module level and rolled up into NERC regions or national average for analysis.

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[18] *STAT FAQs Part 2: Lifetime of PV Panels.* NREL. April 23, 2018. Accessed November 2020. https://www.nrel.gov/state-local-tribal/blog/posts/stat-faqs-part2-lifetime-of-pv-panels.html

[19] National Renewable Energy Laboratory, Sandia National Laboratory, SunSpec Alliance, and the SunShot National Laboratory Multiyear Partnership (SuNLaMP) PV O&M Best Practices Working Group. 2018. Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems; 3rd Edition. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-73822. https://www.nrel.gov/docs/fy19osti/73822.pdf.

[20] EIA Annual Energy Outlook 2020. Accessed September 2020. https://www.eia.gov/outlooks/aeo/data/browser/

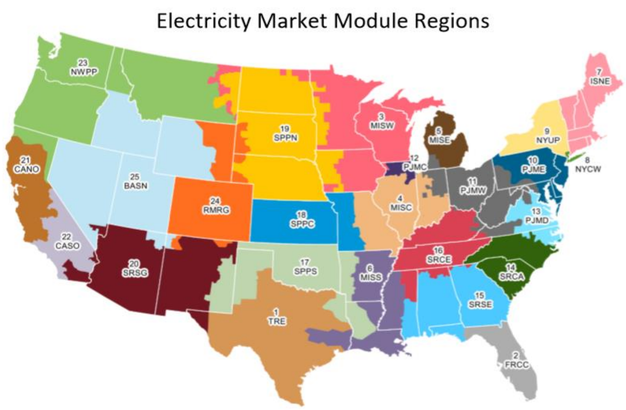

Figure 3. Electricity Market Module Regions used in EIA's Annual Energy Outlook 2020 for electrical grid mix projections. [Source: https://www.eia.gov/outlooks/aeo/assumptions/pdf/electricity.pdf]

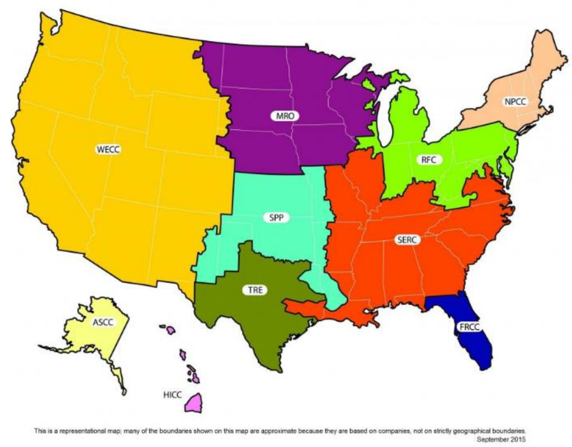

Figure 4. North American Reliability Corporation (NERC) region representational map. [Source: https://www.epa.gov/energy/north-american-reliability-corporation-nerc-region-representational-map]

The fractional grid mix from each fuel type (coal, oil, natural gas, renewable natural gas, nuclear, hydro, biomass, wind, solar, geothermal) is determined through 2050, as shown in Table 3 for the national U.S. generation mix. The default mix for direct-use fuels is one-hundred percent natural gas or propane, with the ability for the user to input fractions of renewable fuels.

Source energy and emissions for each fuel type are based on GTI's Source Energy and Emissions Analysis Tool (SEEAT), as described previously[21]. By applying the source energy and emission factors by fuel type to the annual grid mix fractions, the annual source energy and emission factors are calculated and applied to the site energy use for the year.

For the example of the 2050 national grid mixes, the full fuel cycle source energy factors including extraction, processing, transportation, conversion and distribution losses are available by generation type from SEEAT. The total efficiency also includes 4.9% grid losses in distribution. Applied to the two projected grid mixes, the resulting source energy factor in 2050 is 2.24 and 2.01 for the Reference Case and Low Cost Renewable Energy case respectively when the generation type-specific source energy factors are multiplied by the generation-mix percentages.

[21] Historic regional conversion efficiencies from eGRID2019 as found in SEEAT are used as the basis for the conversion efficiency and transmission losses used to generate source energy factors by fuel type.

Table 3. Generation-specific Efficiencies and Source Energy Factors for the Projected 2050 U.S. Electric Grid Generation Mix

Generation Type	Combined Upstream Efficiency	Conversion Efficiency	Total Efficiency	Source Energy Factor	Reference Case: 2050 Generation Mix (%)	Low Renewable Cost: 2050 Generation Mix (%)
Coal	95.7	32.2	29.3	3.41	14.32	12.20
Oil	89.2	32.2	27.3	3.66	0.07	0.06
Natural Gas	92.7	44.7	39.4	2.54	35.19	28.03
Renewable Natural Gas	79.4	100	75.5	1.32	1.08	1.32
Nuclear	95.1	32.6	29.5	3.39	12.93	10.01
Hydro	100	100	95.1	1.05	5.79	5.90
Biomass	92.1	100	87.6	1.14	0.28	0.32
Wind	100	100	95.1	1.05	13.67	19.16
Solar	100	100	95.1	1.05	15.38	21.69
Geothermal	100	100	95.1	1.05	1.05	1.27
Other	100	20.3	19.3	5.18	0.47	0.26
				Combined Source Energy Factor:	**2.24**	**2.01**

In the same manner, emission factors by generation type are applied to the specific generation mix to produce the emission intensity of the grid in a given year.

Output

EPAT Life Cycle Analysis output reports the following calculations for the base case and alternative:

Case Comparison

- **NPV Savings** — this comparative metric reports the lifetime savings of the alternative versus the base case, taken as the difference of the net present values.
- **Life Cycle Cost of Source Energy Savings** – the cost of reductions in lifetime source energy use for the alternative versus the base case. A negative number indicates that lower source energy was achieved at no increased cost. A positive number indicates the cost for decreases in source energy, for cases when the alternative has higher NPV than the base case. If no source energy reductions are achieved by the alternative compared to the base case, this is reported.
- **Cost of CO_2 Emission Reductions** – the cost of reductions in lifetime carbon dioxide emissions for the alternative versus the base case. A negative number indicates that lower emissions were achieved at no increased cost. A positive number indicates the cost for each metric ton of carbon dioxide reduction, for cases when the alternative has higher NPV than the base case. If no emission reductions are achieved by the alternative compared to the base case, this is reported.

Life Cycle Costs and Energy Consumption

- **Net Present Value (NPV)**—all money flows throughout the analysis period are discounted to present value using the specified discount rate to account for the time-value of money. This value includes all capital expenditures (equipment, installation, maintenance) as well as energy costs and remaining equipment value.
- **Equivalent Annual Cost (EAC)**—the EAC represents the cost per year for each alternative over the analysis period. Like NPV, it includes both the capital expenditures as well as operating costs in the form of energy costs. It is calculated by dividing the NPV by the present value of annuity factor.

$$EAC = \frac{NPV}{A_{n,i}}, \text{where } A_{t,r} = \frac{1 - \frac{1}{(1+i)^n}}{i}$$

  Where i is the annual interest rate and n is the number of years.
- **Energy Usage and cost**—the total life cycle energy use by energy source (electricity, natural gas, propane, and renewables) are provided as single total life cycle values. Additionally, annual energy use profile by energy source is presented graphically and the annual combined energy cost profile is presented graphically.
- **Annual Capital and Maintenance Costs**—a profile of the annual expenditures in $2020 for installed equipment costs and maintenance as well as residual value of equipment at the end of the performance period is presented graphically. These values have not been discounted to present value, but rather show the actual constant dollar annual cash flows.
- **Annual Distributed Generation Profiles**—the annual kWh of electricity from distributed generation that is used directly by the home and the annual kWh of electricity exported to the grid from distributed generation options is presented graphically.

Life Cycle Source Energy and Emissions

- **Source Energy**—the total life cycle source energy and an annual profile of source energy are provided to compare the base case and alternative. These values are calculated based on the annual energy use and annually determined source energy factors that reflect changes in the grid mix and direct fuel mix over time. The annual source energy factors can be accessed via the "View Life Cycle Annual Results" link at the top of the results page.

- **Total Emissions** – the life cycle mass emissions of carbon dioxide, sulfur dioxide, nitrogen oxides, methane, and nitrous oxides are provided. The annual mass emissions from each can be accessed via the "View Life Cycle Annual Results" link at the top of the results page.
- **Annual Emissions Profiles** – the annual emission profile on a CO_2 equivalent basis provided in graphical form for the base case and alternative allows the effect of equipment replacement and grid changes to be visualized. The graph will reflect the CO2e values for methane and nitrous oxide based on the global warming potential time-horizon selected by the user.
- **Incremental Temperature Impacts Profile** – the year by year temperature impact of multi-year emissions through 2120 (100 year horizon) as determined by the formulas from the Fifth Assessment Report of the IPCC.[22] This plot shows the projected incremental temperature increase in year t from multi-year emissions. The plot continues past the end of the life cycle analysis to demonstrate the long term effects of emissions occurring within the analysis period. However, emissions are assumed to be zero past the end date of the life cycle.

The presentation of emissions as separate mass emissions, annual CO2e emissions, and as incremental temperature increase provides the user with a range of climate metrics to be used to compare the technologies in each case. Multi-year assessments, as performed in the EPAT LCA module, can pose a challenge for the use of climate metrics in GHG estimation. Figure 5 shows a simplified cause-effect chain relating GHG emissions to environmental damage. Each link in the chain is connected to the previous one, but also affected by a multitude of other factors that results in increased uncertainty as one moves to the right. For methane, the IPCC estimates an uncertainty of ±30% and ±40% for GWP20 and GWP100, respectively, which provide relative radiative forcing of a pulse emission of methane compared to CO_2 over a given time horizon. In contrast, the GTP100 of methane has an uncertainty of ±75% (with a 90% confidence) when predicting the relative temperature change resulting increased radiative forcing.[23]

Figure 5. The cause-effect chain linking greenhouse gas emissions to climate change-related damage [Source: Balcombe, et.al.]

The three metrics reported in EPAT—mass emissions, CO2e based on GWP, and incremental temperature change—correspond to Emission, Radiative forcing, and Climate change respectively in the cause-effect chain. While mass emissions can be presented with the highest certainty, they provide the least information about the potential effects of the individual GHG emissions. GWP at various time horizons is a commonly used factor that conflates different GHGs to a single metric that can be used to compare alternatives. However, because the physical basis is in the average radiative forcing of a pulse emission

[22] Myhre, G., et al., 2013b. Anthropogenic and Natural Radiative Forcing Supplementary Material. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., et al. (eds.)].

[23] Balcombe, Paul, et.al. Methane emissions: choosing the right climate metric and time horizon. *Environ. Sci.: Process Impacts,* 2018, 20, 1323.

over a defined time frame (e.g. 20 or 100 years), rather than a sustained emission at a specific end-point in time, its use in life cycle analysis is limited. It is therefore presented on an annual basis only, allowing a comparison of the effects of annual changes in grid mix and installed appliances in the two cases. The global mean temperature change trajectory effected by the lifecycle emissions is a metric that is most suited to understanding the actual potential climate effects of sustained emissions. However, the results come with greater uncertainty due to the multifaceted nature of GHG emissions' effect on climate. Those interested in further reading on this topic can reference the papers in the footnotes.[23, 24]

Frequently Asked Questions

1. **Is equipment performance degradation included in the life cycle analysis energy use?**
   A. No, appliance performance degradation is not included in the analysis. Degradation is highly variable, dependent on installation, maintenance, use, and other factors. Not all equipment types exhibit consistent performance degradation over time. The only exception to this is for the solar rooftop photovoltaics and associated battery system as described above.
2. **Are weather projections included in annual energy use projections?**
   A. No, a Typical Meteorological Year (TMY2) is used to calculate the energy demand for every year of the life cycle analysis. If there is no change in equipment year to year, then there will be no change in site energy consumption.
3. **Is renewable natural gas (RNG) included in the projected direct use natural gas mix?**
   A. Although the default direct use natural gas projections do not include RNG, the user can edit the fuel mix to include RNG by clicking on the "View/Edit Grid Mix Projections" link.

[24] Robert Kleinberg, 2020. The Global Warming Potential Misrepresents the Physics of Global Warming Thereby Misleading Policy Makers. (Boston University Institute for Sustainable Energy, Boston, MA, USA). https://doi.org/10.31223/X5P88D