Technical Appendix

Space Heating

1. Introduction

This appendix offers a detailed explanation of the specific assumptions used in the space heating module of Mepsy. For information on outputs and data sources for the parameters, please refer to the comprehensive Mepsy Methodology document.

CLASP's Space Heating model provides energy and emissions assessments for equipment used to provide thermal comfort in residential buildings. The model covers five types of space heating equipment:

- Air Source Heat Pump (ASHP),
- Ground Source Heat Pump (GSHP),
- Condensing Boiler (CB),
- Non-Condensing Boiler (NCB), and
- Electric Resistance (ER).

CLASP classified non-electric furnaces under NCB and electric furnaces under ER, as well as excluded the usage of district heating and stoves in this model. In addition, further categories were assigned for these equipment types. ASHP, GSHP, and ER were assumed to be fully operated with electricity, while NCB and CB might be operated with coal, gas, fuel oil, renewables, and other fuel types outside the available categories.

2. Shipments and Stock

To generate stock estimates of the space heating equipment covered in this model, CLASP utilized secondary sources from key countries located in the Northern hemisphere where space heating energy consumption is prevalent: EU-28 countries, the United States, and Canada. Once the stock data was collected, we used the reversed Weibull distribution, processed with R code, to back-calculate the sales from the stock. Since Mepsy is a bottom-up model, it begins with appliance sales numbers.

Weibull Distribution function is commonly used to model survival probabilities $P\,(x)$ of appliances and calculate the surviving stock of a certain year (y), based on the cumulative survival appliances from the previous year $(Stock(y-1))$.[1]

$$P\,(x) = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}}$$

Where:

$P\,(x)$ is the probability that the appliance is still in use at a certain age (x);

x is the appliance age;

α is the scale parameter, which corresponds to the decay length in an exponential distribution, also known as lifetime. In Mepsy, we set the lifetime of space heating at 25.4 years.[2]

β is the shape parameter, which determines how the failure rate changes over time;

θ is the delay parameter, which introduces a delay before any failures occur.

Based on the Lawrence Berkeley National Laboratory (LBNL) study, Mepsy determines a shape parameter (β) of 3.2 and a delay parameter (θ) of 1.0.[2]

EU-28 STOCK DISTRIBUTION

A summary of the available stock data applied for year 2019 in the European region is provided in Table 1. The dataset is available as an open data source from Pezutto's assessment on the regional space heating and domestic hot water market in Europe.[3] While most low and medium capacity space heating equipment units considered by Pezutto could be assumed to be primarily installed in residential buildings, the stocks below also include heating equipment in non-residential buildings.

TABLE 1. 2019 SPACE HEATING STOCK IN EU

	STOCK (UNITS) - PEZUTTO ET AL. (2019)					
COUNTRY	ASHP	GSHP	CB	NCB	ER	TOTAL
Austria	140,000	120,000	290,000	1,580,000	237,000	2,367,000

[1] LBNL. Lutz et al. 2011. Using National Survey Data to Estimate Lifetimes of Residential Appliances. https://www.osti.gov/biblio/1182737

[2] "Estimating Residential Appliance Lifetime for Energy Efficient Policy Analysis | Energy Technologies Area," accessed January 16, 2025, https://eta.lbl.gov/publications/estimating-residential-appliance.

3 Simon Pezzutto et al., "Assessment of the Space Heating and Domestic Hot Water Market in Europe—Open Data and Results," Energies 12, no. 9 (January 2019): 1760, https://doi.org/10.3390/en12091760.

COUNTRY	STOCK (UNITS) - PEZUTTO ET AL. (2019)					
	ASHP	GSHP	CB	NCB	ER	TOTAL
Belgium	18,000	5,836	100,000	3,610,000	320,000	4,053,836
Bulgaria	149,000	3,875	1,000	440,000	760,000	1,353,875
Croatia	60,000	10,000	50,000	320,000	90,000	530,000
Cyprus	380,000	18,000	1,000	100,000	10,000	509,000
Czech Republic	40,000	20,000	220,000	1,230,000	240,000	1,750,000
Denmark	250,000	36,335	100,000	775,285	209,000	1,370,620
Estonia	100,000	5,955	1,000	19,000	10,200	136,155
Finland	410,000	56,000	7,000	235,000	780,000	1,488,000
France	1,070,000	320,000	1,700,000	11,200,000	9,500,000	23,790,000
Germany	667,000	330,000	5,920,000	14,630,000	2,400,000	23,947,000
Greece	3,500,000	10,000	10,000	2,220,000	430,000	6,170,000
Hungary	1,600	1,000	130,000	1,120,000	4,000	1,256,600
Ireland	11,300	2,388	40,000	990,000	90,000	1,133,688
Italy	1,560,000	3,700	2,140,000	8,940,000	300,000	12,943,700
Latvia	70,000	5,000	10,000	194,000	1,400	280,400
Lithuania	2,430	1,623	30,000	230,000	1,000	265,053
Luxembourg	742	103	10,000	130,000	7,800	148,645
Malta	150,000	100	2,000	10,000	30,000	192,100
Netherlands	147,000	30,400	230,000	4,945,006	5,000	5,357,406
Poland	12,720	370,000	300,000	3,990,000	439,000	5,111,720
Portugal	250,000	15,000	54,556	1,144,000	2,050,000	3,513,556
Romania	580,000	100,000	120,000	1,725,146	50,000	2,575,146
Slovakia	8,500	7,500	60,000	534,934	40,000	650,934
Slovenia	20,000	10,000	2,000	350,016	65,500	447,516

COUNTRY	STOCK (UNITS) - PEZUTTO ET AL. (2019)					
	ASHP	GSHP	CB	NCB	ER	TOTAL
Spain	194,000	890	220,000	6,065,000	7,120,000	13,599,890
Sweden	1,210,000	428,000	13,000	260,000	290,000	2,201,000
United Kingdom	65,835	15,000	1,240,000	16,500,000	2,000,000	19,820,835
EU28	**11,068,127**	**1,926,705**	**13,001,556**	**83,487,387**	**27,479,900**	**136,963,674**

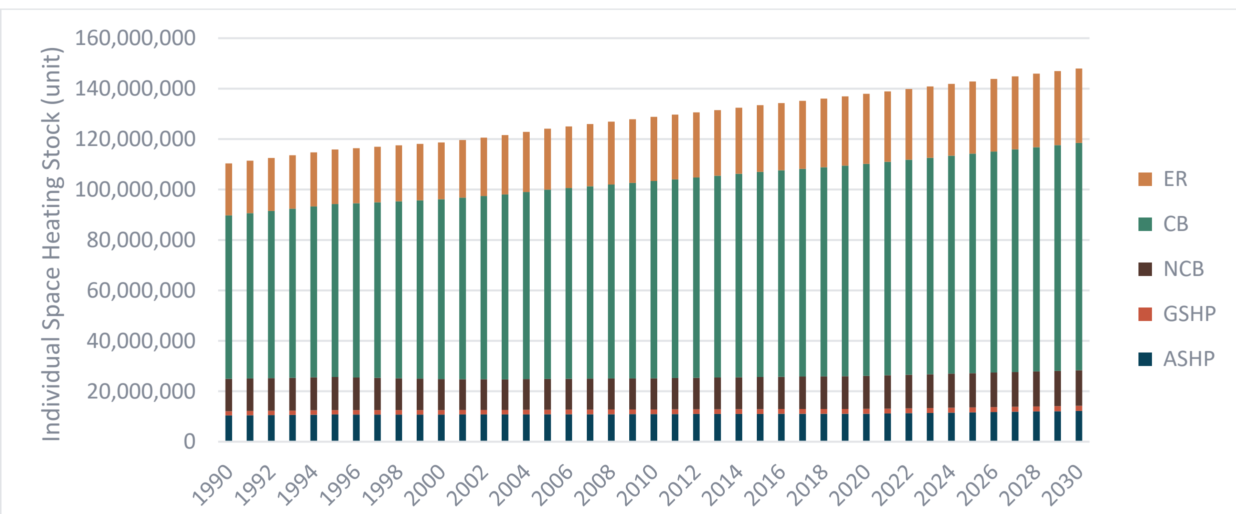
Table 2 is the summary of stock estimates generated for EU countries.

TABLE 2. TOTAL STOCK OF SPACE HEATING IN EU (1990-2030)

YEAR	ASHP	GSHP	NCB	CB	ER
1990	10,441,122	1,676,766	12,857,712	64,785,052	20,591,731
1991	10,509,850	1,688,775	12,907,891	65,520,493	20,791,492
1992	10,579,066	1,700,933	12,959,272	66,265,010	20,994,874
1993	10,648,783	1,713,247	13,011,883	67,018,892	21,201,992
1994	10,719,019	1,725,719	13,065,747	67,784,062	21,412,963
1995	10,789,787	1,738,353	13,120,893	68,583,639	21,627,913
1996	10,785,629	1,744,872	12,951,910	69,098,154	21,809,502
1997	10,781,817	1,751,516	12,789,201	69,623,493	21,993,759
1998	10,778,360	1,758,288	12,627,307	70,159,489	22,180,752
1999	10,775,268	1,765,569	12,466,238	70,706,419	22,370,546
2000	10,772,550	1,773,358	12,306,005	71,264,566	22,563,213
2001	10,788,890	1,782,986	12,234,414	71,947,360	22,874,599
2002	10,805,651	1,792,775	12,164,549	72,644,285	23,190,310
2003	10,822,844	1,802,731	12,096,458	73,355,695	23,510,449
2004	10,841,297	1,812,853	12,164,884	74,181,225	23,835,135
2005	10,859,901	1,823,119	12,234,944	75,019,595	24,164,467
2006	10,876,421	1,830,011	12,260,372	75,633,637	24,419,869
2007	10,892,958	1,836,977	12,286,575	76,256,474	24,678,263
2008	10,909,519	1,844,020	12,313,587	76,888,317	24,939,712
2009	10,926,108	1,851,141	12,341,439	77,529,388	25,204,278
2010	10,942,734	1,858,343	12,370,166	78,179,914	25,472,028
2011	10,961,452	1,865,894	12,426,647	78,787,116	25,657,419
2012	10,980,128	1,873,514	12,495,131	79,402,382	25,845,196
2013	10,998,766	1,881,206	12,565,333	80,025,886	26,038,956
2014	11,017,372	1,888,971	12,644,326	80,669,717	26,235,868
2015	11,035,953	1,896,811	12,728,562	81,323,021	26,453,278

YEAR	ASHP	GSHP	NCB	CB	ER
2016	11,044,426	1,904,227	12,795,174	81,855,155	26,706,292
2017	11,052,613	1,911,681	12,862,858	82,393,199	26,961,704
2018	11,060,514	1,919,173	12,931,642	82,937,245	27,219,558
2019	**11,068,127**	**1,926,705**	**13,001,556**	**83,487,387**	**27,479,900**
2020	11,075,451	1,934,276	13,112,929	84,061,643	27,742,779
2021	11,186,205	1,943,947	13,204,719	84,650,074	27,916,456
2022	11,298,067	1,953,667	13,297,152	85,242,625	28,091,220
2023	11,411,048	1,963,435	13,390,232	85,839,323	28,267,079
2024	11,525,158	1,973,252	13,483,964	86,440,199	28,444,038
2025	11,640,410	1,983,119	13,578,352	87,045,280	28,622,106
2026	11,756,814	1,993,034	13,673,400	87,654,597	28,801,288
2027	11,874,382	2,002,999	13,769,114	88,268,179	28,981,592
2028	11,993,126	2,013,014	13,865,498	88,886,056	29,163,024
2029	12,113,057	2,023,079	13,962,556	89,508,259	29,345,592
2030	12,234,188	2,033,195	14,060,294	90,134,817	29,529,304
CAGR (2020 base)	1.00%	0.50%	0.70%	0.70%	0.63%

FIGURE 1. SPACE HEATING STOCK FOR EACH TECHNOLOGY IN EU (1990-2030)



UNITED STATES SHIPMENTS AND STOCK DISTRIBUTION

Further analysis was done by Lim to calculate shipment data from stock distribution by age as reported in the U.S. Energy Information Administration (EIA)'s 2009 Residential

Energy Consumption Survey (RECS).[4] Table 3 summarizes the reported shipment's values by the surveyed age of the main heating equipment.

TABLE 3. SPACE HEATING SHIPMENT IN USA

	SHIPMENTS (MILLION UNITS)			
YEAR	GAS FURNACE	OIL FURNACE	ELECTRIC FURNACE	HEAT PUMP
1980	0.361	0.017	0.062	0.030
1981	0.385	0.024	0.070	0.040
1982	0.336	0.034	0.058	0.035
1983	0.539	0.045	0.121	0.067
1984	0.658	0.057	0.137	0.090
1985	0.702	0.062	0.154	0.116
1986	0.889	0.091	0.173	0.142
1987	0.940	0.100	0.182	0.165
1988	1.018	0.106	0.152	0.168
1989	1.127	0.099	0.165	0.187
1990	1.074	0.082	0.165	0.210
1991	1.206	0.082	0.153	0.221
1992	1.295	0.093	0.191	0.256
1993	1.681	0.103	0.241	0.311
1994	1.829	0.119	0.290	0.390
1995	1.829	0.102	0.304	0.430
1996	2.111	0.120	0.371	0.526
1997	2.115	0.101	0.329	0.561
1998	2.349	0.108	0.349	0.666
1999	2.552	0.109	0.369	0.73
2000	2.624	0.108	0.389	0.807
2001	2.664	0.113	0.408	0.936
2002	2.855	0.109	0.427	1.027
2003	2.977	0.12	0.445	1.184
2004	3.266	0.125	0.452	1.443
2005	3.297	0.109	0.458	1.715
2006	3.026	0.091	0.462	1.753
2007	2.644	0.083	0.465	1.597
2008	2.162	0.059	0.467	1.616

[4] Lim, T. H. (2014). Geothermal Heat Pump System for U.S. Residential Houses: Barriers of Implementation and its Environmental and Economic Benefits [Doctoral dissertation]. https://deepblue.lib.umich.edu/bitstream/handle/2027.42/108253/Tae%20Lim%20Thesis%20Final%202014.pdf;sequence=1

YEAR	SHIPMENTS (MILLION UNITS)			
	GAS FURNACE	OIL FURNACE	ELECTRIC FURNACE	HEAT PUMP
2009	2.072	0.056	0.469	1.442

Compilation of EIA's RECS space heating data was also collected as an additional reference for stock estimates.[5] Further grouping was done, as provided in the subsequent table, to assess general trends and growth rates.

TABLE 4. OTHER SPACE HEATING DATA COLLECTED FROM ERCS

MAIN HEATING FUEL AND EQUIPMENT (IN MILLION HOUSING UNITS)	1993	1997	2001	2005	2009	2015
Natural Gas	50.8	52.7	55.2	58.2	55.6	57.7
Central Warm-Air Furnace	34.9	37.8	41.9	44.7	44.3	46.5
For One Housing Unit	34.1	36.5	40.2	42.9	42.5	
For Two or More Housing Units	0.9	1.3	1.7	1.8	1.8	
Steam or Hot Water System	8.7	7.2	7.4	8.2	6.9	6.6
For One Housing Unit	5.1	5	4.8	5.1	3.7	
For Two or More Housing Units	3.6	2.2	2.6	3.1	3.2	
Built-In Room Heater	2.8	3.7	2.6	2	2.3	2.2
Floor or Wall Pipeless Furnace	4.3	4	2.9	2.3	1.2	
Other Equipment			0.5	0.9	0.9	2.4
Electricity	25.3	29.2	28.9	33.7	38.1	40.9
Central Warm-Air Furnace	9.5	10.6	11.8	16	19.1	16.1
Heat Pump	7.5	9.5	9.7	9.2	9.8	11.8
Built-In Electric Units	7	7.3	5.7	5	5.7	9.2
Portable Electric Heater	1.3	1.7	1.7	1.3	2.7	3
Other Equipment	0	0	0	0	0.9	0.8
Fuel Oil	10.2	9.3	7.5	7.7	6.9	5.8
Steam or Hot Water System	5.3	5.1	4.1	4.7	3.9	1.7
For One Housing Unit	3.5	3.3	3.1	3.3	2.6	
For Two or More Housing Units	1.8	1.8	1.1	1.4	1.3	
Central Warm-Air Furnace	4.5	3.7	3.1	2.8	2.7	3.5
Other Equipment	0.4	0.4	0.3	0	0.3	0.7
Propane/LPG	4.8	4.5	4.6	6	5.6	5
Central Warm-Air Furnace	3.1	3.1	3.1	4.1	3.9	3.8

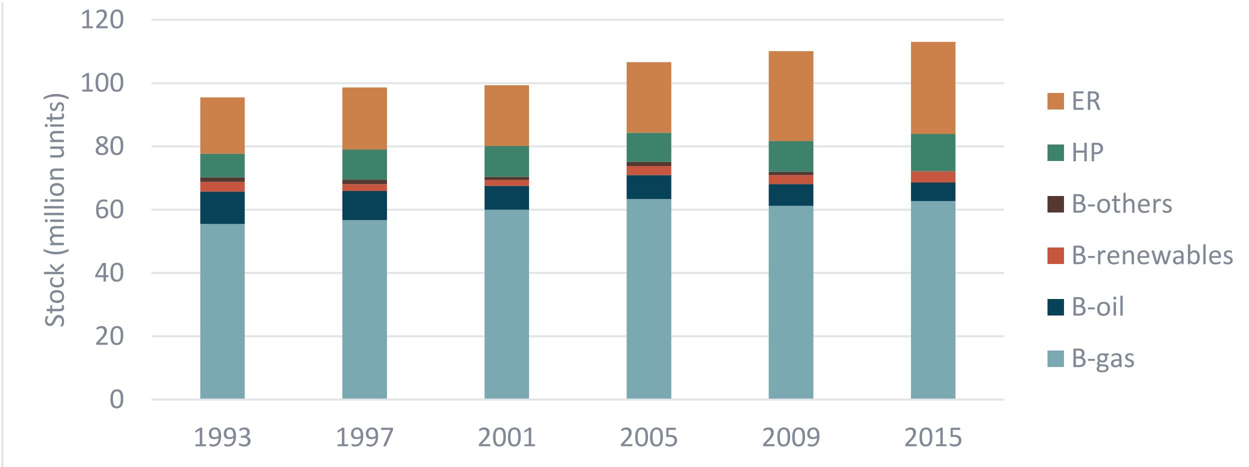
[5] Residential energy consumption survey (RECS) - Data - U.S. Energy Information Administration (EIA). (n.d.). U.S. Energy Information Administration (EIA). https://www.eia.gov/consumption/residential/data/2015/

MAIN HEATING FUEL AND EQUIPMENT (IN MILLION HOUSING UNITS)	1993	1997	2001	2005	2009	2015
Other Equipment	1.7	0.9	1.6	1.2	1.7	1.2
Wood	3.1	2.2	1.9	2.9	2.8	3.5
Heating Stove	2.4	1.5	1.4	2	2.2	2.7
Other Equipment	0.7	0.7	0.5	0.9	0.6	0.8
Kerosene	1.0	1.0	0.8	7.7	0.5	0.0
Other Fuel	0.4	0.4	0.2	0.6	0.5	0.0
Do Not Have or Use Heating Equipment	0.9	0.8	0.9	2	3.5	5.1
TOTAL	96.6	100	100	111.1	113.6	118.2

TABLE 5. SPACE HEATING STOCK IN USA USING MEPSY PRODUCT GROUP

MAIN HEATING FUEL AND EQUIPMENT (IN MILLION HOUSING UNITS)*	1993	1997	2001	2005	2009	2015	CAGR (1993 - 2015)	CAGR (2009 - 2015)	BOILER FUEL SHARE IN 2015
Boiler-gas	55.5	56.7	60	63.4	61.2	62.7	0.6%	0.4%	87%
Boiler-oil	10.2	9.2	7.5	7.5	6.9	5.9	-2.5%	-2.6%	8%
Boiler-renewables	3.1	2.2	1.9	2.9	2.8	3.5	0.6%	3.8%	5%
Boiler-others	1.4	1.4	1	1.3	1	0	-100.0%	-100.0%	0%
HP	7.5	9.5	9.7	9.2	9.8	11.8	2.1%	3.1%	
ER	17.8	19.6	19.2	22.3	28.4	29.1	2.3%	0.4%	

*B = Boilers and furnaces; no differentiation between condensing and non-condensing units



Annual stock estimates from 1993 to 2015 were interpolated from these previously listed values for the defined grouping. Projections from 2016 to 2020 were calculated based on the average growth rate from 2009 to 2015. A share of 84.5% was assigned for non-condensing boilers. Shipments for GSHP were obtained from EIA's geothermal manufacturing report and IEA's regional report for North America.[6,7] Heat pump stock estimates obtained from RECS were fully assigned for ASHP, based on accumulation of US AHRI shipments which yielded nearly double the number of ASHP units in stock relative to RECS data. Table 5 shows the summary of stock estimates generated for the US.

TABLE 6. SPACE HEATING STOCK IN USA

YEAR	ASHP		CB	NCB	ER
1993	7,500,000	-	10,886,631	59,313,369	17,800,000
1994	7,956,588	-	10,859,390	59,164,952	18,233,877
1995	8,440,972	-	10,832,217	59,016,906	18,678,330
1996	8,954,844	-	10,805,112	58,869,231	19,133,616
1997	9,500,000	-	10,778,075	58,721,925	19,600,000
1998	9,549,610	-	10,812,800	58,911,116	19,499,225

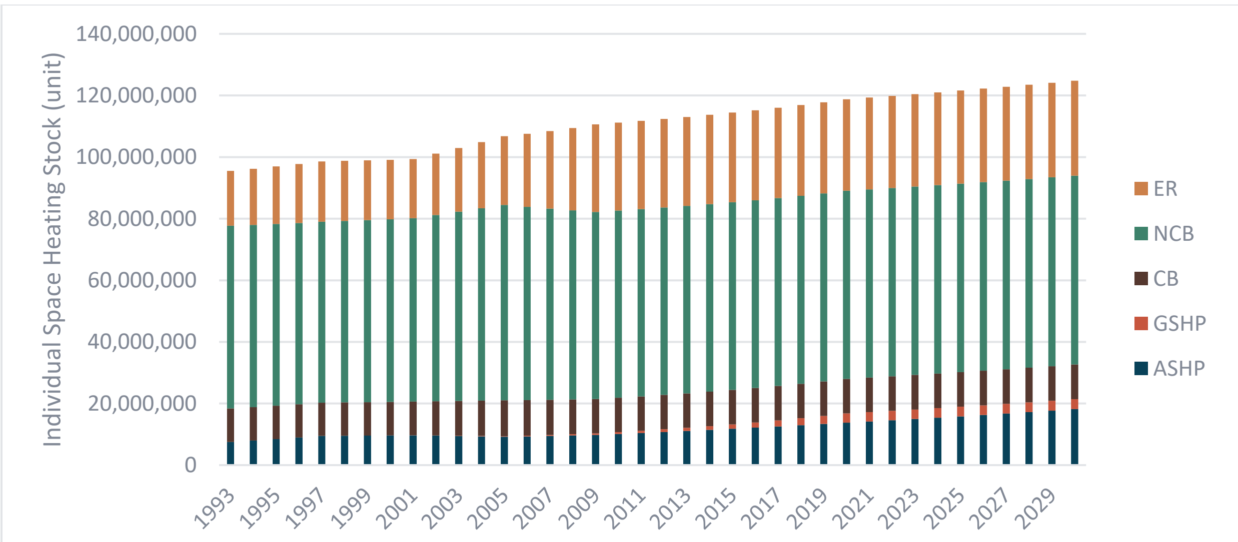
[6] Geothermal heat pump manufacturing activities - Energy Information Administration. (2009). U.S. Energy Information Administration (EIA). https://www.eia.gov/renewable/annual/geothermal/

[7] Lapsa, M., Khowailed, G., Sikes, K., & Baxter, V. (2017). Heat Pumps in North America – 2017 Regional Report / 12th IEA Heat Pump Conference. International Energy Efficiency. http://hpc2017.org/wp-content/uploads/2017/05/P.2.1.3-Heat-Pumps-in-North-America-%E2%80%93-2017-Regional-Report.pdf

YEAR	ASHP		CB	NCB	ER
1999	9,599,479	-	10,847,637	59,100,916	19,398,969
2000	9,649,609	-	10,882,585	59,291,328	19,299,228
2001	9,700,000	35,599	10,917,647	59,482,353	19,200,000
2002	9,572,508	70,890	11,095,474	60,451,205	19,932,058
2003	9,446,693	107,674	11,276,198	61,435,837	20,692,027
2004	9,322,530	143,669	11,459,865	62,436,507	21,480,973
2005	9,200,000	186,939	11,646,524	63,453,476	22,300,000
2006	9,346,465	234,056	11,520,427	62,766,463	23,689,628
2007	9,495,262	296,838	11,395,695	62,086,888	25,165,850
2008	9,646,428	382,011	11,272,313	61,414,671	26,734,063
2009	9,800,000	501,582	11,150,267	60,749,733	28,400,000
2010	10,108,081	614,709	11,155,431	60,777,864	28,515,486
2011	10,425,848	736,946	11,160,596	60,806,009	28,631,442
2012	10,753,604	883,519	11,165,765	60,834,166	28,747,869
2013	11,091,664	1,044,168	11,170,935	60,862,337	28,864,770
2014	11,440,351	1,228,786	11,176,108	60,890,520	28,982,147
2015	11,800,000	1,437,089	11,181,283	60,918,717	29,100,000
2016	12,170,955	1,678,822	11,186,461	60,946,926	29,218,333
2017	12,553,572	1,955,127	11,191,641	60,975,149	29,337,147
2018	12,948,217	2,270,966	11,196,824	61,003,385	29,456,444
2019	13,355,269	2,631,993	11,202,009	61,031,633	29,576,226
2020	13,775,117	3,044,682	11,207,196	61,059,896	29,696,495
2021	14,164,253	3,059,905	11,211,867	61,085,343	29,805,155
2022	14,564,383	3,075,205	11,216,539	61,110,801	29,914,213
2023	14,975,815	3,090,581	11,221,214	61,136,269	30,023,671
2024	15,398,870	3,106,034	11,225,890	61,161,748	30,133,528
2025	15,833,876	3,121,564	11,230,569	61,187,238	30,243,788
2026	16,281,171	3,137,172	11,235,249	61,212,738	30,354,451

YEAR	ASHP		CB	NCB	ER
2027	16,741,102	3,152,858	11,239,932	61,238,249	30,465,519
2028	17,214,025	3,168,622	11,244,616	61,263,771	30,576,993
2029	17,700,308	3,184,465	11,249,302	61,289,303	30,688,875
2030	18,200,328	3,200,387	11,253,991	61,314,846	30,801,167
CAGR (2020 base)	2.82%	0.50%	0.04%	0.04%	0.37%

FIGURE 3. SPACE HEATING STOCK IN US USING MEPSY PRODUCT GROUP



CANADA STOCK DISTRIBUTION

Historical stock of heating system in residential sector is available from the Natural Resources Canada from the year of 1990 to 2017.[8] Summarized values are shown in the following table and graph.

TABLE 7. SPACE HEATING USED IN CANADA IN 1990,2000,2008 AND 2017

HEATING SYSTEM STOCK BY HEATING SYSTEM TYPE (THOUSANDS)	1990	2000	2008	2017
Heating Oil – Normal Efficiency	1,463	457	73	3
Heating Oil – Medium Efficiency	34	773	994	1,180
Heating Oil – High Efficiency	0	0	0	0

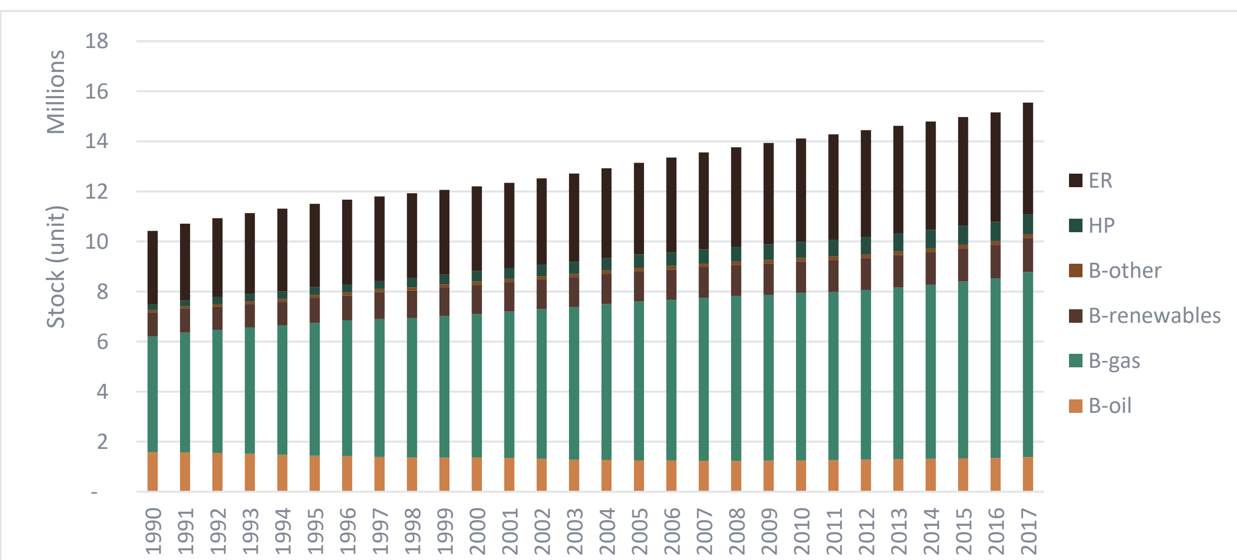
[8] Residential sector Canada Table 27: Heating system stock by building type and heating system type | Natural resources Canada. (2020, February 7). https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP§or=res&juris=ca&rn=27&page=0

Natural Gas – Normal Efficiency	4,061	2,748	1,042	10
Natural Gas – Medium Efficiency	221	1,861	2,901	2,370
Natural Gas – High Efficiency	303	1,081	2,568	4,928
Electric	2,932	3,390	3,974	4,458
Heat Pump	239	416	596	799
Other1	87	130	138	150
Wood	180	271	268	294
Dual Systems				
Wood/Electric	536	603	656	720
Wood/Heating Oil	253	286	315	341
Natural Gas/Electric	30	53	69	84
Heating Oil/Electric	85	137	169	208

TABLE 8. STOCK DATA OF SPACE HEATING PRODUCTS: FUEL SHARE, CAGR, AND EQUIPMENT SHARE IN CANADA

HEATING SYSTEM STOCK (UNIT)	2017	BOILER FUEL SHARE	CAGR (2013-2017)	EQUIPMENT SHARE
Boiler-oil	1,391,228	14%	1.4%	9%
Boiler-gas	7,392,486	76%	1.5%	48%
Boiler-renewables	1,354,855	20%	0.8%	9%
Boiler-other	149,838	3%	0.9%	1%
HP	798,526		2.4%	5%
ER	4,458,238		0.7%	29%

FIGURE 4. SPACE HEATING STOCK IN CANADA (1990-2017)



Annual shipments for GSHP were assumed to be one-tenth of the shipments reported for the US, and proportional to US stock estimates.[9] ASHP stock was calculated based on GSHP stock estimates, subtracted from total heat pump stock values. A share of 84.5% was assigned for non-condensing boilers. The formulas below describe the calculation process:

$$\text{Cananda GSHP Shipments} = \frac{1}{10} \times US\ GSHP\ Shipments$$

$$\text{Cananda ASHP Shipments} = \text{Canada Total Heat Pump Stock } - \text{Canada G}SHP\ Stock$$

$$\text{Cananda non} - \text{condensing boilders share} = 84.5\% \times Canada\ Boiler\ Stock$$

Where:

$US\ GSHP\ Shipments$ = the annual shipment number of GSHP units in the US;

Canada Total Heat Pump Stock = the total number of heat pump units in Canada (this should include both ASHP and GSHP);

Canada G$SHP\ Stock$ = the calculated stock of GSHP in Canada, based on the proportional assumption for the US stock;

Canada Boiler Stock = the total number of boilers in Canada (for this calculation, this should be available or assumed).

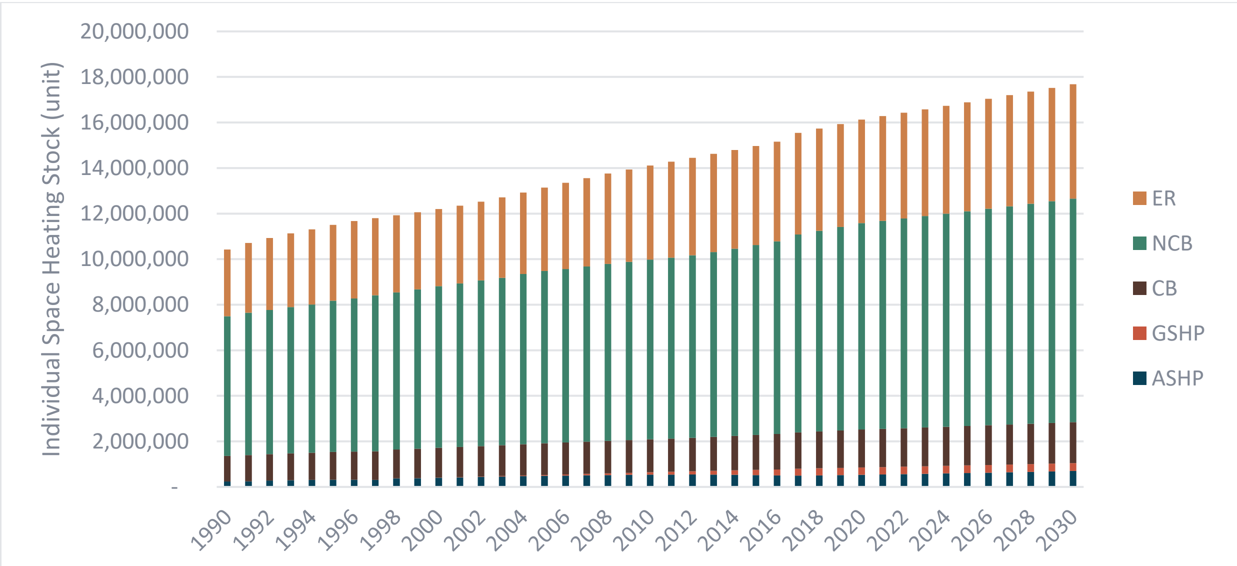
TABLE 9. SPACE HEATING STOCK IN CANADA (1990-2030)

YEAR		GSHP	NCB	CB	ER
1990	239,142	-	1,124,952	6,129,046	2,932,426
1991	245,579	-	1,148,169	6,255,542	3,063,595
1992	278,088	-	1,162,109	6,331,489	3,156,183
1993	291,790	-	1,179,537	6,426,443	3,237,707
1994	310,463	-	1,193,560	6,502,845	3,302,624
1995	315,738	-	1,218,856	6,640,664	3,331,186
1996	315,037	-	1,234,059	6,723,493	3,399,563
1997	307,866	-	1,256,925	6,848,073	3,386,131
1998	371,353	3,576	1,265,991	6,897,468	3,390,836

[9] Lapsa, M., Khowailed, G., Sikes, K., & Baxter, V. (2017). Heat Pumps in North America – 2017 Regional Report / 12th IEA Heat Pump Conference. International Energy Efficiency. http://hpc2017.org/wp-content/uploads/2017/05/P.2.1.3-Heat-Pumps-in-North-America-%E2%80%93-2017-Regional-Report.pdf

YEAR		GSHP	NCB	CB	ER
1999	387,448	7,105	1,284,258	6,996,993	3,382,778
2000	404,761	10,783	1,302,423	7,095,960	3,390,154
2001	421,933	14,382	1,317,831	7,179,904	3,411,102
2002	440,000	18,709	1,334,579	7,271,157	3,457,281
2003	458,318	23,420	1,349,420	7,352,015	3,530,128
2004	475,303	29,698	1,371,026	7,469,730	3,581,319
2005	489,587	38,215	1,388,458	7,564,700	3,661,209
2006	499,445	50,171	1,398,680	7,620,393	3,782,464
2007	510,983	61,483	1,412,207	7,694,094	3,877,849
2008	522,103	73,706	1,425,705	7,767,634	3,973,714
2009	530,546	88,363	1,436,220	7,824,921	4,055,897
2010	537,467	104,427	1,448,615	7,892,457	4,129,046
2011	541,358	122,888	1,458,463	7,946,110	4,209,798
2012	543,528	143,717	1,471,057	8,014,727	4,274,458
2013	542,516	167,890	1,489,244	8,113,810	4,308,123
2014	533,329	195,519	1,509,280	8,222,975	4,329,713
2015	520,558	227,102	1,530,740	8,339,891	4,352,667
2016	504,602	263,204	1,553,070	8,461,557	4,375,839
2017	494,053	304,473	1,595,528	8,692,879	4,458,238
2018	505,744	311,677	1,617,709	8,813,724	4,488,883
2019	517,710	319,052	1,640,208	8,936,304	4,519,739
2020	529,960	326,601	1,663,029	9,060,643	4,550,806
2021	544,931	328,234	1,676,334	9,133,129	4,596,314
2022	560,325	329,875	1,689,744	9,206,194	4,642,277
2023	576,154	331,525	1,703,262	9,279,843	4,688,700
2024	592,430	333,182	1,716,888	9,354,082	4,735,587
2025	609,165	334,848	1,730,624	9,428,915	4,782,943
2026	626,374	336,522	1,744,469	9,504,346	4,830,772
2027	644,069	338,205	1,758,424	9,580,381	4,879,080
2028	662,263	339,896	1,772,492	9,657,024	4,927,871
2029	680,971	341,596	1,786,672	9,734,280	4,977,150
2030	700,208	343,304	1,800,965	9,812,154	5,026,921
CAGR (2020 base)	2.82%	0.50%	0.80%	0.80%	1.00%

FIGURE 5. SPACE HEATING STOCK IN CANADA (1990-2030)



OTHER COUNTRIES

CLASP developed regression models based on the EU-28 dataset and macroeconomic parameters (country-level monthly income, electrification rate, urbanization rate, and number of households) to estimate stock up to 2020 in other countries, as well as for EU-28 countries where historical data for each type of space heating equipment was limited. To capture global variation of space heating needs, CLASP utilized country-level Heating Degree Days at a base temperature of 15.6°C (60.5°F).[10]

The following formula represents the multivariable linear regression model generated for each space heating equipment to stocks and shipments historical estimates for 162 countries from 1950 to 2020. Stock projection up to 2030 for each space heating equipment was done based on CAGR assumptions applied for each space heating equipment, defined for each region as shown in the Table 10.

$$Stock = \Big(\big((a\ HDD) + (b\ Monthly\ income) + (c\ Electrification\ ) + (d\ Urbanization) + (e\ Number\ of\ Households)\big)\Big)$$

TABLE 10. CAGR ASSUMPTIONS FOR STOCK PROJECTION OF SPACE HEATING EQUIPMENT BY REGION

[10] World average degree days database. (n.d.). — KAPSARC Data Portal. https://kapsarc.opendatasoft.com/explore/dataset/world-average-degree-days-database-1964-2013/table/?disjunctive.temperature&disjunctive.country

VARIABLE	UNIT	ASHP	GSHP	CB	NCB	ER
HDD	°C	-1.31E+02	4.27E+01	1.36E+03	-1.75E+02	-3.23E+02
Monthly income	USD	-1.97E+01	-1.48E+00	3.98E+01	6.20E+01	5.52E-01
Electrification ratio	dimensionless	4.09E+05	-1.29E+05	-6.13E+05	-1.59E+06	2.71E+05
Urbanization ratio	dimensionless	3.90E+05	5.53E+04	-3.69E+05	2.11E+06	9.48E+05
Number of households	count	1.19E-02	5.34E-03	8.78E-02	3.70E-01	1.07E-01
Multiple R-squared[11]		0.3060	0.4685	0.7452	0.9578	0.4846
Adjusted R-squared[12]		0.1551	0.3529	0.6899	0.9479	0.3725

CAGR ASSUMPTIONS				
REGION	ASHP	GSHP	BOILERS & FURNACES	ELECTRIC RESISTANCE
Australia	1.0%	0.5%	2.0%	1.3%
Central Asia	0.5%	0.3%	2.0%	1.6%
East Asia	1.5%	0.8%	1.6%	1.6%
Europe	1.0%	0.5%	0.7%	0.6%
Latin America	0.1%	0.1%	0.8%	1.1%
Middle East & North Africa	1.0%	0.5%	0.8%	1.0%
North America - USA	2.8%	0.5%	0.04%	0.4%
North America - Canada	2.8%	0.5%	0.8%	1.0%
Russia	1.0%	0.5%	0.7%	0.6%
South Asia	0.5%	0.3%	2.0%	1.6%
Southeast Asia	0.5%	0.3%	2.0%	1.6%
Sub-Saharan Africa	0.5%	0.3%	2.0%	1.6%

The stock estimates obtained through regression were then adjusted based on specific assumptions:

Space Heating Needs: CLASP assumed there were no space heating needs in countries where the estimated full load hours (calculated from Heating Degree Days, HDD) were

[11] Multiple R-squared value can be used to evaluate how well the regression model fits the dataset, indicating how variance in the predicted variable can be explained by the independent variables. For instance, a value of 0.8 indicates that the model would represent nearly 80% of the variance in the dataset.

[12] Adjusted R-squared presents similar information as multiple R-squared; however, the value is adjusted based on the number of variables present in the model.

below 56 hours. This threshold represents one week's heating duration, assuming 8 hours of heating per day. For these countries, stock estimates were set to zero.

Boiler Type Distribution: A general distribution of boiler types was applied across all countries, based on assumptions by Pezutto et al. for EU-28 countries.[1] This included an 84.5% share for non-condensing boilers and a 15.5% share for condensing boilers.

We further adjusted estimates for China, Russia, and India based on regional or country-level studies and reports, by multiplying the estimated stock with the defined factors as follows:

China:

- Adjusted the calculated ASHP and GSHP stock by a factor of 1/5
- Adjusted the calculated CB and NCB stock by a factor of 3
- Adjusted the calculated ER by a factor of 2
- Distribution of space heating device in percentages used in two zones; (1) DHZ; District Heating Zone, where district heating network is present in the cold and severe cold zones which includes Beijing, Gansu, Hebei, Heilongjiang, Jilin, Liaoning, Ningxia, Qinghai, Shandong, Shanxi, and Tianjin, (2) HSCW; Hot Summer and Cold Winter Zone, which includes Anhui, Chongqing, Gansu, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Shanghai, Sichuan, and Zhe-jiang where even though winter is milder, space heating is still required—based on a residential energy consumption survey in 201513
- General distribution of space heating installations in North and South China with a remark that 50% of the population in North China has no access to district heating[14]
- Stock estimates based on household count in 2016 for the two zones[15]

[13] Hu, S., Yan, D., Guo, S., Cui, Y., & Dong, B. (2017). A survey on energy consumption and energy usage behavior of households and residential building in urban China. Energy and Buildings, 148, 366-378. https://doi.org/10.1016/j.enbuild.2017.03.064. LINK: https://isiarticles.com/bundles/Article/pre/pdf/149423.pdf

[14] Su, C., Madani, H., & Palm, B. (2019). Building heating solutions in China: A spatial techno-economic and environmental analysis. Energy Conversion and Management, 179, 201-218. https://doi.org/10.1016/j.enconman.2018.10.062

[15] National Bureau of Statistics of China. http://data.stats.gov.cn/english/easyquery.htm?cn=E0103 (accessed June 2020)

FIGURE 6. SPACE HEATING DEVICE DISTRIBUTION IN CHINA (DISTRIBUTION HEATING ZONE(DHZ), SAMPLE SIZE =2225; HEATING AND SERVICE CIRCULATION WATER (HSCW), SAMPLE SIZE = 1410)

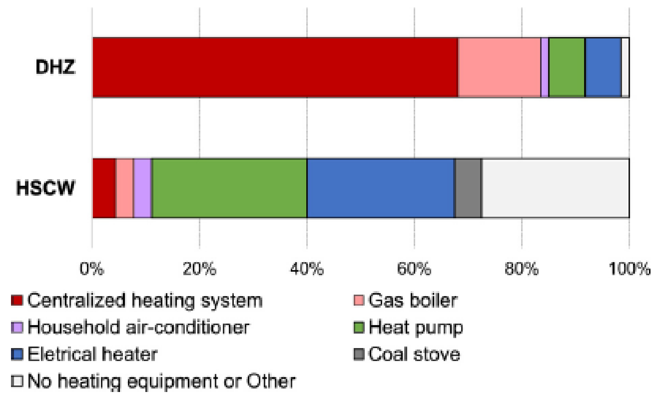
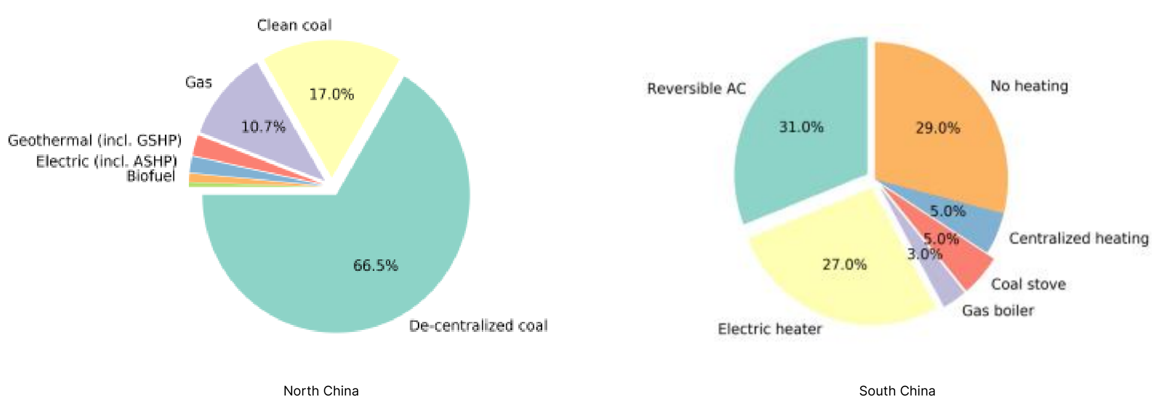


FIGURE 7. GENERAL DISTRIBUTION OF SPACE HEATING INSTALLATIONS IN NORTH AND SOUTH CHINA



Russia:

- Assumed zero stock for ASHP and GSHP
- Assumed over 16 million customers use boilers and stove, at referenced distribution of heating equipment types in residential and commercial sector in 2017[16]

[16] Aquatherm Moscow. HVAC Market in Russia. 2017. https://www.aquatherm-moscow.ru/content/dam/sitebuilder/rxru/aquatherm-moscow/docs/HVAC_market_in_Russia.pdf

India:

- Assumed zero stock for ASHP and GSHP
- Multiplied the calculated stock of ER by a factor of 1/5
- Information on three types of heating equipment used in Kashmir; biomass stoves, LPG radiant heater, electric heater17

General assumptions cited in a modeling effort:

- 10% penetration of electric heater, total number of households located in each severe and moderate winter region.
- Assumed 8 hours of operation per day.18

3. Unit Energy Consumption, Usage, and Standards Scenarios

UNIT ENERGY CONSUMPTION (UEC)

CLASP assigned average capacity, equivalent full load hours, and operating efficiency for each space heating equipment to calculate UECs.

$$UEC = \frac{Capacity \times Equivalent\ full\ load\ hour}{Operating\ efficiency}$$

Where capacity is in the unit of kW, equivalent full load hour in the unit of hour, and operating efficiency as a dimensionless factor.

Assumptions for each parameter are listed below:

- Capacity in kW
    - EU-28 countries, individual country values as reported in Pezutto et al.[1] open data source
    - Remaining countries, the EU-28 average capacity applied to all countries
        - ASHP 5.37 kW
        - GSHP 12.14 kW
        - CB 25.5 kW
        - NCB 25.5 kW
        - ER 9.76 kW

[17] H. A. Bhat MSc & S. Rubab (2008) Financial evaluation of different space heating options used in the Kashmir valley, International Journal of Ambient Energy, 29:2, 75-82, DOI: 10.1080/01430750.2008.9675060

[18] Sivasakthivel, T., Murugesan, K., & Sahoo, P. (2012). Potential reduction in CO2 emission and saving in electricity by ground source heat pump system for space heating Applications-A study on northern part of India. Procedia Engineering, 38, 970-979.
https://doi.org/10.1016/j.proeng.2012.06.123.
https://www.sciencedirect.com/science/article/pii/S187770581202036X

- Exceptions
    - USA, Canada / ASHP 10 kW
    - USA, Canada / GSHP 15 kW
    - USA / CB & NCB 30 kW
    - USA / ER 10 kW
    - Russia / ER 5 kW
    - India / ER 5 kW
    - India / CB & NCB 15 kW
    - China / ER 6.5 kW

- Operating efficiency
  - EU-28 countries, single values as reported in Pezutto et al. open data source
    - ASHP 3.65
    - GSHP 4.58
    - CB 0.92
    - NCB 0.82
    - ER 0.98915

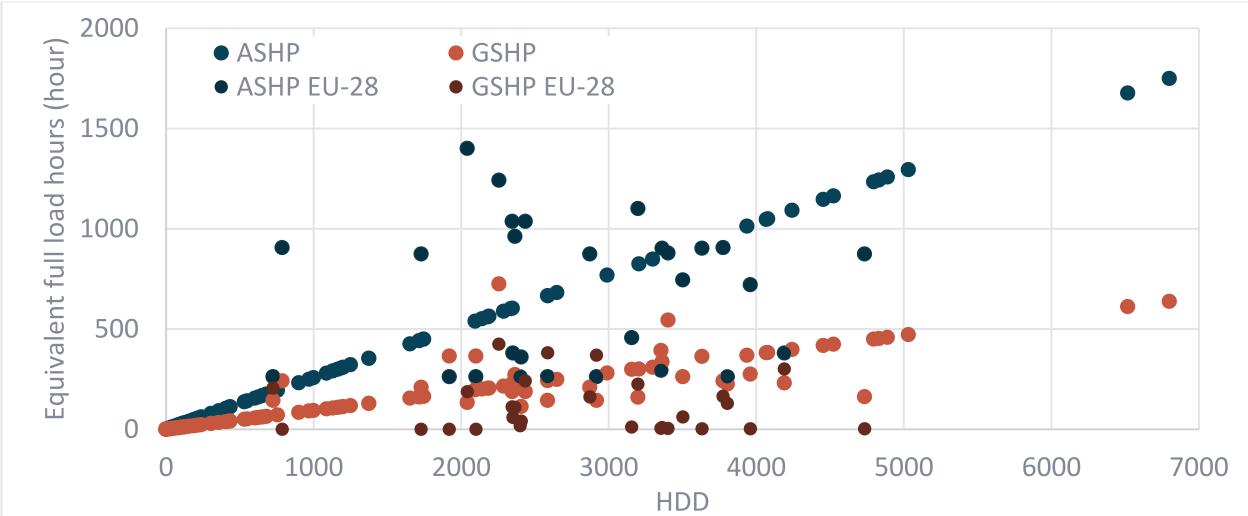
- Equivalent full hours
  - EU countries, individual country values as reported in Pezutto et al. open data source
  - Remaining countries, linear regression model as a function of HDD

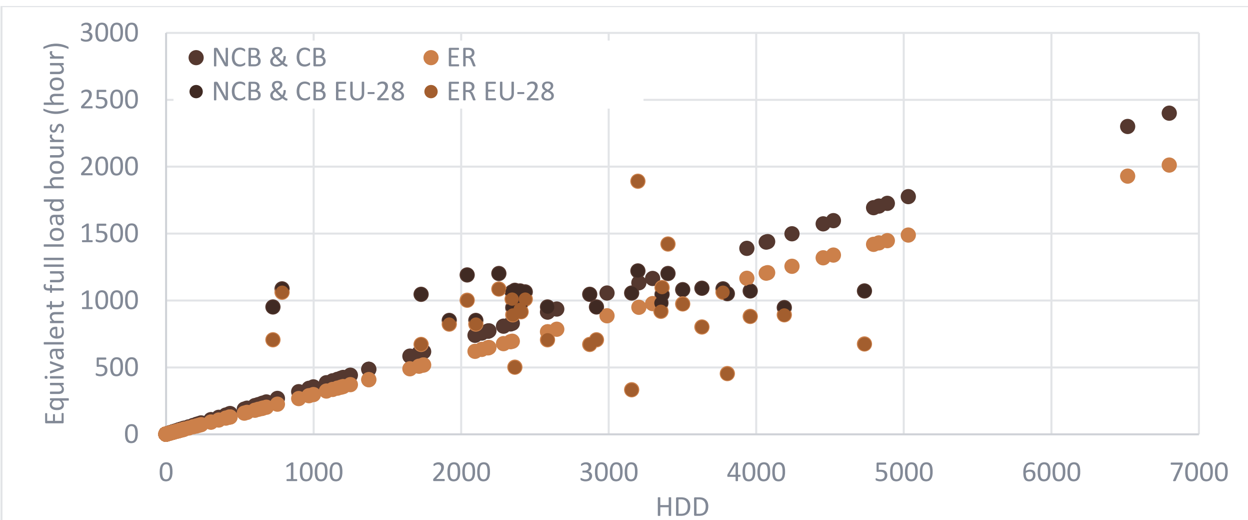
$$Equivalent\ full\ load\ hour = a\ HDD$$

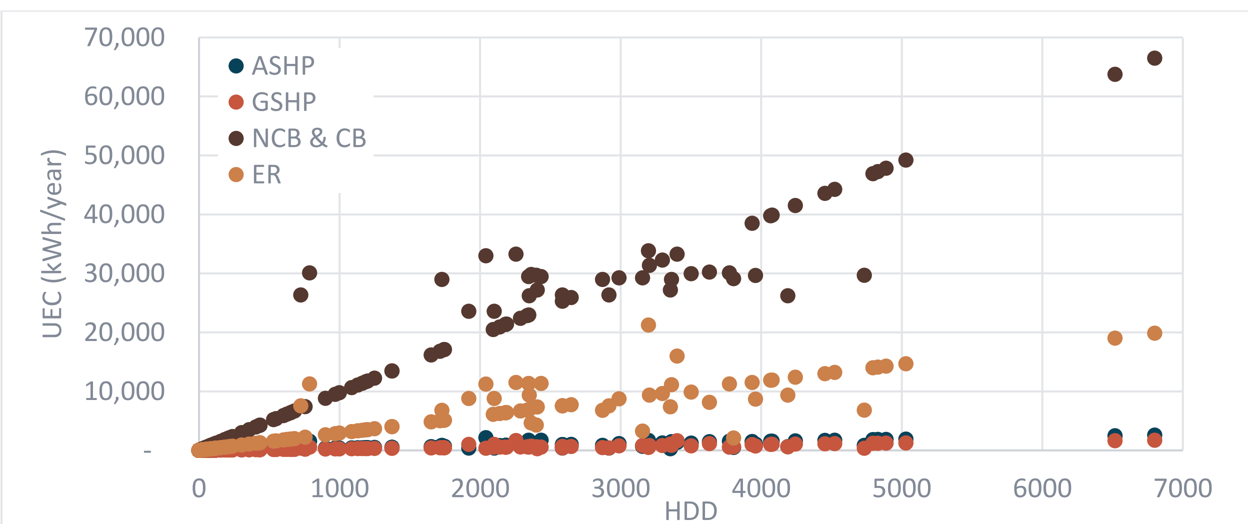
TABLE 11. SUMMARY OF REGRESSION ANALYSIS

VARIABLE	UNIT	ASHP	GSHP	CB	NCB	ER
HDD	degC	0.2574	0.0938	0.3527	0.3527	0.2957
Multiple R-squared		0.8953	0.8293	0.9374	0.9374	0.8482
Adjusted R-squared		0.8915	0.8230	0.9351	0.9351	0.8426

The equivalent full load hours for different types of space heating equipment are plotted below for the EU-28 and 162 other countries. The subsequent figure illustrates the resulting Unit Energy Consumption (UECs) across all 162 countries.







Potential impacts in fuel share distribution were also estimated in this model, based on the defined national energy shares of fuel types used in each space heating equipment.

The fuel types considered for Non-Condensing Boilers (NCB) and Condensing Boilers (CB) include coal, gas (natural gas, propane, and LPG), oil (various types of distillate fuel oils), renewables, and other fuels not included in these categories. Air Source Heat Pumps (ASHP), Ground Source Heat Pumps (GSHP), and Electric Resistance (ER) heating systems were assumed to be powered by electricity.

The Unit Energy Consumption (UEC) values, measured in kWh/year, represent the total energy consumption of each respective fuel type.

Based on the defined fuel shares, the model calculation sequence was applied to these six space heating fuel types. The results were then aggregated in the final calculation step to identify shifts in fuel use distribution. Specific fuel shares were assigned to NCB and CB for key countries, which were designated as representative for the regions listed in the tables below.

TABLE 12. FUEL SHARES FOR NCB AND CB ASSIGNED TO KEY COUNTRIES AND REPRESENTATIVE REGIONS

	COAL	GAS	OIL	OTHER	RENEWABLES
EU28-Pezutto_CB (country-specific)	0%	66%	34%	0%	0%
EU28-Pezutto_NCB (country-specific)	2%	54%	38%	0%	5%
China_NCB	18%	82%	0%	0%	0%
China_CB	0%	100%	0%	0%	0%
India_NCB	2%	1%	17%	0%	80%
India_CB	0%	6%	94%	0%	0%
USA_NCB	0%	83%	17%	0%	0%
USA_CB	0%	83%	17%	0%	0%
CAN_NCB	0%	66%	9%	0%	24%
CAN_CB	0%	87%	13%	0%	0%
RUS_NCB	14%	74%	0%	0%	12%
RUS_CB	0%	100%	0%	0%	0%
Indonesia_NCB	0%	100%	0%	0%	0%
Indonesia_CB	0%	100%	0%	0%	0%

COUNTRY	ISO A3	ASSUMPTION	REGION
Australia	AUS	EU28-Pezutto	Australia
Iran (Islamic Republic of)	IRN	EU28-Pezutto	Central Asia
China	CHN	China	East Asia
Japan	JPN	EU28-Pezutto	East Asia
Republic of Korea	KOR	EU28-Pezutto	East Asia
Albania	ALB	EU28-Pezutto	Europe

Armenia	ARM	EU28-Pezutto	Europe
Bosnia and Herzegovina	BIH	EU28-Pezutto	Europe
Iceland	ISL	EU28-Pezutto	Europe
North Macedonia	MKD	EU28-Pezutto	Europe
Norway	NOR	EU28-Pezutto	Europe
Republic of Moldova	MDA	EU28-Pezutto	Europe
Switzerland	CHE	EU28-Pezutto	Europe
Ukraine	UKR	EU28-Pezutto	Europe
Brazil	BRA	EU28-Pezutto	Latin America
Turkey	TUR	EU28-Pezutto	Middle East & North Africa
Canada	CAN	CAN	North America
United States of America	USA	USA	North America
Russian Federation	RUS	RUS	Russia
India	IND	India	South Asia
Indonesia	IDN	Indonesia	Southeast Asia
South Africa	ZAF	EU28-Pezutto	Sub-saharan Africa

BASELINE AND EFFICIENT SCENARIOS

Due to the model complexity, Mepsy sets the default market shift trend of each technology under three scenarios:

- **Business-as-usual scenario**, representing business-as-usual case
- **Global Benchmark (GB) scenario**: Heat pumps replace 25% of electric resistance and 40% of boilers/furnaces by 2050.
- **Net Zero Hero (NZH) scenario**: Deployment of high efficiency technologies, causing the market shift of the projected demand for gas boilers.

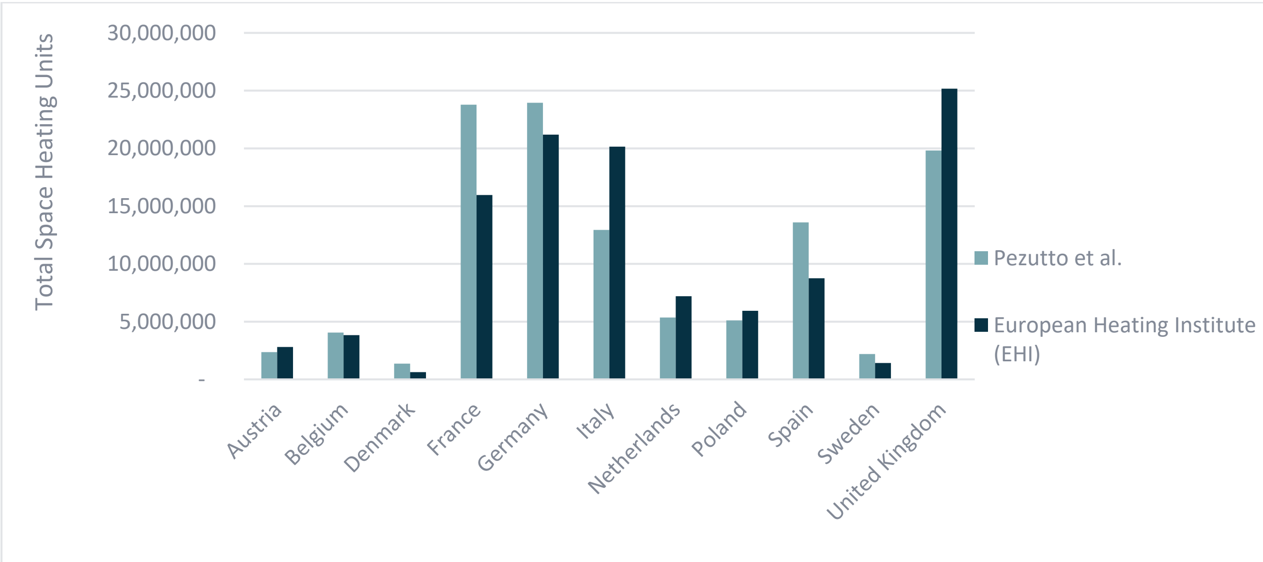
4. Model Outputs and Validation

Comparative Analysis

Stock projections for other countries were based on available country-level data for year 2019 from Pezutto et al.'s study.[1] These stock projections are comparable to those generated by the European Heating Industry (EHI),[19] an industry association which publishes annual data gathered directly from industry participants. The following figure offers a comparison of EHI space heating stock reports to the estimates provided by Pezutto.

[19] "Heating Market Report M," EHI, accessed January 16, 2025, https://ehi.eu/heating-market-report/.

FIGURE 8. STOCK COMPARIONS BETWEEN EHI AND PEZUTTO



Pezutto et al. reports that total energy consumption in the EU-28 for space heating was 3315 TWh and domestic hot water, was580 TWh, combined at 3880 TWh. Comparison with other notable space heating and domestic hot water energy consumption at EU-28 level was provided by Pezutto et al., summarized below:

- In close range with deviation from 3 to 6%
  - H2020 project, HRE4 — 4025 TWh
  - Partonen et al. (2012) — 3980 TWh
  - IEE STRATEGO project — 4150 TWh
- Lower estimates, with deviation from 12 to 47%
  - Boermans et al. (2012) — 3400 TWh
  - The 7th Framework Programme (FP7) iNSPiRe project — 2760 TWh
  - Von Manteu et al. (2016) — 2070 TWh
- Higher estimates, with deviation from 13 to 35%
  - Sanner et al. (2011) — 4450 TWh
  - Scoccia et al. (2018) — 4715 TWh
  - Balaras et al. (2007) — 5990 TWh

Final energy consumption for space heating end-use in residential buildings is also reported in two IEA publications. The following comparison was done using the available data from IEA's 2017 Energy Technology Perspective (ETP) and 2020 Energy Efficiency Indicator report.[20,21]

[20] International Energy Agency, Energy Technology Perspectives 2017 - www.iea.org/etp2017

[21] International Energy Agency, Energy Efficiency Indicators Statistics Report – June 2020. https://www.iea.org/reports/energy-efficiency-indicators-2020

Provided in the following figure is the comparison of the energy consumption values for the key countries available in **IEA's 2017 ETP report.** The report provides projections for three scenarios in energy use:

- Reference Technology Scenario, taking into account today's commitments and recent trends;
- 2°C Scenario, where trajectories align to limit global temperature increase of 2°C by 2011;
- Beyond 2C Scenario, representing further "technology push" to limit temperature increase to 1.75°C. Values for residential and services sectors are grouped under buildings.

FIGURE 9. COMPARISON OF SPACE HEATING ENERGY CONSUMPTION (TWH): MEPSY VS. OTHER DATA SOURCES IN EU, USA, RUSSIA AND CHINA

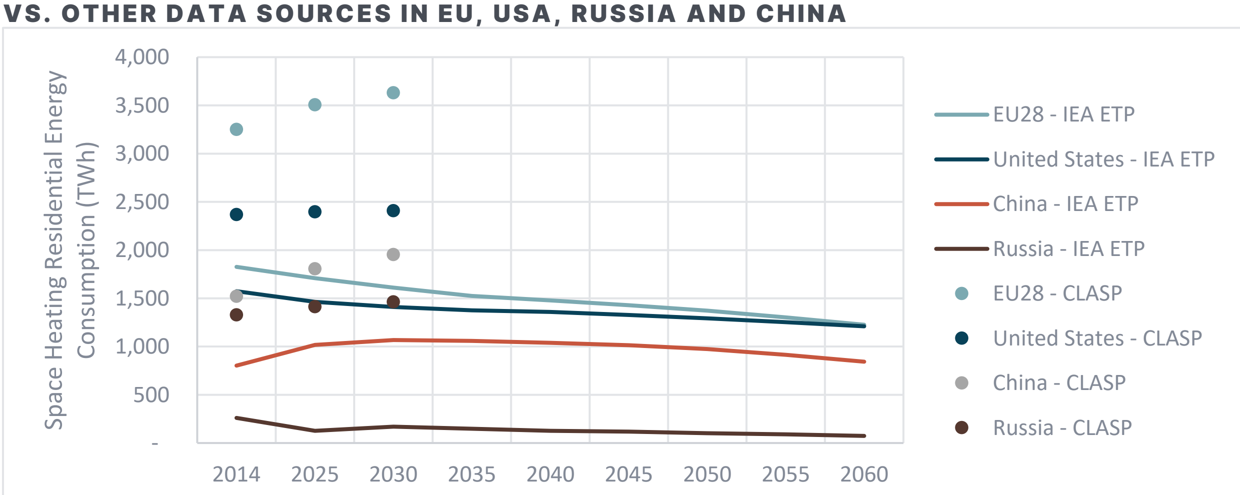
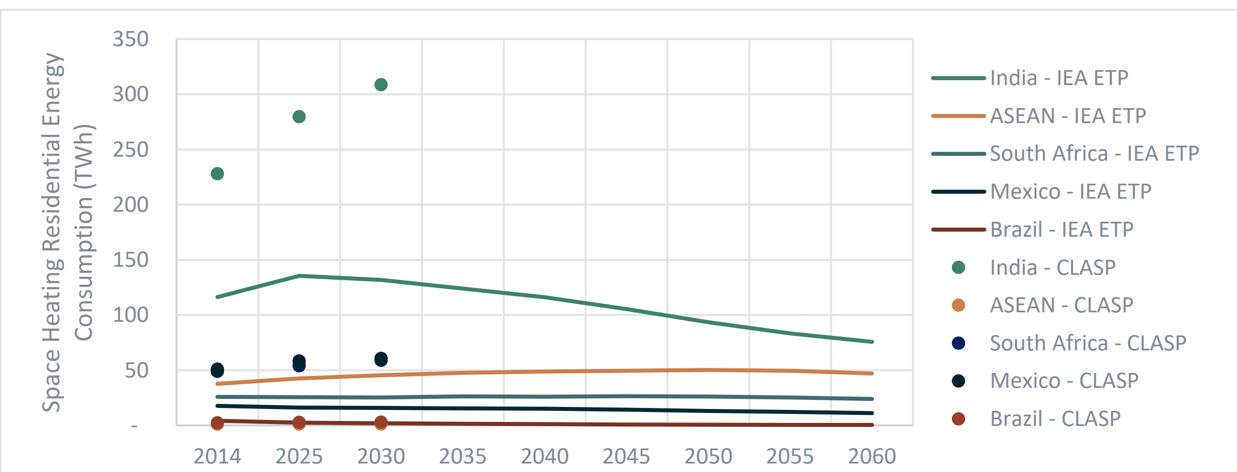
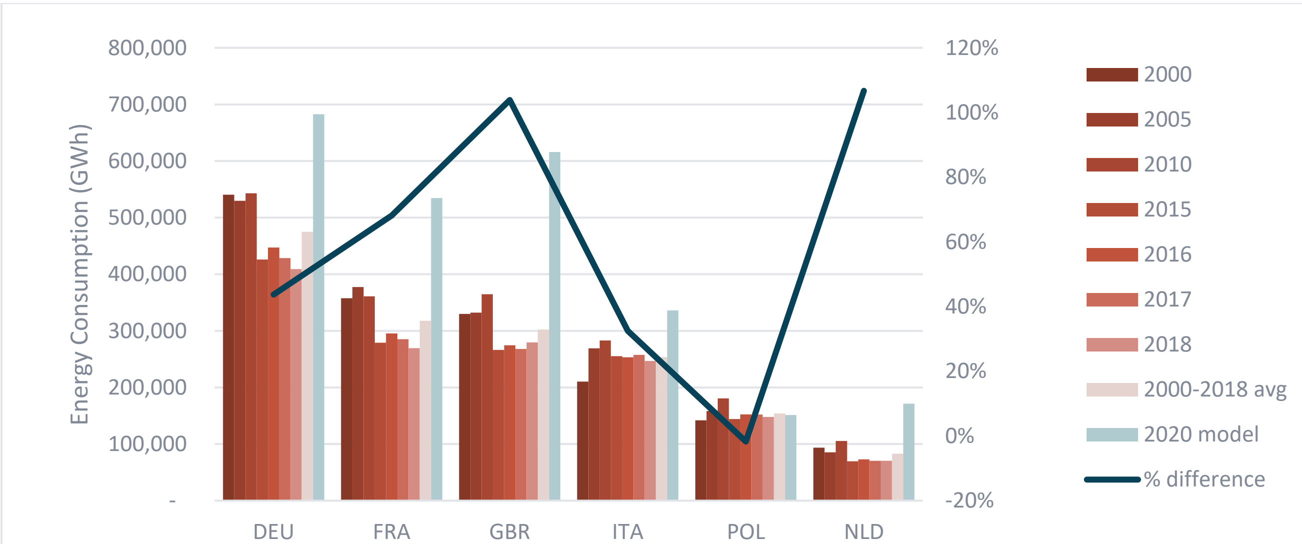


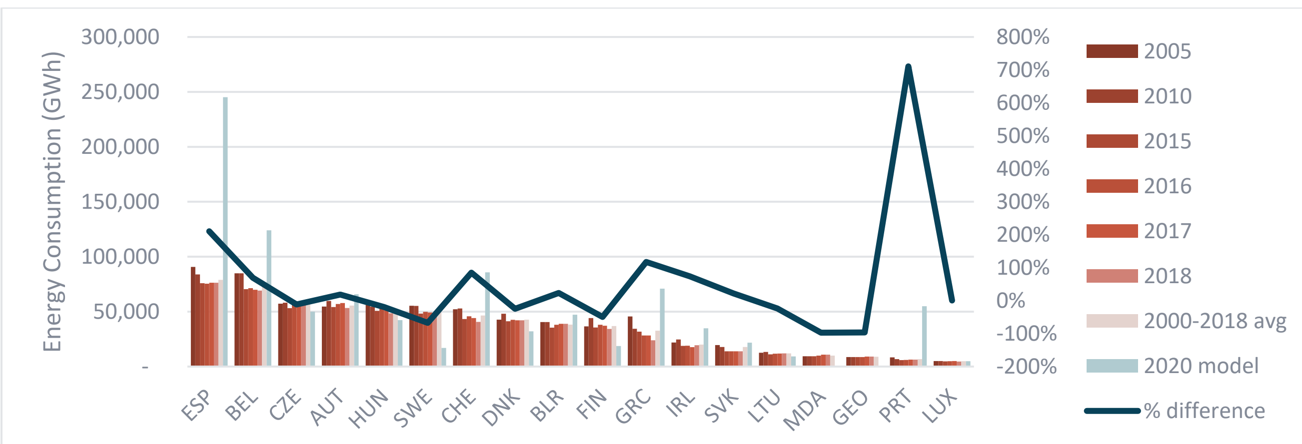
FIGURE 10. COMPARISON OF SPACE HEATING ENERGY CONSUMPTION (TWH): MEPSY VS. OTHER DATA SOURCES IN INDIA, ASEAN REGION, MEXIO AND BRAZIL

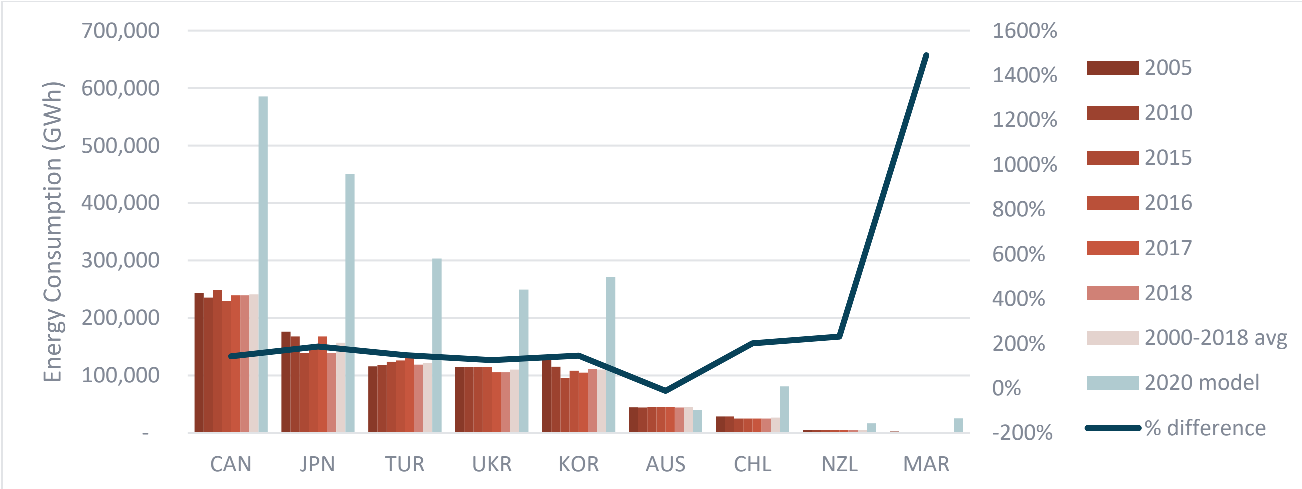


Provided in the following figures are the comparison for 34 countries, reported in IEA's 2020 Energy Efficiency Indicator statistics report.

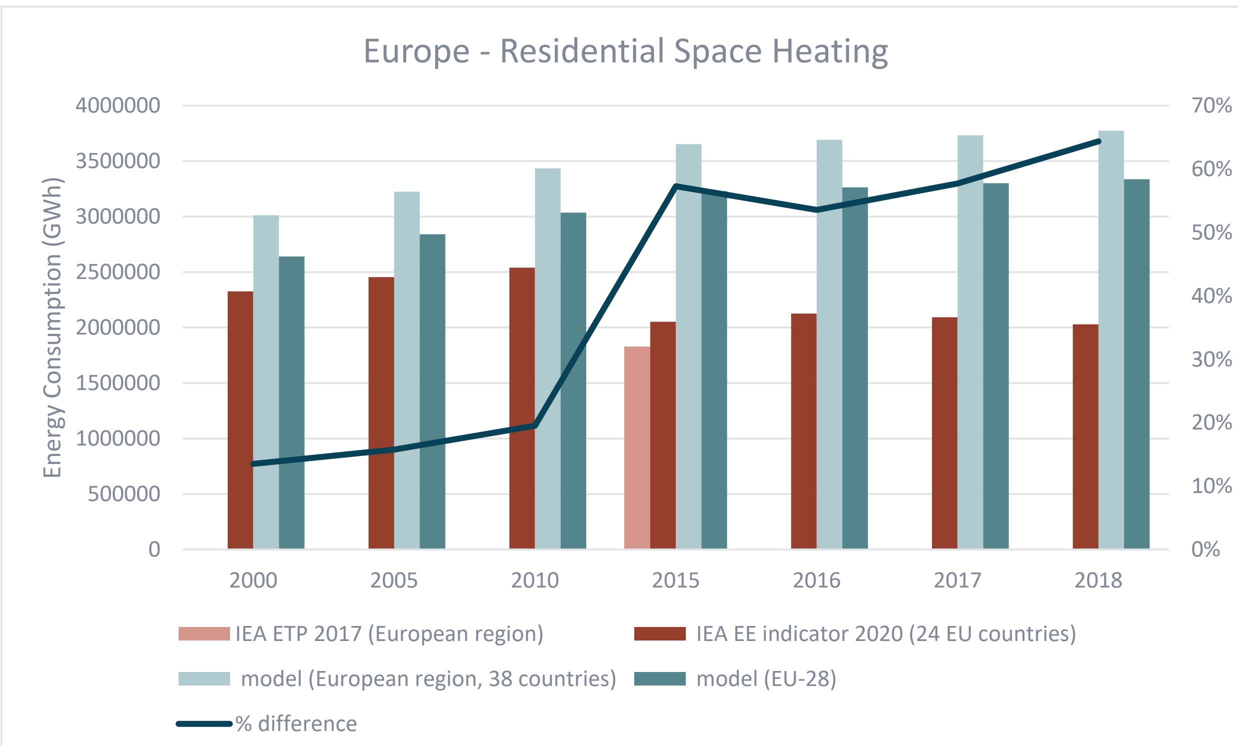
FIGURE 11. ENERGY CONSUMPTION RESULTS COMPARISON FOR 34 COUNTRIES



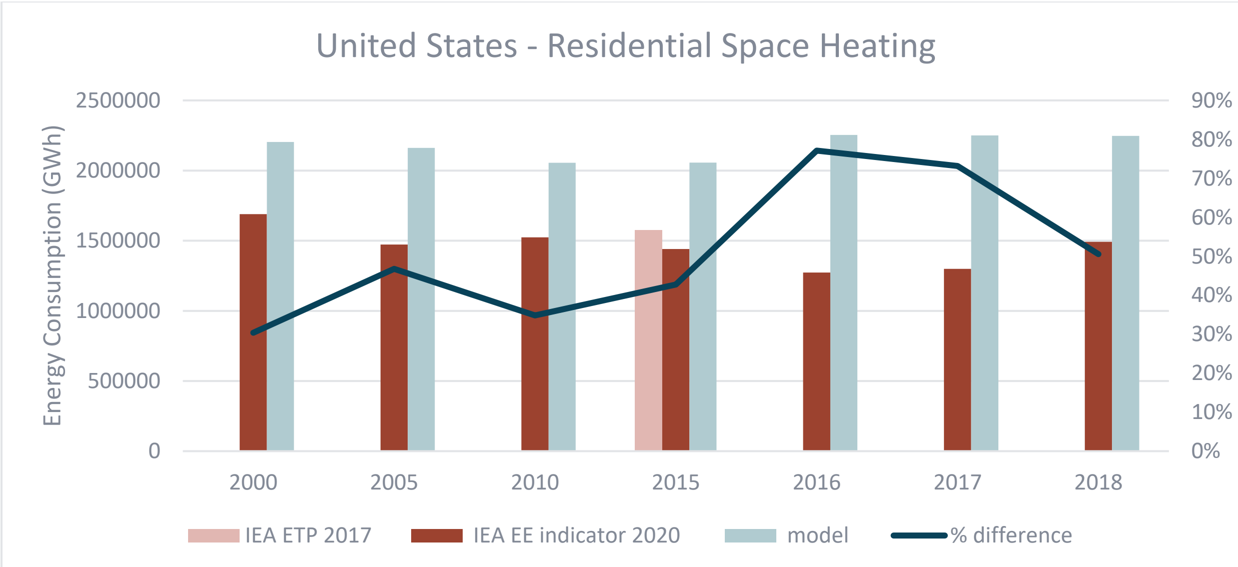




Energy Consumption (GWh)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
-
CAN
JPN
TUR
UKR
KOR
AUS
CHL
NZL
MAR
1600%
1400%
1200%
1000%
800%
600%
400%
200%
0%
-200%
2005
2010
2015
2016
2017
2018
2000-2018 avg
2020 model
% difference



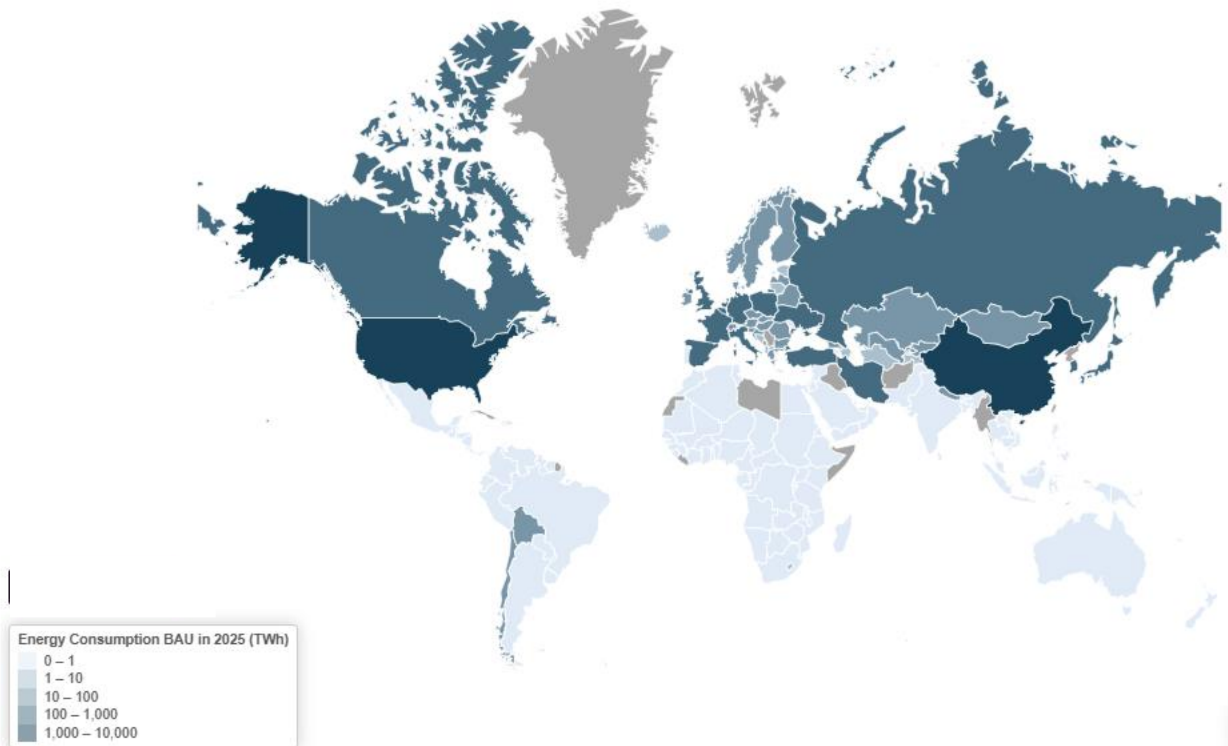
Europe - Residential Space Heating
Energy Consumption (GWh)
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
70%
60%
50%
40%
30%
20%
10%
0%
2000
2005
2010
2015
2016
2017
2018
IEA ETP 2017 (European region)
IEA EE indicator 2020 (24 EU countries)
model (European region, 38 countries)
model (EU-28)
% difference


United States - Residential Space Heating
Energy Consumption (GWh)
2500000
2000000
1500000
1000000
500000
0
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2000
2005
2010
2015
2016
2017
2018
IEA ETP 2017
IEA EE indicator 2020
model
% difference

Model Outputs

The map below illustrates the distribution of energy consumption (in GWh) under the BAU scenario for the year 2025.

FIGURE 12. SPACE HEATING ENERGY CONSUMPTION IN GWH UNDER BAU SCENARIO IN 2025



EMISSIONS FACTOR FOR SPACE HEATING

TABLE 13. EMISSION FACTOR FOR DIFFERENT TYPES OF SPACE HEATING (ASSUMPTIONS APPLY AS TABULATED BELOW FOR EACH PRODUCT TYPE)

PRODUCT TYPE	ENERGY SOURCE	EMISSION FACTOR	SOURCE
Air Source Heat Pump (ASHP)	Grid electricity	Country-level, based on Mepsy's default inputs	International Financial Institutions Technical Working Group (IFI TWG) "Harmonized Grid Emission Factor Data", 2019 GCAM's assumption—extended to 2060 using the assumption offered by Robbie Orvis "decreasing by roughly 0.02-0.022 (5-6%) every 5 years."
Ground Source Heat	Grid electricity	Country-level, based on Mepsy's default inputs	International Financial Institutions Technical Working Group (IFI TWG) "Harmonized Grid Emission Factor Data", 2019

Pump (GSHP)			GCAM's assumption—extended to 2060 using the assumption offered by Robbie Orvis "decreasing by roughly 0.02-0.022 (5-6%) every 5 years."
Condensing Boiler (CB)	Mixed fuel – share of coal, gas, fuel oil, renewables, and other fuel types outside the available categories	Unit: kgCO2/kWh-eq Coal: 0.349 Gas: 0.181 Fuel oil: 0.250 Renewables (biomass): 0.292 Other fuel types: 0.320	National Accounting - Table II. Carbon Conversion Factors for Fuels. (n.d.). Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (1997), IPCC/OECD/IEA, Paris. https://www.sciencedirect.com/topics/earth-and-planetary-sciences/national-accounting
Non-Condensing Boiler (NCB)	Mixed fuel – share of coal, gas, fuel oil, renewables, and other fuel types outside the available categories	Unit: kgCO2/kWh-eq Coal: 0.349 Gas: 0.181 Fuel oil: 0.250 Renewables (biomass): 0.292 Other fuel types: 0.320	National Accounting - Table II. Carbon Conversion Factors for Fuels. (n.d.). Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (1997), IPCC/OECD/IEA, Paris. https://www.sciencedirect.com/topics/earth-and-planetary-sciences/national-accounting
Electric Resistance (ER)	Grid electricity	Country-level, based on Mepsy's default inputs	International Financial Institutions Technical Working Group (IFI TWG) "Harmonized Grid Emission Factor Data", 2019 GCAM's assumption—extended to 2060 using the assumption offered by Robbie Orvis "decreasing by roughly 0.02-0.022 (5-6%) every 5 years."

Glossary

ASHP (Air Source Heat Pump): A type of heat pump that uses outside air to heat a building.

BAU (Business-As-Usual): A scenario that assumes no changes in lighting or appliance policies between 2020 and 2030, reflecting current trends without additional interventions.

CB (Condensing Boiler): A type of boiler that recycles heat from exhaust gases to improve efficiency.

CAGR (Compound Annual Growth Rate): The rate of return (or growth rate) that would be required for an investment to grow from its beginning balance to its ending balance, assuming the profits were reinvested at the end of each period of the investment's life span.

CO2 (Carbon Dioxide): A greenhouse gas produced by burning fossil fuels and through other industrial processes.

ER (Electric Resistance): A type of heating that directly converts electrical energy into heat.

GB (Global Benchmark) Scenario: The global benchmarks are those efficiency levels recommended by CLASP and others such as United for Efficiency. These levels are generally considered to be quite ambitious.

GSHP (Ground Source Heat Pump): A heat pump that uses the ground as a heat source or sink for heating and cooling a building.

HDD (Heating Degree Days): A measurement designed to reflect the demand for energy needed to heat a building.

HSCW (Hot Summer and Cold Winter Zone): A region classification for China where winter is milder but heating is still required.

IEA (International Energy Agency): An autonomous agency that provides policy advice, data, and analysis to promote energy security, economic growth, and environmental sustainability.

MEPSY: CLASP's tool that provides energy and emissions assessments for space heating equipment.

NCB (Non-Condensing Boiler): A type of boiler that does not recycle heat from exhaust gases, leading to lower efficiency than condensing boilers.

Net Zero Hero (NZH) Scenario: This is a high-ambition policy scenario. This scenario aligns with the targets outlined in the Net Zero Heroes report published by CLASP in 2023, which calls for doubling the efficiency of ten key appliances.

RECS (Residential Energy Consumption Survey): A survey conducted by the U.S. Energy Information Administration (EIA) that collects data on residential energy use in the U.S.

UEC (Unit Energy Consumption): A metric used to estimate the energy consumption per unit of space heating equipment.

US AHRI (U.S. Air-Conditioning, Heating, and Refrigeration Institute): An organization that provides performance data for heating, ventilation, and air conditioning (HVAC) equipment.

US EIA (U.S. Energy Information Administration): A federal agency that collects, analyzes, and disseminates energy-related data.

Zoning (DHZ, HSCW): The classification of different areas based on climate and space heating requirements (District Heating Zone and Hot Summer and Cold Winter Zone for China).

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