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Price Elasticity for Energy Use in Buildings in the United States

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Introduction

Within the U.S. Energy Information Administration's (EIA) National Energy Modeling System (NEMS), the Residential Demand Module (RDM) and Commercial Demand Module (CDM) are two separate modules that are used to project energy consumption in the residential and commercial sectors. Despite similarities between these models, they differ in terms of equipment technology choice and internal accounting.[1]

This report explains the responses in the *Annual Energy Outlook 2020* (AEO2020) version of the NEMS RDM and CDM to changes in delivered energy prices. The economic concept is known as *price elasticity of demand*, or the percentage change in energy consumption relative to the percentage change in prices, all other factors being equal. In general, an increase in a fuel price causes consumers to use less of that fuel or switch to a different fuel. The extent to which each of these changes takes place is useful to stakeholders in the energy sector and, particularly, in energy policy design.

The NEMS residential and commercial models can provide both short-run and long-run responses to energy price changes.[2] Short-run responses to price changes are more behavioral and temporary in nature and may affect energy consumption of energy-using appliances or equipment. An example of a short-run response would be a building occupant adjusting the thermostat during cold or hot weather in response to high energy bills, leading to lower energy demand for heating or cooling. Long-run elasticities are driven by stock turnover and by technology choices for major fuels and major end uses, and they usually take place over a longer time period. For example, installing a more efficient space conditioning system or upgrading windows in a building.

To estimate responses to energy price changes, this analysis considers a series of simulations performed by adjusting the energy price paths from the AEO2020 Reference case. Only the buildings[3] modules are used in these simulations; integrated effects with the rest of NEMS are not included.[4] The elasticities computed from the NEMS projections reflect the results of statistical analyses of historical energy price and consumption data, along with expert judgment. The three main energy sources for the commercial and residential sectors are electricity, natural gas, and distillate. To compute the price elasticities, for each simulation, the price of one of these energy sources is doubled.

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[1] For detailed information on both models, see U.S. Energy Information Administration (EIA), *Model Documentation Report: Commercial Sector Demand Module of the National Energy Modeling System*, DOE/EIA-M066; and *Model Documentation Report: Residential Sector Demand Module of the National Energy Modeling System*, DOE/EIA-M067. For modeling assumptions and general techniques, see EIA, *Assumptions to AEO2020*.

[2] In economics, the short run is generally defined as a period over which capital stock remains fixed. Because the typical service lifetime of installed capital can vary among economic sectors, energy end uses, and equipment types, no single definition differentiates between short run and long run.

[3] Throughout the paper "buildings" or "buildings sector" refer to the residential and commercial demand sectors.

[4] NEMS is an integrated, modular system where fuel prices and energy demand interact until an equilibrium is met for the entire system for each model year. In the buildings modules of NEMS, energy demand equilibrates to fuel prices from other modules. Although year-to-year changes in fuel price have the biggest effect on energy demand during the year in which they occur, the full effect of fuel price change is also spread over the following two years to prevent unrealistic demand responses to price spikes of one year or other short-term durations. Table 1 and Table 2 present elasticity results for Years 1–3, where Year 1 in the model is when the simulated price change from the Reference case was programmed to take place and Year 2 and Year 3 are the two following years (Year 1 corresponds to 2020 in the model).

Own-Price and Cross-Price Elasticities

The two types of fuel price elasticity presented in this report are own-price and cross-price elasticities. Own-price elasticity refers to changes in consumption of a particular fuel when the price for that fuel changes (for example, electricity use changes when electricity price changes), and cross-price elasticity refers to changes in consumption of a particular fuel when the price of a different fuel changes (for example, the change in electricity use when the price of natural gas changes). Own-price elasticities are usually negative—indicating that fuel consumption goes down as the price of that fuel goes up—and cross-price elasticities are usually positive—consumption of a fuel goes up when the price of a competing or substitute fuel goes up. Price responses are considered to be *elastic* if the absolute value of the price elasticity is greater than one (the proportionate change in energy consumption is greater than the proportionate change in price). The absolute value of the price elasticity of energy is generally less than one, in other words, *inelastic* (the proportionate change in energy consumption is less than the proportionate change in price).

Table 1 and Table 2 present the estimated own-price and cross-price elasticities, respectively. The estimates are based on simulations where a single fuel price is doubled in the AEO2020 Reference case for all years.[5] The price doubling adjustments start in 2020 and continue through the end of model projections in 2050 (Year 30). By assumption, short-run price responses occur over a three-year interval (that is, the first three years of price changes). Long-run price responses refer to consumption changes in 2050. The elasticity results presented in the report show the percentage change in fuel use for every 1.0% increase in fuel price. For example, in Table 1, a 1.0% increase in electricity price results in a 0.13% decrease in electricity use in Year 1.[6]

[5] Elasticity calculations are based on simulations where a single fuel price is doubled. However, calculated elasticities would be different if different price paths were used. For example, the attached Appendix (Table 5 and Table 6) shows the elasticities that result if individual fuel prices are divided in half instead of doubled. The differences between the two sets of elasticities are caused by existing market conditions and consumer preferences in the buildings sector.
[6] Elasticities are computed using the following expression: ln (Q1/Q0)/ln (P1/P0), where P0 and Q0 are base prices and quantities, and P1 and Q1 represent an alternative price-quantity combination.

Table 1. Own-price elasticities in AEO2020 Residential Demand Module and Commercial Demand Module

	Short run			Long run
	Year 1	Year 2	Year 3	Year 30
Residential				
Electricity	-0.13	-0.22	-0.26	-0.50
Natural gas	-0.08	-0.13	-0.15	-0.23
Distillate fuel	-0.09	-0.16	-0.19	-0.24
Commercial				
Electricity	-0.08	-0.13	-0.15	-0.18
Natural gas	-0.03	-0.18	-0.25	-0.28
Distillate fuel	-0.13	-0.22	-0.26	-0.30

Table 1 shows that the commercial sector contains larger long-run own-price elasticities than the residential sector for fossil fuel. The largest energy demand changes in the long run occur in the residential sector in response to electricity prices. The large long-run own-price elasticity for residential delivered electricity is partly explained by increases in distributed generation (DG), particularly solar photovoltaic. Short-run elasticities range from -0.03 to -0.13 in Year 1 and from -0.15 to -0.26 in Year 3. Long-run elasticities at Year 30 ranged from -0.18 to -0.50.

Table 2 shows that long-run cross-price elasticities are lower, in absolute value, than own-price elasticities for all three fuels. In both sectors, the highest cross-price elasticities are between natural gas and electricity, perhaps because of conversions from electric to natural gas heating systems.

Table 2. Cross-price elasticities in AEO2020 Residential Demand Module and Commercial Demand Module

(Long run, Year 30)

		Change in fuel price		
		Electricity	Natural gas	Distillate
Change in fuel use	**Residential**			
	Electricity	--	0.03	0.00
	Natural gas	0.10	--	0.01
	Distillate fuel	0.02	0.02	--
	Commercial			
	Electricity	--	0.01	0.00
	Natural gas	0.04	--	0.01
	Distillate fuel	0.00	0.01	--

Energy price elasticities also vary across end uses and fuels (Table 3). Based on the hypothetical doubling of prices, electricity price elasticities exceed natural gas elasticities in both sectors. For the reported end uses, own-price elasticities vary from -0.08 for residential natural gas space conditioning and water heating in the short run to -0.93 for residential electric water heaters in the long run.

Table 3. Own-price elasticities in AEO2020 Residential Demand Module and Commercial Demand Module for selected end uses

	Short run		Long run	
	Year 1	Year 2	Year 3	Year 30
Commercial electricity				
Space heating	-0.14	-0.23	-0.28	-0.41
Space cooling	-0.14	-0.23	-0.27	-0.39
Water heating	-0.15	-0.25	-0.31	-0.60
Commercial natural gas				
Space heating	-0.13	-0.22	-0.26	-0.30
Space cooling	-0.12	-0.21	-0.25	-0.28
Water heating	-0.13	-0.22	-0.26	-0.28
Residential electricity				
Space heating	-0.16	-0.27	-0.33	-0.48
Space cooling	-0.17	-0.29	-0.34	-0.66
Water heating	-0.17	-0.31	-0.38	-0.93
Residential natural gas				
Space heating	-0.08	-0.13	-0.15	-0.21
Space cooling	-0.08	-0.14	-0.16	-0.16
Water heating	-0.08	-0.14	-0.17	-0.31

Energy Consumption in Selected Price Cases

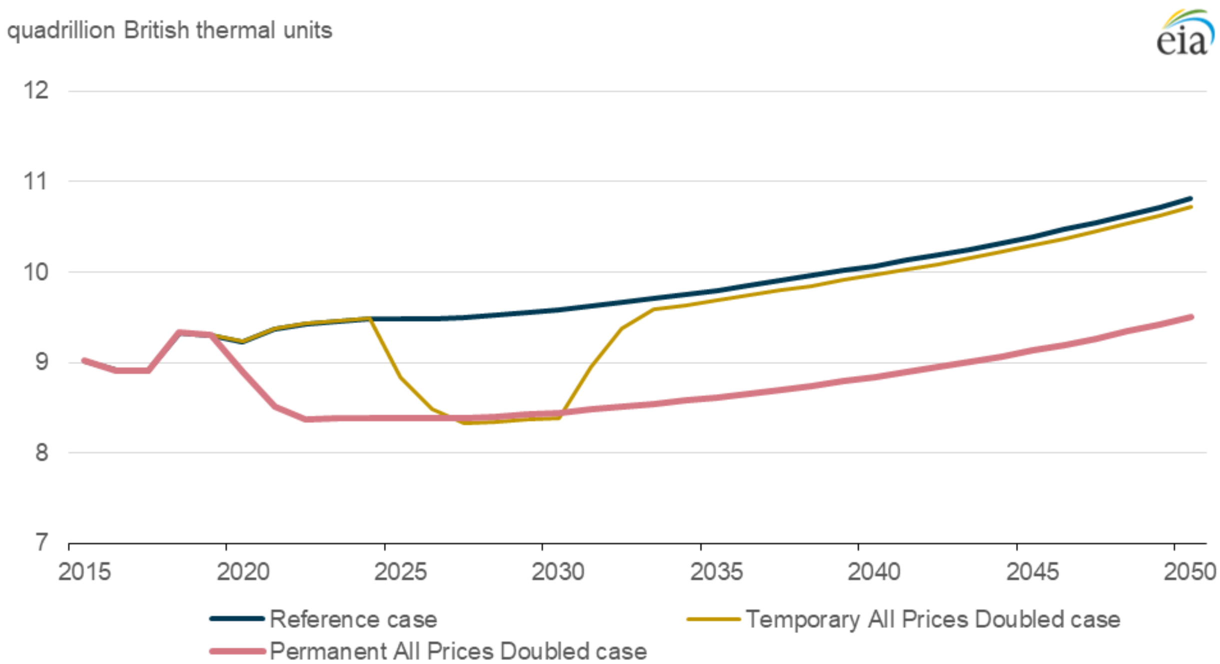
In this section, for the purpose of illustration, the report includes two additional scenarios:

- A permanent doubling of all electricity, natural gas, and distillate prices in all years from 2020 to 2050, relative to the Reference case (Permanent All Prices Doubled case)
- A temporary doubling of fuel prices between 2025 and 2030, relative to the Reference case (Temporary All Prices Doubled case), in which prices from 2031 to 2050 are equal to the Reference case prices

When prices are permanently doubled, commercial energy demand drops to less than the Reference case level in 2020 and drops 11.3% (1.1 quadrillion British thermal units [Btu]) from the Reference case level in 2022 (Figure 1). The gap between the Reference case and the Permanent All Prices Doubled case widens slightly—with commercial energy demand 12.1% (1.3 quadrillion Btu) lower than the Reference case in 2050—as equipment and building stock continue to be replaced with more efficient options. The preference for more efficient options occurs in response to the higher fuel prices.

In contrast, the Temporary All Prices Doubled case projects a drop in energy demand to a similar level between 2025 and 2030 and then shifts back toward the Reference case a few years later. By 2033, the gap between the Temporary All Prices Doubled case and the Reference case is only about 1.3% (0.1 quadrillion Btu). This gap continues to narrow through the rest of the projection period, but the Temporary All Prices Doubled case does not actually meet the Reference case by 2050. The continued difference is the result of purchase decisions with long-run effects that were made during the price shock years. The upgrades in equipment and building shells purchased during the temporary price shock continue to provide some energy savings even after prices return to Reference case levels in 2030.

Figure 1. Delivered energy consumption in the commercial sector

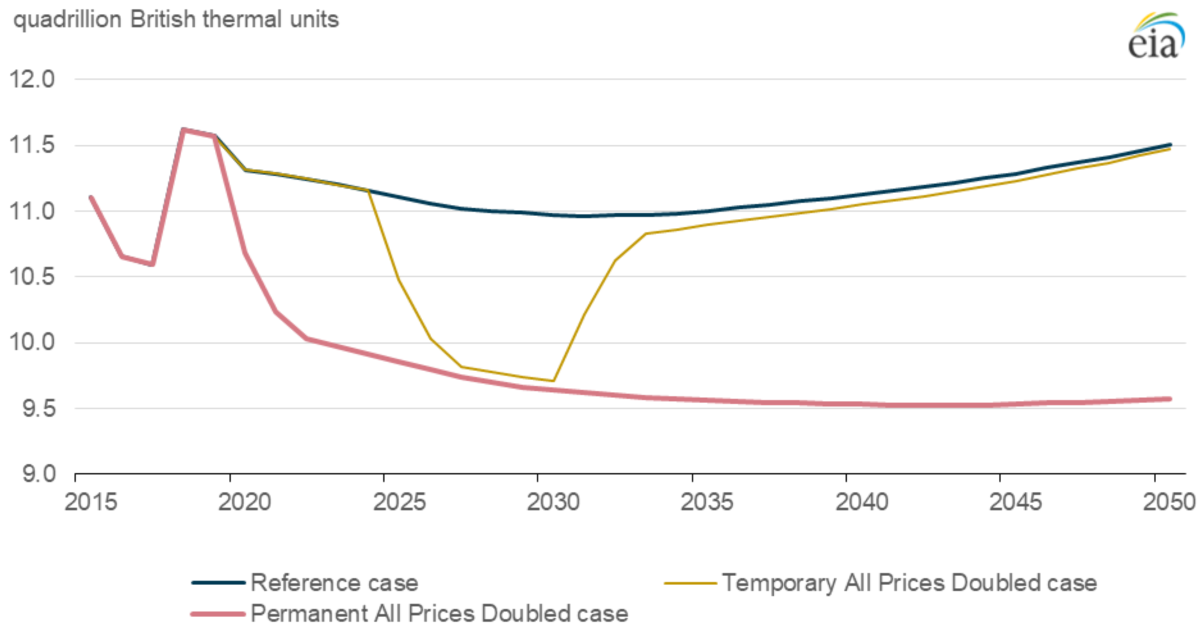


Source: U.S. Energy Information Administration, AEO2020 National Energy Modeling System

Figure 2 shows the energy demand projections in the residential sector for the two cases. The residential sector and commercial sector share some similarities but with a few additional interesting features. Both sectors see an initial drop when price changes take effect, but instead of a near-constant gap between energy demand in the Reference case and the Permanent All Prices Doubled case (like in the commercial sector), residential demand shows a widening gap after the initial drop.[7] Energy demand in the residential sector drops 10.8% (1.2 quadrillion Btu) lower than the Reference case level by 2022 and then continues falling to 16.8% (1.9 quadrillion Btu) lower than the Reference case level in 2050. This widening gap is associated with the continued selection of higher efficiency appliances and equipment under the higher price case.

[7] In the commercial sector, the gap in energy demand between the Reference case and the Permanent Prices Doubled case does increase in absolute terms between 2022 to 2050, albeit slowly, from 1.1 quadrillion Btu to 1.3 quadrillion Btu.

Figure 2. Delivered energy consumption in the residential sector

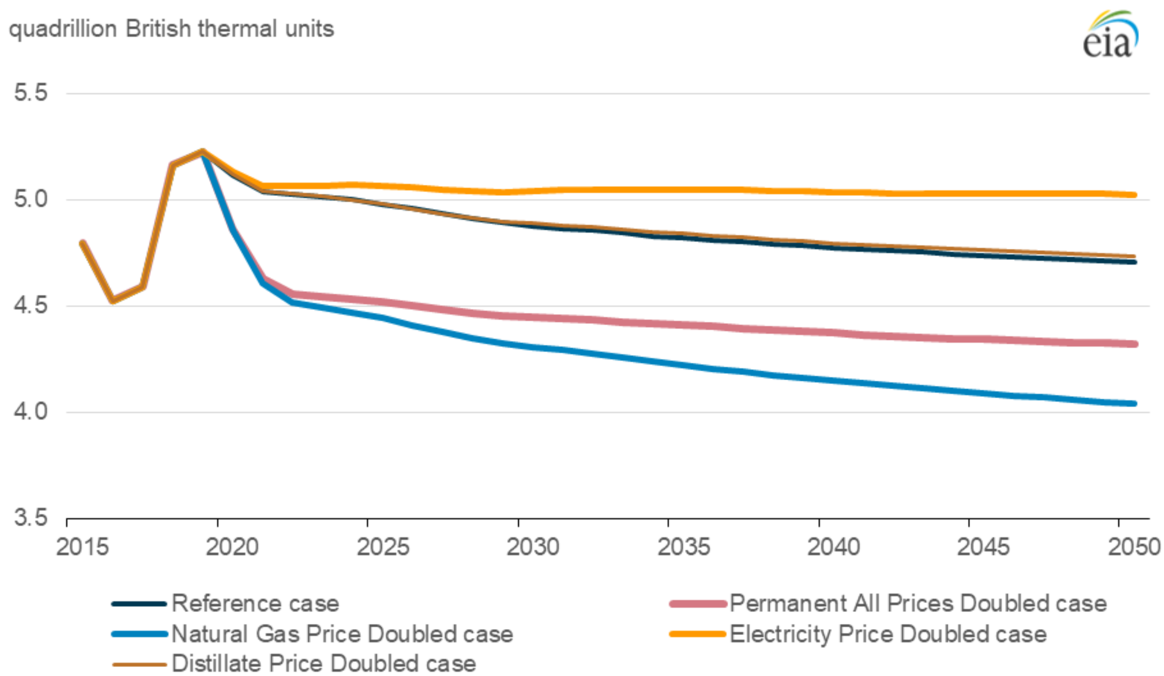


Source: U.S. Energy Information Administration, AEO2020 National Energy Modeling System

Natural Gas Consumption in Price Sensitivity Cases

Figure 3 illustrates the sensitivity of residential natural gas consumption in the cases when a single fuel price is doubled (used in computation of elasticities) and when all prices are doubled permanently. When only the electricity price increases, natural gas consumption grows at a faster rate than in the Reference case. This response is consistent with the positive long-run cross-price elasticity of natural gas with respect to electricity prices in Table 2 (+0.10). When natural gas prices are doubled, the simulation reflects a large drop in residential consumption, which parallels the corresponding negative long-run own-price elasticity in Table 1 (-0.23). The long-run cross-price elasticity of almost 0 with respect to distillate fuel prices explains why natural gas demand in the Distillate Price Doubled case remains virtually unchanged from the Reference case (Figure 3). Natural gas demand decreases when all fuel prices double. However, the effect is most pronounced when only the natural gas price doubles because doubling the other fuel prices keeps natural gas competitive, meaning fewer consumers in the residential sector will switch to other fuels when all fuel prices double compared with when only the natural gas price doubles. However, total delivered energy in the sector drops by 1.9 quadrillion Btu in 2050 when all fuel prices are permanently doubled. As a result, when all fuel prices are doubled, improving efficiency and doing without energy services has a larger effect on lower natural gas demand than fuel switching.

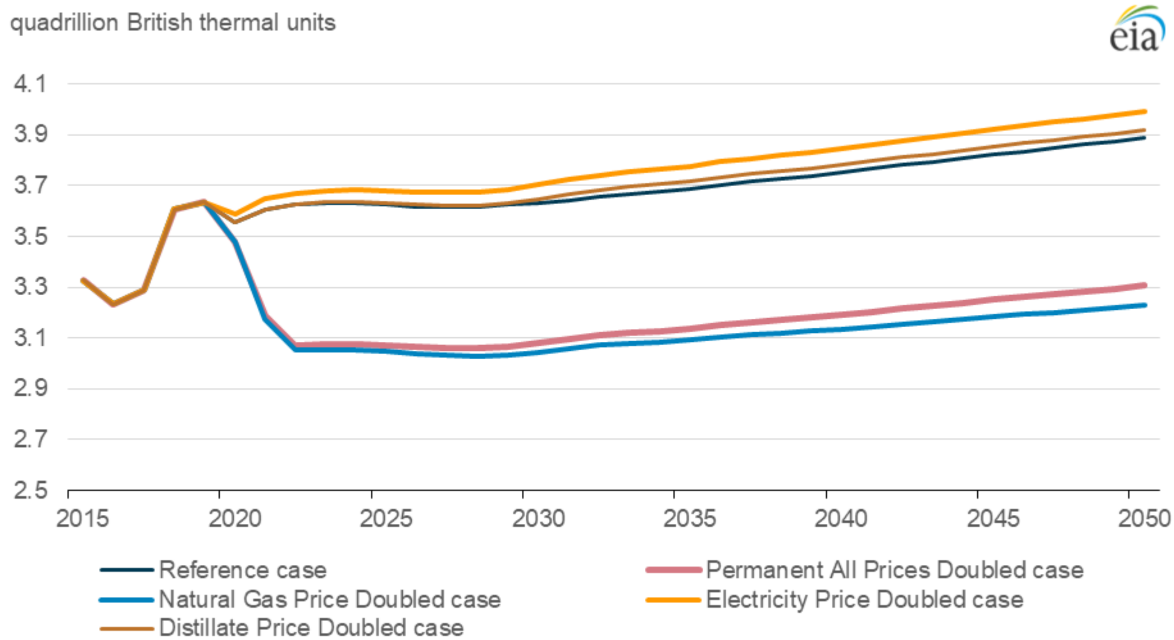
Figure 3. Natural gas consumption in the residential sector across price cases



Source: U.S. Energy Information Administration, AEO2020 National Energy Modeling System

Figure 4 illustrates a similar dynamic in the commercial sector. The absolute value of long-run own-price elasticity of natural gas is higher (-0.28) than the long-run cross-price elasticity with respect to the electricity price (0.04). These elasticities are consistent with the smaller absolute change in commercial natural gas demand by 2050, when the electricity price is doubled (0.1 quadrillion Btu), relative to the simulation with the doubled natural gas price (0.7 quadrillion).

Figure 4. Natural gas consumption in the commercial sector across price cases

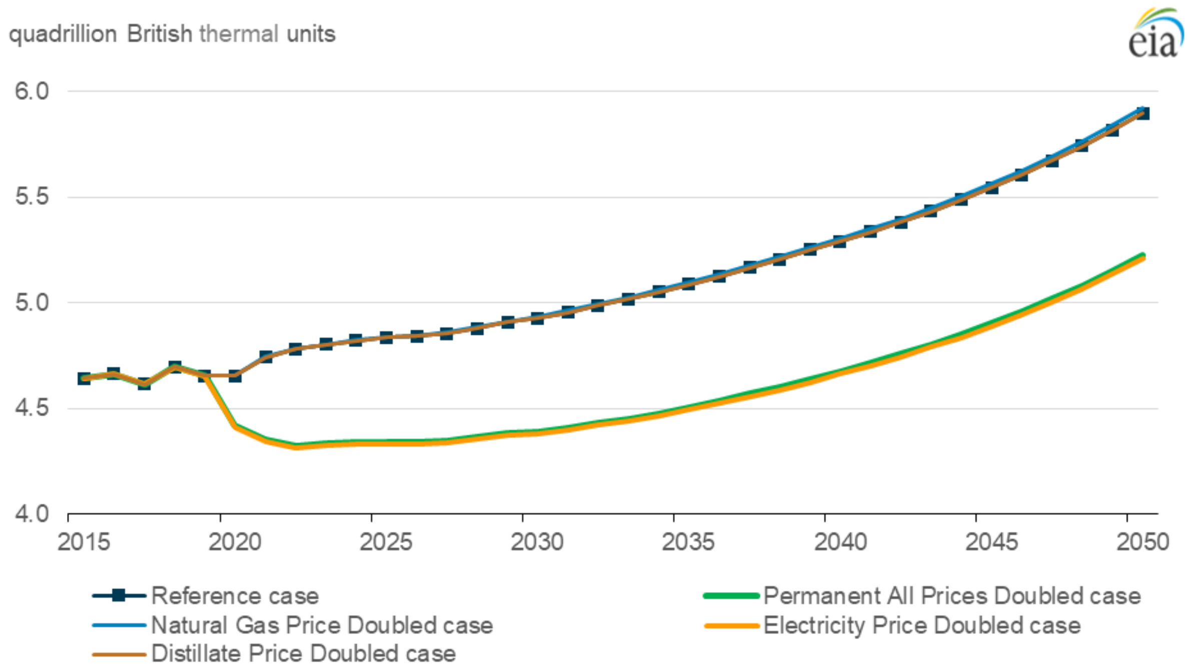


Source: U.S. Energy Information Administration, AEO2020 National Energy Modeling System

Electricity Consumption in Price Sensitivity Cases

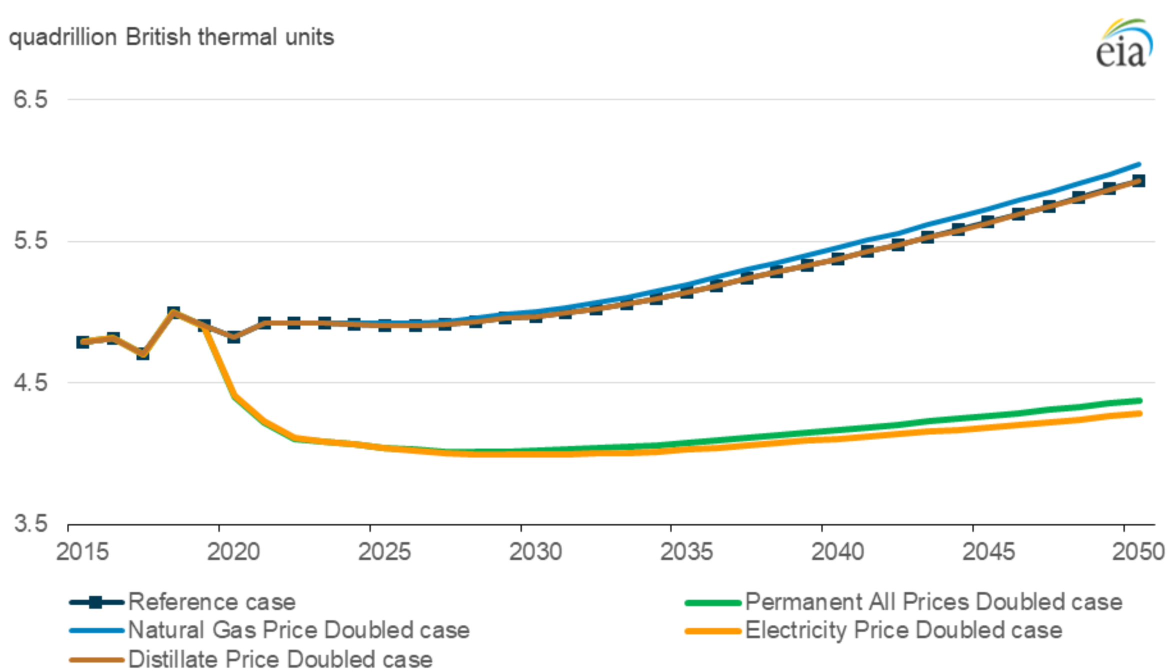
Figure 5 and Figure 6 show how electricity consumption changes in the price cases for the commercial and residential sectors, respectively. The largest drop in electricity consumption in both sectors occurs in the Electricity Price Doubled case. This case includes the highest combination of fuel switching away from electricity and of efficiency improvements in electricity end uses.

Figure 5. Electricity consumption in the commercial sector across price cases



Source: U.S. Energy Information Administration, AEO2020 National Energy Modeling System

Figure 6. Delivered electricity consumption in the residential sector across price cases



Source: U.S. Energy Information Administration, AEO2020 National Energy Modeling System

The two primary ways electricity fuel switching occurs is replacing electric equipment with equipment that runs on another fuel and increasing distributed generation (DG).[8] Equipment replacement could occur in the normal equipment lifecycle, when an existing piece of equipment is due to be replaced, or it could happen before the expected lifetime ends. Table 4 illustrates an example of fuel switching as a result of equipment stock changes, specifically heating equipment in the residential sector. The table presents the total number of units used for heating in households, broken out by equipment type. Comparing heating equipment stocks between the cases shows that the Electricity Price Doubled case has significantly fewer electric heaters (particularly electric furnaces) and significantly more equipment that uses other fuels (particularly natural gas furnaces).

Table 4. Changes in the number of residential heating equipment, 2050

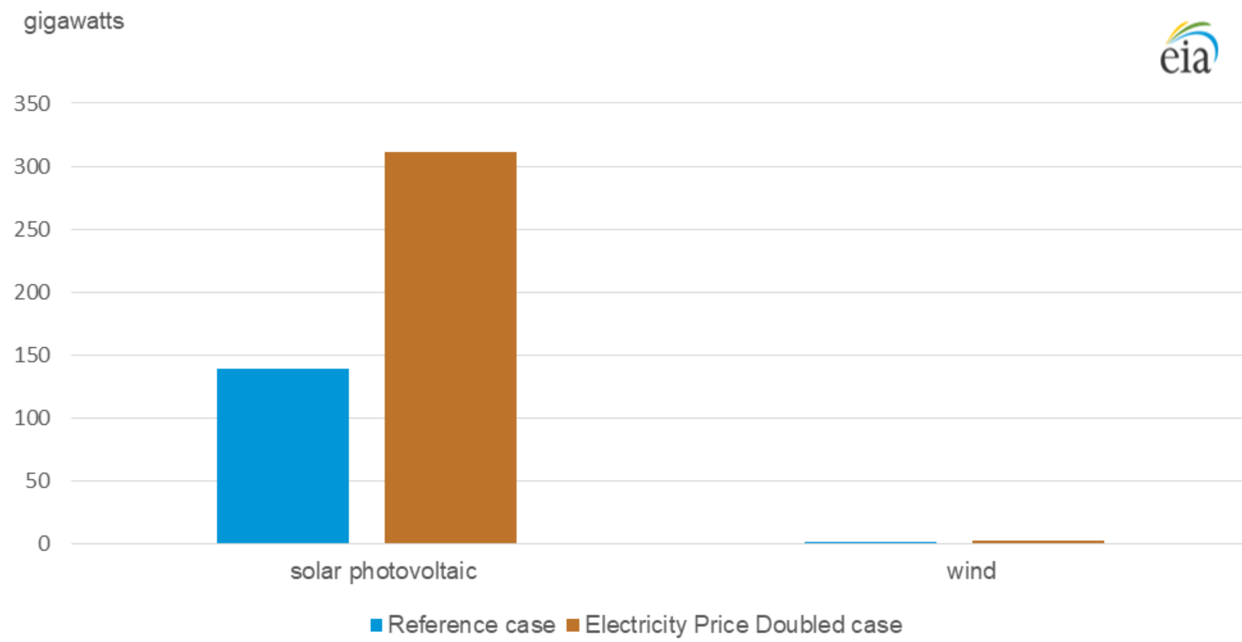
Equipment	Reference case	Electricity Price Doubled case	Change[a]
Electric furnace	31,756,901	29,519,232	-2,237,669
Air-source heat pump (electric)	18,282,896	16,734,275	-1,548,621
Geothermal heat pump	2,240,904	1,798,270	-442,634
Natural gas furnace	67,590,849	71,391,727	+3,800,878
Natural gas boiler	10,032,195	10,053,160	+20,965
Natural gas heat pump	1,158,852	1,158,854	+2
Propane furnace	4,324,370	4,478,750	+154,380
Distillate and kerosene furnace	2,400,326	2,418,123	+17,797
Distillate boiler	1,706,345	1,706,447	+102
Wood stove	2,351,929	2,587,379	235,450

[a]Change from Reference case relative to the Electricity Price Doubled case.

Increased use of DG at building sites is another form of fuel switching and also results in building occupants using less electricity from central power plants. The large increase in DG in the Electricity Price Doubled case comes from rooftop solar panels (Figure 7). In this case, rooftop solar grows 7.3% per year between 2020 and 2050, compared with 4.6% per year in the Reference case.

[8] Distributed generation refers to a category of electricity generation that includes combined heat and power (CHP) and renewables, such as rooftop solar and wind power systems, at building locations. CHP is generating equipment that provides electric power for a building and uses residual heat from that process for heating services. The buildings sector use non-utility-scale CHP as a form of distributed generation. CHP is uncommon in the residential sector.

Figure 7. Buildings distributed generation in price cases, 2050



Source: U.S. Energy Information Administration, AEO2020 National Energy Modeling System

In addition to fuel switching, efficiency improvements also play a role in reducing electricity demand in the Electricity Price Doubled case. The case reflects efficiency improvements among most electric equipment, but the end uses that contribute the most electricity savings are space cooling, lighting, and water heating.

Figure 8 and Figure 9 show the average stock efficiency improvements in residential and commercial space cooling equipment where electricity prices are doubled relative to the Reference case. Central air conditioners and room air conditioners are the most prevalent space cooling equipment in the residential sector, accounting for 88% or more of household space cooling equipment throughout the projection period in both cases.[9] Although the percentage gains in efficiency are highest for geothermal heat pumps in this sector, this technology is relatively costly and is unlikely to gain wide adoption without further improvements in cost.

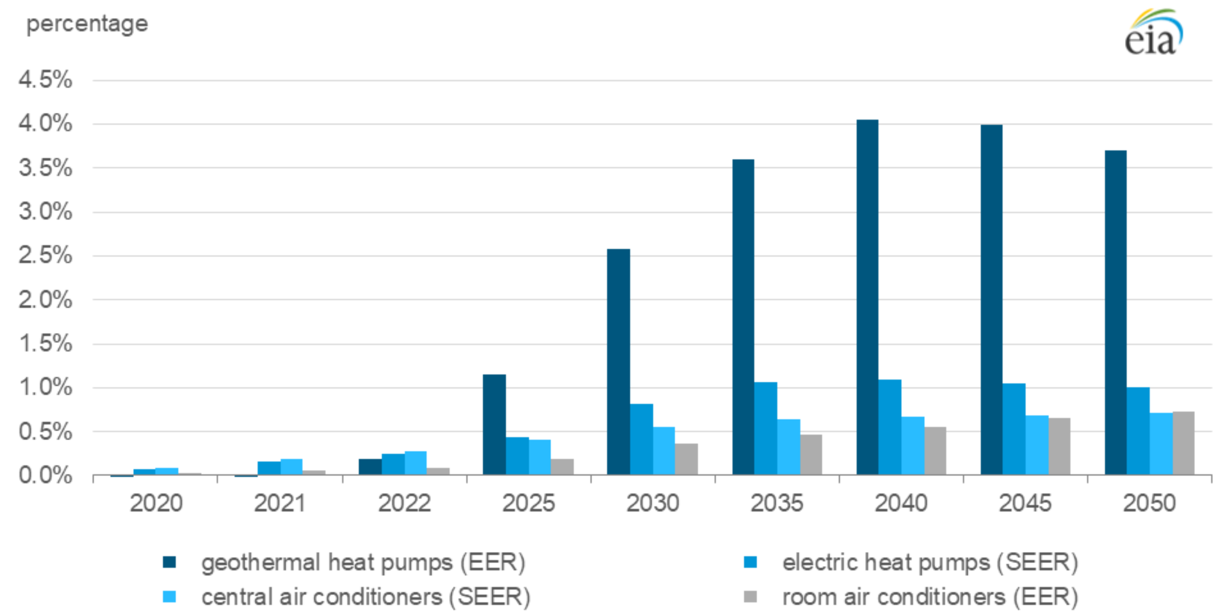
In the commercial sector, electric space cooling equipment accounts for 95% or more of the energy consumed for space cooling throughout the Reference case projections. Electric space cooling equipment shows smaller efficiency gains than natural gas space cooling equipment in the Electricity Price Doubled case. However, this smaller increase in efficiency leads to a greater reduction in energy consumption because of the large share of demand met by electric cooling equipment. In 2050, electricity demand for space cooling in the Electricity Price Doubled case is 0.45 quadrillion Btu (35%)

[9] The RDM also has a category for natural gas heat pumps that provide space cooling, but that category was not included in Figure 8 because there was no efficiency improvement in that category for the Electricity Price Doubled case.

lower than the Reference case level in the residential sector and 0.15 quadrillion Btu (23%) lower than the Reference case level in the commercial sector.[10]

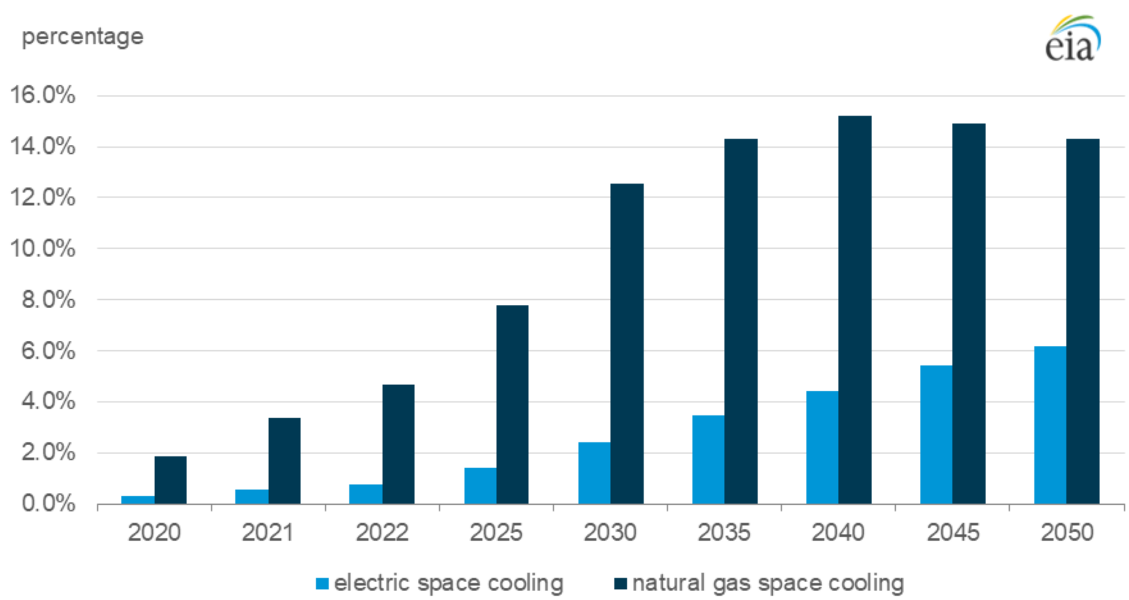
[10] After 2040, the average efficiency of space cooling in the Electricity Price Doubled case changes very little relative to the Reference case for residential geothermal heat pumps (Figure 8) and commercial natural gas (Figure 9). This trajectory is particularly affected by the residential and commercial technology choice models as the electricity price increases and improvement in the average efficiency of available equipment stabilizes in later projection years.

Figure 8. Percentage of improvement in efficiency of residential cooling equipment in the Electricity Price Doubled case relative to the Reference case



Source: U.S. Energy Information Administration, AEO2020 National Energy Modeling System

Figure 9. Percentage of improvement in efficiency of commercial cooling equipment in the Electricity Price Doubled case relative to the Reference case

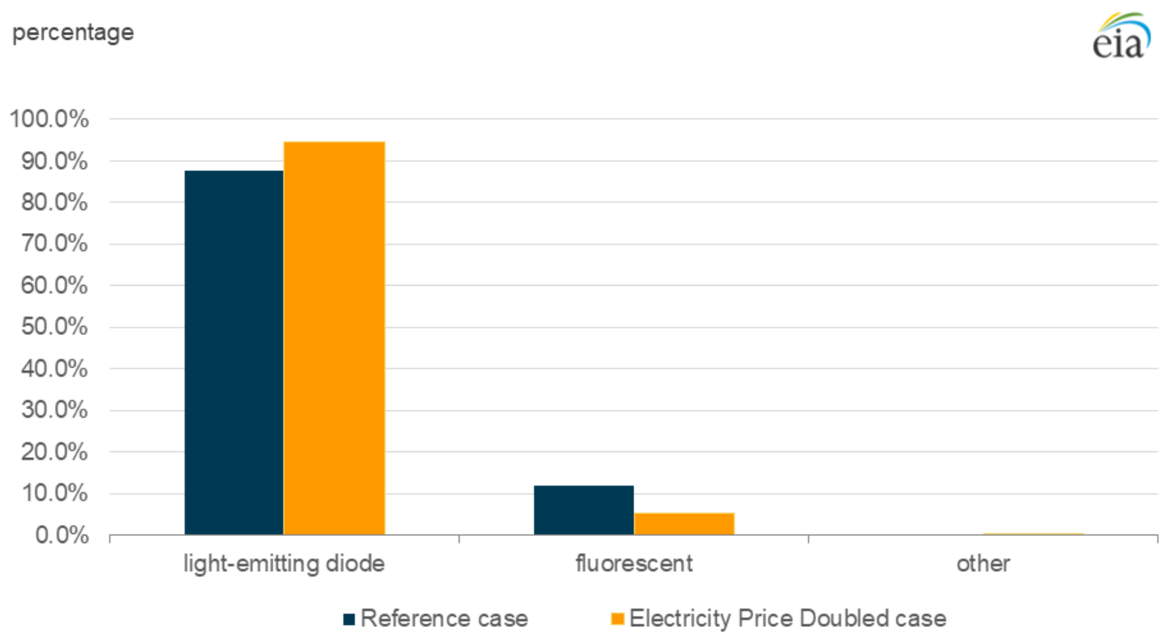


Source: U.S. Energy Information Administration, AEO2020 National Energy Modeling System

In 2019, almost twice as much energy was consumed for lighting in the commercial sector (0.48 quadrillion Btu) as in the residential sector (0.26 quadrillion Btu).[11] In the Reference case, electricity demand for lighting declines faster in the commercial sector than in the residential sector as a result of faster growth in use of efficient light-emitting diodes (LEDs). LEDs produce less waste heat while producing light, which makes them more efficient than other lighting options. In 2019, LED lighting technology accounted for 44% of the residential lighting market while LED lighting only accounted for 17% of commercial lighting demand, providing greater potential for declines in energy demand as a result of efficiency gains in the commercial sector.

In the Electricity Price Doubled case, savings in electricity consumption for lighting come from efficiency improvements largely in the commercial sector. Energy use for lighting in the buildings sector in this case is 0.14 quadrillion Btu (27%) lower than the Reference case level in 2050, with 0.11 quadrillion Btu coming from the commercial sector. Figure 10 shows LED technologies are projected to meet most of the service demand for commercial lighting by 2050 as a result of federal standards and increasing penetration of LED lighting technologies.[12] In the Electricity Price Doubled case, the share of commercial lighting demand for these lighting technologies increases.

Figure 10. Lighting service demand for the commercial sector, Reference case versus Electricity Price Doubled case in 2050



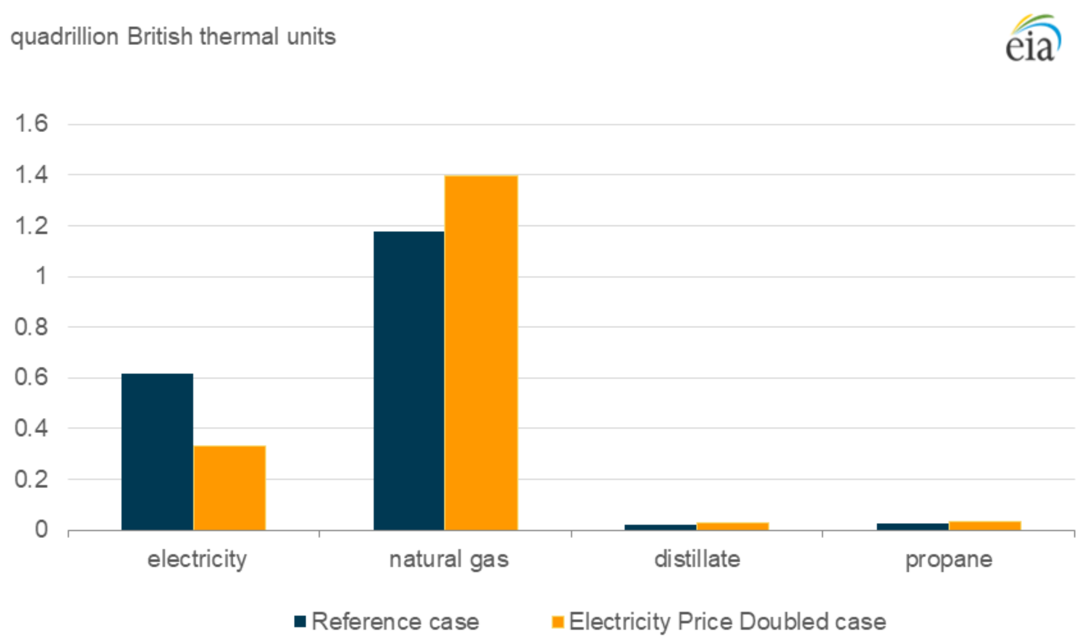
Source: U.S. Energy Information Administration, AEO2020 National Energy Modeling System

[11] This result is the same in all cases presented because price effects begin in 2020.

[12] Service demand is not the same as energy demand. Service demand is a modeling concept meaning how much an end user demands of a service (for example, lighting). The end user then has to use energy-using equipment to fulfill that service demand (for example, light bulbs). Different types of equipment (for example, incandescent lighting, fluorescent lighting, LED lighting) may use different amounts of energy to meet service demand.

Water heating accounts for about 10% of energy consumption in the buildings sector. Electricity savings in the Electricity Price Doubled case for water heating come almost entirely from the residential sector. In 2050, residential sector water heating electricity use is about 0.28 quadrillion Btu (46%) lower than the Reference case level in the Electricity Price Doubled case. Figure 11 shows the amount of energy consumed for water heating in the residential sector, by fuel, in 2050. In the Electricity Price Doubled case, natural gas consumption for residential water heating increases by 19% relative to the Reference case. This expectation is consistent with the positive long-run cross-price elasticity that natural gas has with electricity prices (+0.10). [13]

Figure 11. Water heating demand for the residential sector, Reference case versus Electricity Price Doubled case



Source: U.S. Energy Information Administration, AEO2020 National Energy Modeling System

Costs in Elasticity Cases

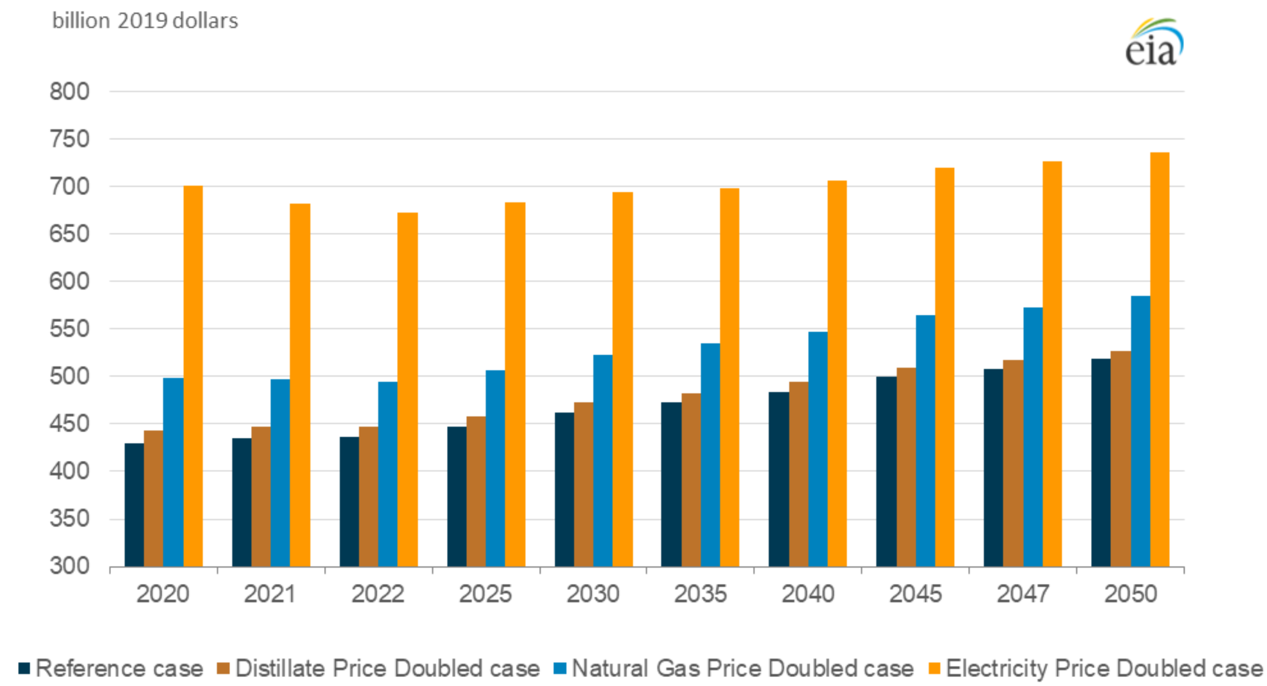
As shown in the preceding sections, price spikes cause changes in fuel consumption. This section examines the change in costs across the elasticity cases. Specifically, it examines costs for fuels supplied to buildings sector energy consumers and the equipment and shell upgrades that take place in buildings.

Figure 12 presents total expenditures for all fuels supplied to consumers in the buildings sector in the different cases simulated. Even with the decreased energy usage, total expenditures for fuels rise

[13] Energy consumption for residential water heating is also affected by improvements in energy efficiency of water heating equipment.

significantly because of the simulated doubling of fuel prices. Yet, interestingly, total fuel expenditures differ when different fuel prices rise. Compared with the Reference case, between 2020 and 2050, fuel expenditures increase by an average of $229 billion (2019 dollars) per year in the Electricity Price Doubled case, $63 billion per year in the Natural Gas Price Doubled case, and $10 billion per year in the Distillate Price Doubled case.

Figure 12. Total fuel expenditures for energy customers in price cases



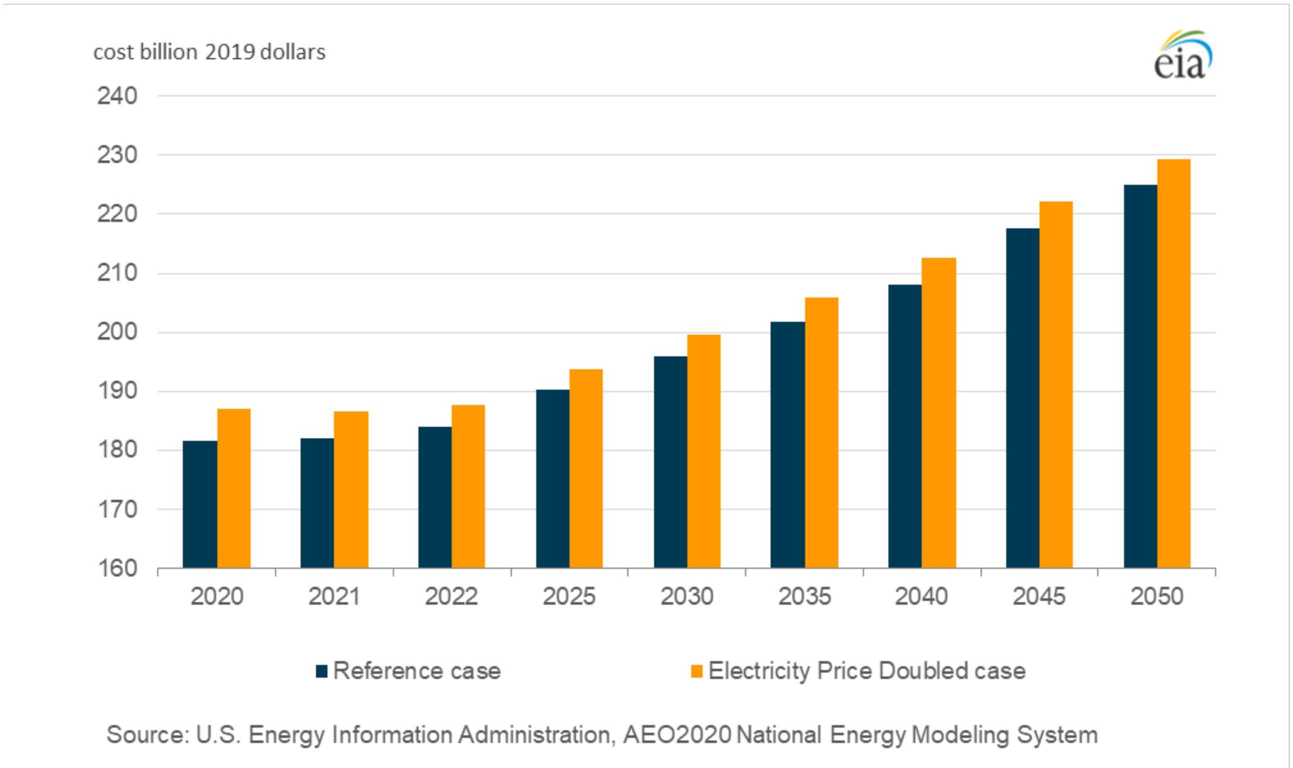
Source: U.S. Energy Information Administration, AEO2020 National Energy Modeling System

Figure 13 shows the investment in higher-efficiency equipment, DG systems, and residential shell improvements across the cases.[14] It combines what buildings sector energy consumers pay for upgrades and also what utilities and the federal government pay through tax credit and subsidy programs as currently legislated.

Energy consumers pay a much higher share than the government and utilities in additional costs for upgraded equipment and shells. In the Electricity Price Doubled case, the upgrades cost consumers an average of $3.4 billion per year more than the Reference case between 2020 and 2050 and cost the government and utilities an average of $0.7 billion more per year.

[14] Results for investment in commercial building shells are not available.

Figure 13. Consumer, government, and utilities investment in equipment and shells, Reference case versus Electricity Price Doubled case



Conclusion

The three possible responses for an energy user to react to an increase in the cost of a particular fuel are to switch to another fuel, use that fuel more efficiently, or do without services provided by that fuel. Whether one option is more desirable than another, or even possible, depends on many factors. For example, lighting demand is powered almost entirely through electricity, and no general service lighting runs on natural gas. As a result, an increase in electricity price will not cause fuel switching in lighting, but it may persuade building occupants to purchase more efficient light bulbs or to be more aware of turning off lights when they are not needed.

Electricity and natural gas are the most important fuels in the buildings sector. Even though predicting an exact future price for these fuels is impossible, the simulations described in this report provide a range of possibilities to help understand price-demand dynamics, particularly for the buildings sector. In the Reference case, electricity accounts for 46% of delivered energy in 2020 and grows to 53% in 2050. The share of energy from natural gas is lower and accounts for 42% of delivered energy in 2020 and 39% in 2050. Most likely, the high and growing use of electricity results in larger elasticities when the electricity price is doubled than when other energy prices are doubled. These interactions, along with the other described changes induced by fuel price increases, help in understanding energy consumption and planning for future energy needs.

Appendix

Table 5. Summary of own-price elasticities in AEO2020 Residential Demand Module and Commercial Demand Module (using simulations where fuel price is cut in half between 2020 and 2050)

	Short run		Long run	
	Year 1	Year 2	Year 3	Year 30
Residential				
Electricity	-0.12	-0.21	-0.25	-0.29
Natural gas	-0.07	-0.12	-0.15	-0.21
Distillate fuel	-0.08	-0.14	-0.17	-0.24
Commercial				
Electricity	-0.07	-0.12	-0.14	-0.15
Natural gas	-0.03	-0.19	-0.25	-0.28
Distillate fuel	-0.13	-0.21	-0.25	-0.28

Table 6. Summary of cross-price elasticities in AEO2020 Residential Demand Module and Commercial Demand Module (using simulations where fuel price is cut in half between 2020 and 2050)

		Change in fuel price		
		Electricity	Natural gas	Distillate
Change in fuel use	**Residential**			
	Electricity	--	0.02	0.00
	Natural gas	-0.13	--	-0.01
	Distillate fuel	-0.18	0.01	--
	Commercial			
	Electricity	--	0.00	0.00
	Natural gas	0.00	--	-0.01
	Distillate fuel	0.01	0.02	--