GU J Sci, Part C, 9 (2): 182-199 (2021)

Gazi University

Journal of Science

PART C: DESIGN AND TECHNOLOGY

http://dergipark.gov.tr/gujsc

Estimation of Large Household Appliances Stock in the Residential Sector and Forecasting of Stock Electricity Consumption: Ex-Post and Ex-Ante Analyses

Bilal DÜZGÜN[1,*], Ramazan BAYINDIR[1], Merih AYDINALP KÖKSAL[2]

[1]*Gazi University Faculty of Technology, Department of Electrical Electronics Engineering, 06500, Yenimahalle/ANKARA*

[2]*Hacettepe University Faculty of Engineering, Department of Environmental Engineering, 06800, Beytepe/ANKARA*

Article Info

Research article
Received: 01/02/2021
Revision: 27/03/2021
Accepted: 09/04/2021

Keywords

Stock accounting modeling
Large household appliances
Forecasting of electricity consumption
Electricity consumption in the residential sector

Abstract

Energy efficiency offers a wide variety of opportunities that will provide efficient resource utilization, alleviate the pressure of energy costs on the economy and reduce foreign energy dependency, and support in combating the harmful effects of climate change. This paper aims to develop necessary data sets to guide policymakers in their decision-making process to identify energy efficiency policy options through an ex-post analysis. One of the targets of this paper is to determine the large household appliances stock and its electricity consumption, which constitutes an important share in residential electricity consumption over the period of 2005-2019. In light of the findings from the ex-post analysis, electricity consumption scenarios for large household appliances were developed from 2020 to 2030. According to the results, the total stock consumption of the refrigerator and washing machine appliances has reached a plateau, leaving behind an increasing trend due to the improvements in efficiency despite the growth in the stock amounts. Besides, the electricity consumption of freezer, tumble dryer, and dishwasher stock has increased significantly due to the increase in the household ownership rates. The analyses also showed that the total electricity consumption of the large household appliances' stock increased from 17,973 GWh in 2005 to 23,067 GWh in 2019. In addition, the ex-ante analysis revealed that the electricity consumption of refrigerator stock would show most likely a downward trend until 2030, while deep freezers, tumble dryers, dishwashers, and electric ovens stocks would demand more electricity with the increase in ownership rates. However, the analysis showed an uncertain pathway for the electricity consumption of washing machine stock since annual sales during the projection period would show in which direction their consumption would evolve.

1. INTRODUCTION

After the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change held in Paris in 2015, many countries have declared their decarbonization targets for achieving carbon neutrality. The most ambitious target announced in this context is undoubtedly the European Commission's goal of making Europe the first carbon-neutral continent with the Green Deal Plan. Energy efficiency, which provides multiple benefits including preventing waste, alleviating the pressure of energy costs on the economy, and reducing the dependence on foreign energy resources in addition to tackling climate change, is one of the main policy tools that Europe will need to achieve the long-term climate targets set by the Green Deal.

Meanwhile, Turkey follows the developments in climate policies closely and restructures her policy and strategy plans within the framework of transformational change to cope with increasing energy demand driven by population growth and economic development.

*Corresponding author, e-mail: bilalduzgun@gmail.com
DOI: 10.29109/gujsc.871922

The main framework of energy efficiency programs was drawn up by the Energy Efficiency Law published in 2007. The Law aims to prevent waste, reduce energy costs and protect the environment by using energy effectively and efficiently [1]. Its secondary legislation, the Regulation on Energy Performance in Buildings and the Regulation on Increasing Efficiency in the Use of Energy Resources and Energy, was published in 2008 and 2011 to ensure promoting energy efficiency in all processes from production to final consumption. With Turkey's Climate Change Strategy 2010-2023 published by the Ministry of Environment and Urbanization in 2010, dissemination of energy efficiency was determined as one of the main pillars of the national vision on climate change strategies.

Subsequently, the Energy Efficiency Strategy Document 2012-2023 was published in 2012 with the decision of the High Planning Council by aiming at reducing the energy intensity of Turkey by at least 20% compared to the 2011 level [2]. The actions to be taken in achieving the efficiency goals were announced with the National Energy Efficiency Action Plan (NEEAP) published in 2018. Under the NEEAP, it is aimed to reduce the primary energy consumption of Turkey by 14% until 2023 through 55 actions defined in six categories: buildings and services, energy, transport, industry and technology, agriculture and cross-cutting (horizontal) areas. The NEEAP targets to save 23.9 million toe cumulatively and mitigate 66.6 million tonnes of carbondioxide equivalent (MtCO2-eq) by investing 10.9 billion USD [3].

The building sector was chosen as one of the focal areas within the NEEAP due to its high energy efficiency potential. A total of 12 actions were determined by focusing on increasing energy efficiency in existing buildings, making new buildings more efficient, carrying out building inventory studies, and conducting awareness-raising activities to benefit the most from the existing potential.

One of the actions defined in the building sector is the improvement of the energy efficiency of existing buildings (named as B5 in the NEEAP). In this context, the development of a mechanism that will include practices such as incentives, support schemes, taxation, and sanctions are targeted to disseminate the use of efficient equipment and technologies [3]. This action also indicates that the market transformation of efficient household appliances will be a focal point where in-depth analyses are needed.

On the other side, there is limited research on household appliance stock and its energy consumption for Turkey. For some household appliances, the ownership rates of households were determined in the survey study conducted in 2020 by the Ministry of Energy and Natural Resources (MENR) within the scope of the Energy Efficiency Awareness Index Research [4]. Selçuk (2018) also used the Household Budget Survey conducted by the Turkish Statistical Institute (TurkStat) to determine the ownership rates [5]. Şahin (2012) identified the electricity consumption and CO_2 emissions of household appliances by conducting surveys and measurements in 201 households in Ankara [6]. However, the data on the breakdown of electricity consumption in residential buildings in the literature does not provide a clear picture of the end-use consumption shares. For example, the shares of major electricity consumers in households electricity consumption are listed in Şahin's (2012) study as refrigerator, television, and dishwasher with 31%, 10%, and 8%, respectively; in TEVEM's (2010) study as refrigerator, air conditioners and lighting with 31.1%, 15%, and 11.7%, respectively; in Yumartacı and Dönmez's (2013) study as refrigerator, lighting and electric ovens with 30.4%, 28.6%, and 10.4%, respectively [6], [7], [8]. Yet, these researches do not include any assessment regarding the total household appliance stock and its total electricity consumption in the Turkish residential sector.

Within the scope of this study, the evaluations and assessments will be made on large household appliances, which have a significant share in the electricity consumption of residential buildings, by developing data sets to contribute the analysis that policymakers may need. This study also aims to fill the existing gap in the literature on Turkey's large household stock and its electricity consumption with the analyses to be conducted.

For this purpose, the followed methodology to determine the appliance stock in use in the residential sector will be presented by explaining the scope and data limitations in Section 2. Then, the stock will be estimated in Section 3, and the calculations for the stock electricity consumption will be shown with the results obtained in Section 4. The stock electricity consumption forecast for 2030 will be made in Section 5, and the findings obtained from the analyses will be assessed in Section 6.

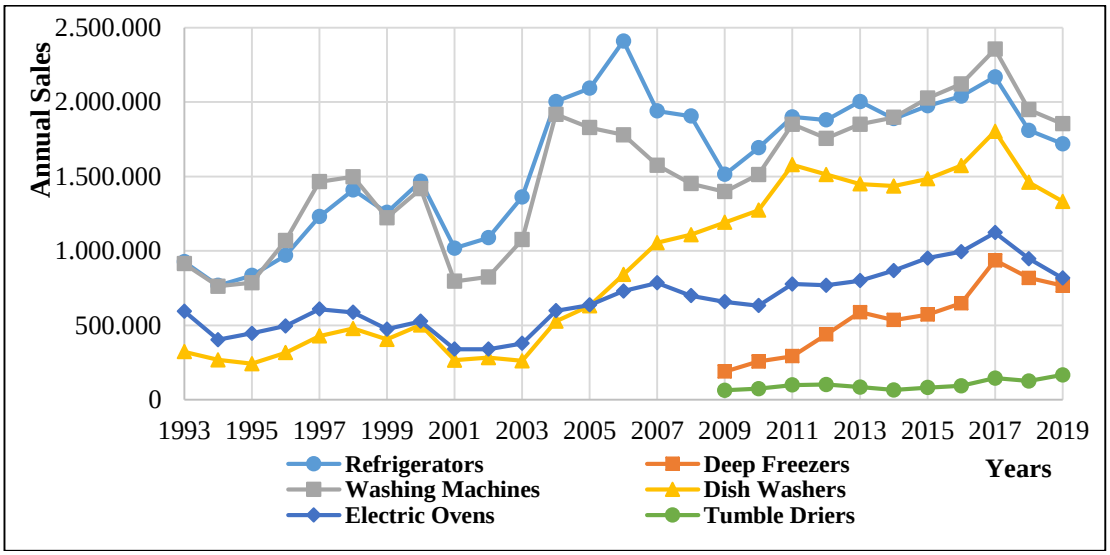
2. METHODOLOGY AND DATA SOURCES

Household appliances can be classified under two categories as large household appliances, also known as white goods, including refrigerators, deep freezers, tumble dryers, washing machines and dishwashers; and small household appliances including vacuum cleaners, microwaves, irons, televisions, computers, audio, video systems, etc. The European Statistical Office (Eurostat) categorizes electric ovens under use for cooking purposes [9].

Unfortunately, no official data source exists for appliance stock in Turkey. However, annual sales numbers for large household appliance products are shared by the White Goods Manufacturers' Association of Turkey (TÜRKBESD). The sales data provided by TÜRKBESD covers not only refrigerators, deep freezers, washing machines, tumble dryers, and dishwashers but also electric ovens. The sales data of these six product groups between 1993 and 2019 are presented in Figure 1. Besides, no data source for the sales of small household appliances is available in Turkey. For this reason, six product groups, namely refrigerators, deep freezers, washing machines, tumble dryers, dishwashers, and electric ovens, are analyzed in this study due to the availability of the data.

The equipment ownership rates can be estimated by conducting annual surveys on households. In the case of the surveys are not carried out regularly each year, the missing data on ownership rates can be predicted by interpolation methods since the ownership rates of large household appliances will not differ significantly from year to year [12]. If the ownership rates are known, the total appliance stock can be estimated by considering the total number of households. Another way to calculate the total stock is a bottom-up approach based on a stock accounting model whose inputs are annual sales numbers, and the average lifetime of the product can be used.

Selçuk (2018) calculated the household appliance ownership rates using the Household Budget Surveys which were conducted in 2003 and 2016 by TurkStat, and determined that 98% of households have a refrigerator, 97% have a washing machine, 18% have an air conditioner, and 44% have a computer [5]. Another survey conducted by the MENR in 2020 based on 3000 people showed that 99% of the households have a television, 98% have a washing machine, 97% have a refrigerator, 91% have a dishwasher, 87% have an electric oven, 46% have a deep freezer, 43% have an air conditioner, and 27% have a tumble dryer [4]. However, these researches do not provide any figures regarding total appliance stock in the Turkish residential sector.



The sales data for deep freezers and tumble driers are available after 2009.

Figure1. *Annual sales data of six main product groups for the period of 1993-2019 (Adapted from [10] and [11]).*

In developing countries where stock data lacks for the past years, the total stock in-use and annual sales can be estimated simply by multiplying the household appliance ownership rates to be obtained from the surveys by the total number of households as shown in Equation 1.

$$Stock_i^a = HH_i \times \gamma_i^a \quad (1)$$

i: Analyzed year;

a: Appliance type representing refrigerators, deep freezers, washing machines, tumble driers, dishwashers, or electric ovens;

$Stock_i^a$: Total number of units of appliance a in operation in year i;

HH_i: Number of households in year i;

γ_i^a: Ownership rate of appliance a at time i.

Within the scope of the UNDP/GEF Project on Increasing Energy Efficiency in Buildings under the coordination of the MENR, a monitoring study to profile residential electricity consumption was carried out in 55 households in 2015. The study revealed that some households had more than one product of the same type. For example, the refrigerator ownership rate of the surveyed households was found as 110.3% [13]. Although the sampling number in the study is comparatively low, the findings show that households may have more than one household appliance of the same type. For this reason, more accurate results can be obtained by employing comprehensive stock modeling in the case of data availability.

When sufficient data is available, the stock can be modeled with the sales data over the past years and survival rates [14]. Accordingly, the stock is calculated by adding the previous year's stock plus the appliance sales minus the stock of retired appliances in the current year, as shown in Equation (2).

$$Stock_i^a = Stock_{i-1}^a + S_i^a - AR_i^a \quad (2)$$

$Stok_{i-1}^a$: Total number of units of appliance a in operation in year $i-1$;

S_i^a: Sales of appliance a in year i;

AR_i^a: Stock of retired appliance a in year i.

The total retired appliance stock is calculated as the total of retired appliances each year. In other words, the total retired appliances over the years are determined with the survival rates, which depend on the age distribution for the starting year. Consequently, the total of retired appliances from the previous years gives the total appliance stock as shown in Equation (3).

$$AR_i^a = S_i^a \times \left(1 - \varphi_a(0)\right) + \sum_{j=i-k}^{i-1} S_j^a \times \left(\varphi_a(i-j+1) - \varphi_a(i-j)\right) \quad (3)$$

k: Age of appliance in terms of years

$\varphi_a(i-j+1), \varphi_a(i-j)$: Probability of survival of appliance a with age $(i-j+1)$ and$(i-j)$, respectively.

Martinez-Montejo and Sheinbaum-Pardo (2016) developed their model by assuming that all appliances would be in operation until the end of their lifetime, and all of them would retire at the end of their life, which was accepted as 16 years [15]. However, linear and nonlinear survival functions have been defined in the literature to identify survival rates, also called survival curves. Mahlia, Masjuki, and Choudhury (2002) employed linear survival function in their study and assumed that appliances would not retire before 2/3 of the life span of the appliances, all of those who are over 4/3 would be fully retired, and those in between would retire proportionally according to the life expectancy [16]. On the other hand, Welch and Rogers (2010) concluded that the retirement life of household appliances would follow the "Adapted Weibull Probability Density Function" proposed by Zachariadis, Samaras, and Zierock (1995) [17], [18]. Diawou et al. (2018) and Diawou et al. (2019) also used the survival curves suggested by Zachariadis, Samaras, and Zierock (1995) to calculate the number of retired appliances in their studies [19], [20]. The Adapted Weibull Probability Density Function proposed by Zachariadis, Samaras, and Zierock (1995) is presented in Equation 4.

$$\varphi^a(k) = exp - \left[\left(\frac{k + b^a}{T^a}\right)^{b^a}\right] ; \varphi^a(0) \cong 1 \quad (4)$$

$\varphi^a(k)$: Probability of survival of appliance a being k year old;

b^a: Failure steepness for appliance a ($b^a > 1$, i.e. survival rate decrease as appliance get older)

T^a: Characteristic service life for appliance a

The survival curves for large household appliances presented in Chapter 3 are determined using Equation (4). Then, the stock for each appliance group is calculated by years using the annual sales data for the period 1993-2019.

3. ESTIMATION OF LARGE HOUSEHOLD APPLIANCES STOCK USING STOCK ACCOUNTING MODEL

The most up-to-date research for the age status of the appliance stock for Turkey is the Energy Efficiency Awareness Index Survey conducted by MENR in 2020 [4]. The MENR study is used to estimate T^avalue which is assumed as 19 years for six appliances. The stock in use for refrigerators, deep freezers, washing machines, tumble dryers, dishwashers, and electric ovens show similar age distribution according to the survey results. Zachariadis, Samaras, and Zierock (1995) stated that the b^avalue converges to 50% of the average life span [18]. With this information, survival curves are drawn for six appliances, as presented in Figure 2.

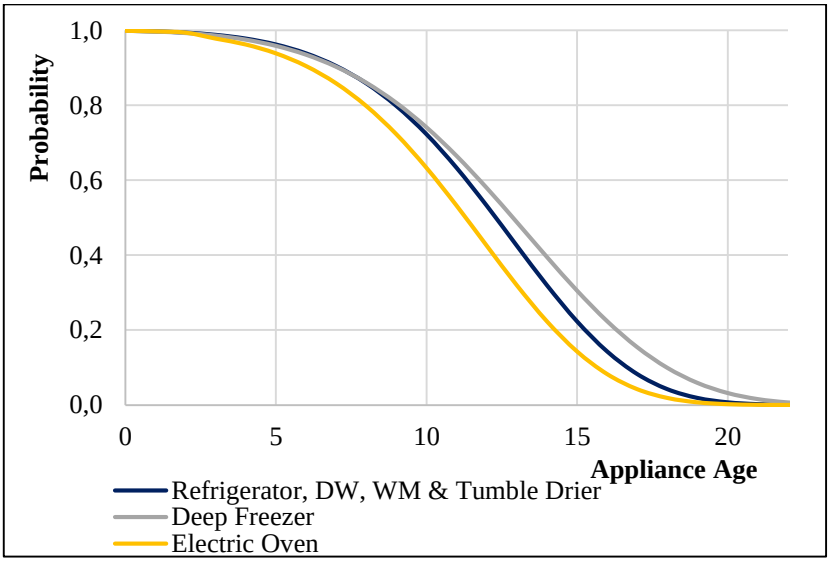


Figure2. *Survival Curves of Appliances*

MENR's completed Project on Market Transformation of Energy Efficient Appliances in Turkey and TURKBESD statistics on annual sales are used to calculate the total stock. However, the sales statistics extend until 1993 for refrigerators, washing machines, dishwashers, and electric ovens and until 2009 for deep freezers and tumble dryers. For the appliances that do not have annual sales statistics before 1993, the sales numbers are estimated backward by considering the annual average increase in the sales between 1993 and 2003. Likewise, for the appliances that do not have sales statistics before 2009, the sales numbers are estimated backward by taking the period of 2009-2019 as reference. The assumptions on sales data are summarized in Table 1.

Table 1. *Years without sales data and assumptions on annual sales*

Appliances	***Years without Sales Data***	***Assumed Annual Sales Growth Rate based on the Reference Period [%]***
Refrigerators	*Before 1993*	*5*
Deep Freezers	*Before 2009*	*15*
Washing Machines	*Before 1993*	*5*
Tumble Driers	*Before 2009*	*15*
Dishwashers	*Before 1993*	*2*
Electric Ovens	*Before 1993*	*2*

In the light of sales data and assumptions, the estimated total stock of large household appliances after 2005 is presented in Table 2, and the stock growth over the years is shown in Figure 3.

Table 2. *Estimated stock for large household appliances calculated from stock modeling*

Years	**Refrigerators**		**Deep Freezers**		**Washing Machines**		**Tumble Driers**		**Dishwashers**		**Electric Ovens**	
	Total Number of Units	**Stock Growth Rate**	**Total Number of Units**	**Stock Growth Rate**	**Total Number of Units**	**Stock Growth Rate**	**Total Number of Units**	**Stock Growth Rate**	**Total Number of Units**	**Stock Growth Rate**	**Total Number of Units**	**Stock Growth Rate**
2005	14,609,327		453,909		14,934,354		218,985		4,777,356		5,812,371	
2006	15,798,571	8.1%	547,612	20.6%	15,782,229	5.7%	251,759	15.0%	5,292,656	10.8%	6,000,923	3.2%
2007	16,498,885	4.4%	660,659	20.6%	16,377,680	3.8%	289,437	15.0%	6,014,829	13.6%	6,257,486	4.3%
2008	17,094,189	3.6%	797,042	20.6%	16,800,495	2.6%	332,754	15.0%	6,779,525	12.7%	6,439,107	2.9%
2009	17,515,230	2.5%	961,579	20.6%	17,117,852	1.9%	382,554	15.0%	7,614,264	12.3%	6,586,434	2.3%
2010	18,049,794	3.1%	1,189,369	23.7%	17,500,848	2.2%	442,276	15.6%	8,513,320	11.8%	6,711,824	1.9%
2011	18,722,810	3.7%	1,447,050	21.7%	18,172,704	3.8%	524,084	18.5%	9,697,883	13.9%	6,982,931	4.0%
2012	19,410,169	3.7%	1,842,172	27.3%	18,706,136	2.9%	606,202	15.7%	10,791,632	11.3%	7,243,618	3.7%
2013	20,160,095	3.9%	2,377,456	29.1%	19,293,839	3.1%	668,491	10.3%	11,790,633	9.3%	7,529,267	3.9%
2014	20,734,653	2.8%	2,849,691	19.9%	19,888,935	3.1%	707,942	5.9%	12,737,222	8.0%	7,869,645	4.5%
2015	21,333,471	2.9%	3,345,828	17.4%	20,574,073	3.4%	760,174	7.4%	13,683,596	7.4%	8,275,135	5.2%
2016	21,935,090	2.8%	3,903,176	16.7%	21,310,199	3.6%	819,945	7.9%	14,658,080	7.1%	8,699,624	5.1%
2017	22,603,676	3.0%	4,726,521	21.1%	22,229,044	4.3%	927,506	13.1%	15,787,405	7.7%	9,220,501	6.0%
2018	22,851,661	1.1%	5,411,146	14.5%	22,687,596	2.1%	1,010,586	9.0%	16,484,847	4.4%	9,532,470	3.4%
2019	22,953,045	0.4%	6,018,092	11.2%	22,997,003	1.4%	1,128,863	11.7%	16,954,196	2.8%	9,680,721	1.6%
Average Growth Rate		**3.3%**		**20.4%**		**3.1%**		**12.5%**		**9.5%**		**3.7%**

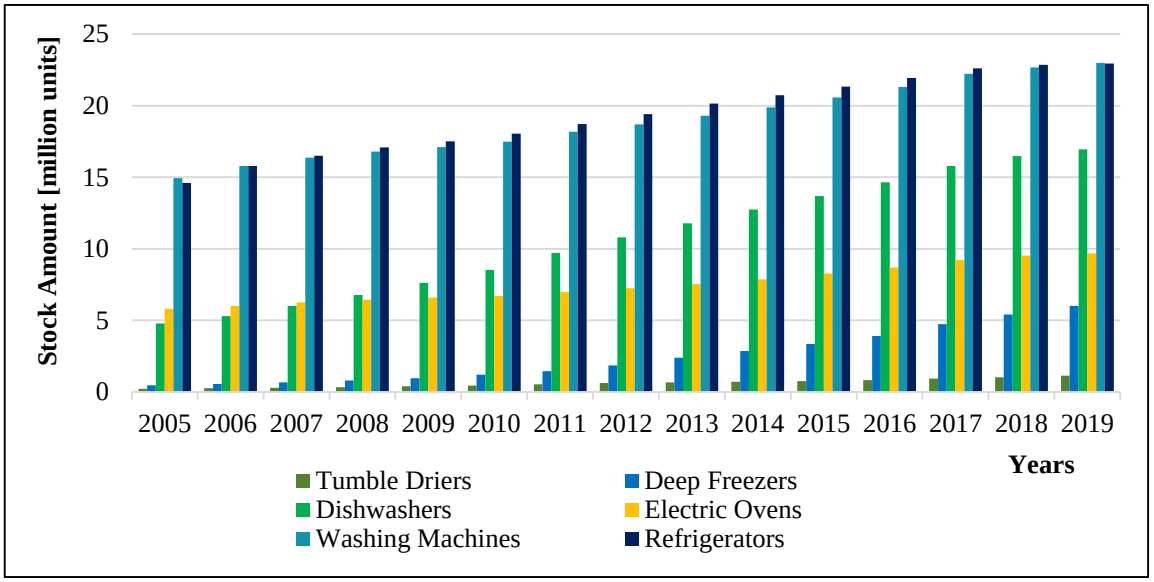


Figure 3. *The total stock growth of large household stock by years*

The total stock in use are estimated for 2019 as 22,953,045 units for refrigerators, 6,018,092 units for deep freezers, 22,997,003 units for washing machines, 1,128,863 units for tumble driers, 16,954,196 units for dishwashers and 9,680,721 units for electric ovens. If the estimated stock for each appliance group is divided by household numbers, the ownership rates can be calculated for the respected year. The ownership rates for refrigerators, deep freezers, washing machines, tumble driers, dishwashers, and electric ovens are found for 2019 as 98%, 25%, 96%, 5%, 71%, and 40%, respectively. The results of the model overlap with the findings from Selçuk's (2018) and MENR's (2020) studies, except for tumble driers and electric ovens. The MENR's (2020) study indicates that 27% of households have a tumble drier, and 87% have an electric oven. In other words, the study depicts that the stock amount for tumble driers and electric ovens according to Equation 2 is expected to be 6,480,524 and 20,202,460 units, respectively. However, since the average sales of tumble dryers in the last ten years are approximately 100 thousand units per year and the characteristic service life is assumed 19 years, the tumble drier stock will never reach the findings in the MENR's study. On the other side, according to the MENR's study, the stock of electric ovens is more than two times compared to the calculated stock in this paper. As the reason for this difference, the participants who attended the MENR's study may have answered the question in the survey regarding electric ovens by considering their cooking equipment such as mini/midi ovens, microwave ovens, etc., which are classified under small household appliances. The other reason for the high results in the MENR study can be that the survey may focus on participants with high socioeconomic levels.

4. DETERMINING THE ELECTRICITY CONSUMPTION OF THE APPLIANCE STOCK

The electricity consumption of large household appliances can be determined by energy efficiency indexes and product electricity consumption formulas given in the energy labeling and eco-design communiqués. Due to the Customs Union agreement, Turkey harmonizes her legislation with the EU acquis. Therefore, the equations in this section are the same as given in the relevant EU legislation.

4.1. The Electricity Consumption of Refrigerators and Deep Freezers

The average electricity consumption of refrigerators and deep freezers is calculated by efficiency classes using the methodology based on the eco-design and labeling regulations on cooling products. The energy efficiency index (EEI) and the standard annual energy consumption (SAE) for household refrigerating

appliances are represented by Equation 5 and Equation 6 in the Communiqué on Environmentally Sensitive Design Requirements for Household Refrigerating Appliances (SGM 2011/17) [21];

$$EEI = \left(\frac{AE_a}{SAE_a}\right) \times 100 \quad (5)$$

$$SAE_a = VE_{eq} \times M + N + CH \quad (6)$$

EEI: Energy efficiency index;

$\boldsymbol{AE_a}$: Annual energy consumption of the refrigerating appliance;

$\boldsymbol{SAE_a}$: Standard annual energy consumption of the refrigerating appliance (kWh/yr);

$\boldsymbol{VE_{eq}}$: Equivalent volume of the refrigerating appliance;

$\boldsymbol{CH}$: Equal to 50 kWh/yr for refrigerating appliances with a chill compartment with a storage volume of at least 15 litres;

$\boldsymbol{M}$ ve $\boldsymbol{N}$: Coefficients determined according to the refrigerating appliance categories defined in Table 7 of the Annex of the Communiqué.

The energy efficiency indexes are determined according to the energy efficiency classes put in practice as 01.07.2014, specified in the Communiqué on Energy Labeling of Household Refrigerating Appliances (SGM-2012/4) [22]. The average volumes for refrigerators and deep freezers are assumed as 500 and 200 liters, respectively. Accordingly, the stock electricity consumptions of refrigerators and deep freezers for 2019 are estimated as 9,630 GWh and 2,012 GWh, respectively.

4.2. The Electricity Consumption of Washing Machines

The EEI and the SAE for washing machines are presented by Equation 7 and Equation 8 in the Communiqué on Environmentally Sensitive Design Requirements for Household Washing Machines (SGM 2011/18) [23];

$$EEI = \left(\frac{AE_a}{SAE_a}\right) \times 100 \quad (7)$$

$$SAE_a = 47 \times c + 51{,}7 \quad (8)$$

$\boldsymbol{AE_a}$: Annual energy consumption of the washing machine;

$\boldsymbol{SAE_a}$: Standard annual energy consumption of the washing machine (kWh/yr);

$\boldsymbol{c}$: Rated capacity of the washing machine for the standard 60°C cotton programme at full load or the standard 40 °C cotton programme at full load, whichever is the lower.

The energy efficiency indexes are determined according to the energy efficiency classes put in practice as of 22.06.2012, specified in the Communiqué on Energy Labeling of Household Washing Machines (SGM-2012/6) [24]. The capacity and washing cycles of washing machines are assumed as 7 kg and 220 cycles per year, respectively. Accordingly, the stock electricity consumption of washing machines for 2019 is estimated as 4,655 GWh.

4.3. The Electricity Consumption of Tumble Dryers

The EEI and the SAE for tumble driers are presented by Equation 9 and Equation 10 in the Communiqué on Environmentally Sensitive Design Requirements for Household Tumble Driers (SGM 2013/2) [25];

$$EEI = \left(\frac{AE_a}{SAE_a}\right) \times 100 \quad (9)$$

$$SAE_a = 140 \times c^{0.8} \quad (10)$$

$\boldsymbol{AE_a}$: Annual energy consumption of the tumble driers;

$\boldsymbol{SAE_a}$: Standard annual energy consumption of the tumble driers (kWh/yr);

$\boldsymbol{c}$: Rated capacity of the tumble drier for the standard cotton programme.

The energy efficiency indexes are determined according to the energy efficiency classes put in practice as of 16.12.2015, specified in the Communiqué on Energy Labeling of Household Tumble Driers (SGM-2013/6) [26]. The capacity of the tumble driers is assumed as 7 kg. Accordingly, the stock electricity consumption of tumble driers for 2019 is estimated as 422 GWh.

4.4. The Electricity Consumption of Dishwashers

The EEI and the SAE for dishwashers are presented by Equation 11 and Equation 12 in the Communiqué on Environmentally Sensitive Design Requirements for Household Dishwashers (SGM 2011/19) [27];

$$EEI = \left(\frac{AE_a}{SAE_a}\right) \times 100 \quad (11)$$

$$SAE_a = 7 \times ps + 378 \quad (12)$$

$\boldsymbol{AE_a}$: Annual energy consumption of the dishwashers;

$\boldsymbol{SAE_a}$: Standard annual energy consumption of the dishwashers (kWh/yr);

$\boldsymbol{ps}$: Number of place settings.

The energy efficiency indexes are determined according to the energy efficiency classes put in practice as of 22.06.2012, specified in the Communiqué on Energy Labeling of Household Dishwashers (SGM-2012/5) [28]. The number of place settings of dishwashers is assumed as 12. Accordingly, the stock electricity consumption of dishwashers for 2019 is estimated as 4,977 GWh.

4.5. The Electricity Consumption of Electric Ovens

The EEI and the SAE for electric ovens are presented by Equation 13 and Equation 14 in the Communiqué on Environmentally Sensitive Design Requirements for Domestic Ovens and Range Hoods (SGM 2015/7) [29];

$$EEI_{cavity} = \left(\frac{EC_{cavity}}{SEC_{cavity}}\right) \times 100 \quad (13)$$

$$SEC_{cavity} = 0.0042 \times V + 0{,}55 \quad (14)$$

EEI_{cavity}: Energy Efficiency Index for each cavity of a domestic oven;

EC_{cavity}: Energy consumption required to heat a standardised load in a cavity of an electrically heated oven during a cycle, expressed in kW;

SEC_{cavity}: Standard energy consumption required to heat a standardised load in a cavity of an electrically heated oven during a cycle, expressed in kWh;

V: Volume of the cavity of the electric oven in litres (L).

The energy efficiency indexes are determined according to the energy efficiency classes put in practice as of 14.01.2015, specified in the Communiqué on Energy Labeling of Domestic Ovens and Range Hoods (SGM-2015/8) [30]. The average capacity of electric ovens is assumed as 65 L. Accordingly, the stock electricity consumption of electric ovens for 2019 is estimated as 1,310 GWh.

4.6. An Assessment on the Electricity Consumption of Large Household Appliance Stock For the Period 2005-2019

The model results showed that the electricity consumption of large household appliances stock increased from 17,973 GWh in 2005 to 23,067 GWh in 2019. The stock represents 42.5% of residential electricity consumption in 2019.

One of the most remarkable findings in stock modeling is the decrease in electricity consumption of refrigerators by 47% in the period of 2005-2019. Thanks to improvements in energy efficiency, the total electricity consumption of the refrigerator stock firstly reached a plateau and then showed a slight downward trend, as presented in Figure 4. Although the energy efficiency of deep freezers has improved significantly over the years in parallel with the advancements in refrigerators, the increase in the deep freezers stock by 1,226% caused the stock consumption to increase approximately seven times in the last 15 years.

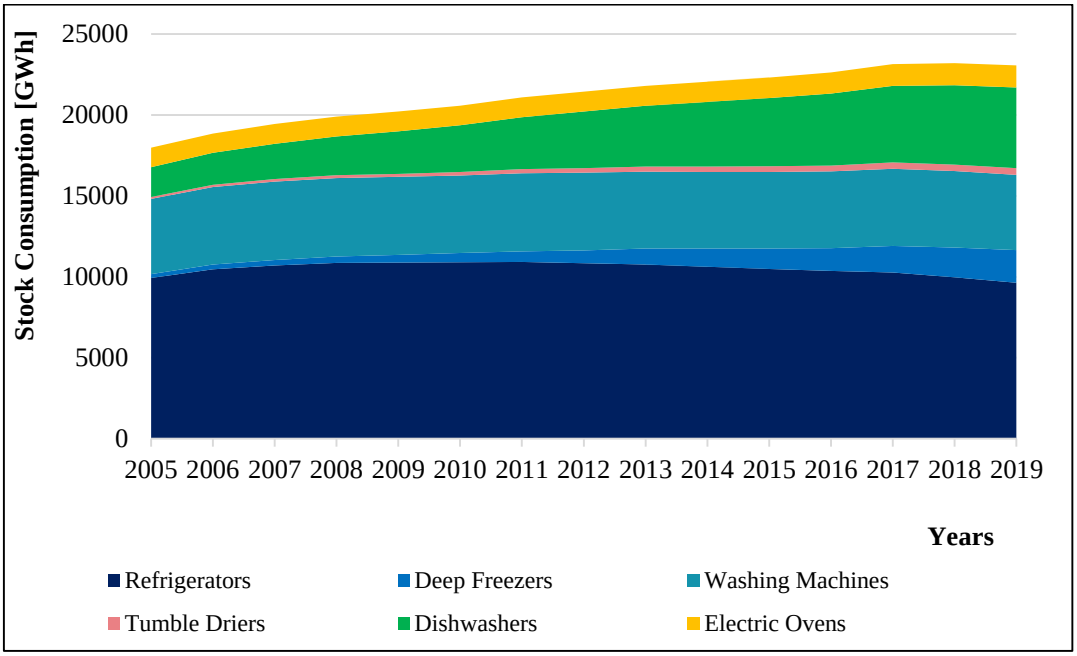


Figure 4. *The estimated electricity consumption of large household appliances stock for the period 2005-2019*

The model also revealed that the electricity consumption of washing machine stock followed similar trends with the electricity consumption of refrigerator stock. Despite a 38% improvement in energy efficiency in the washing machines, the electricity consumption of washing machine stock did not decrease due to the rise in the total stock by 54%. Although the energy efficiency of tumble driers showed a 44% improvement during the analyzed period, the electricity consumption of the tumble driers stock increased by 262% due to the rapid increase in the ownership rates.

Among the large household appliances, the modest energy efficiency improvement was seen in dishwashers with only 19% progress. The electricity consumption of dishwasher stock increased by 170% due to the increase in the stock by 255% over the analysis period. On the other hand, the electric ovens showed a 26% improvement in energy efficiency. The electric oven stock increased by 67%, leading to a rise in electricity consumption by only 15%.

Table 3 summarizes the increase in the stock amount of the large household appliances, the improvements in energy efficiency for each appliance group, and the total stock consumption over the analysis period.

Table 3. *The total change in the stock, energy efficiency improvements in appliances and stock electricity consumption growth for the period 2015-2019*

Appliances	***The Total Change in the Stock [%]***	***Energy Efficiency Improvements in Appliances [%]***	***Stock Electricity Consumption Growth [%]***
Refrigerators	*57*	*47*	*-3*
Deep Freezers	*1,226*	*38*	*716*
Washing Machines	*54*	*38*	*1*
Tumble Driers	*415*	*44*	*262*
Dishwashers	*255*	*19*	*170*
Electric Ovens	*67*	*26*	*15*

Nevertheless, a monitoring program for the large household appliances to meter real-time consumption in the residential sector by considering different socioeconomic groups is recommended for future analyses if the budget is available. Since the implementation of monitoring and audit programs is very costly, a bottom-up approach based on the stock accounting model can estimate the total electricity consumption of large household appliances. However, it is important to keep in mind that several factors may cause a significant difference between the results obtained from the real-time measurement and the stock model. One factor is that the equations in the eco-design and labeling communiqués are based on empirical formulas obtained from laboratory measurements. Thus the appliance usage practices in real life and consumer habits differ significantly from laboratory conditions. Another factor is that the increase in the welfare of the society encourages consumers to buy appliances with larger capacities that hamper to harvest energy efficiency potential.

5. THE FORECASTING OF STOCK ELECTRICITY CONSUMPTION UNTIL 2030

The development of the appliances stock and the progress in energy efficiency in the upcoming years will determine how the total electricity consumption of the household appliances stock evolves. As explained in Section 2, the stock can be estimated by household numbers and ownership rates according to Equation (1).

The correlation between the number of households and the population is examined to determine the number of households for the forecasting period of 2020-2030. Population and household statistics are taken from the TurkStat. The statistics are given in five-year periods between 1955 and 1990, for the years 2000 and 2011, and annually after 2014 by theTurkStat. As a result, a regression model is established and observed that a high positive correlation ($r = 0.9877$) between the number of households and the population exists.

The number of households is estimated for the analysis period with the polynomial regression model using the main scenario on the population projection of the TurkStat. The results are summarized in Table 4.

Table 4. *Estimated number of households obtained from the regression model*

Years	***TurkStat Population Projection***	***Estimated Number of Households***
2020	*83,900,373*	*24,413,582*
2021	*84,908,658*	*24,993,914*
2022	*85,911,035*	*25,578,870*
2023	*86,907,367*	*26,168,226*
2024	*87,885,571*	*26,754,550*
2025	*88,844,934*	*27,336,981*
2026	*89,784,584*	*27,914,548*
2027	*90,703,600*	*28,486,233*
2028	*91,601,117*	*29,051,035*
2029	*92,476,323*	*29,607,975*
2030	*93,328,574*	*30,156,168*

Equipment ownership rates are estimated by assuming that the equipment ownership rates will grow at the same scale in the 2020-2030 period in line with the growth rates from 2005 to 2019. The appliance ownership rates between 2005 and 2019 and estimated ownership rates between 2020 and 2030 are presented in Figure 6.

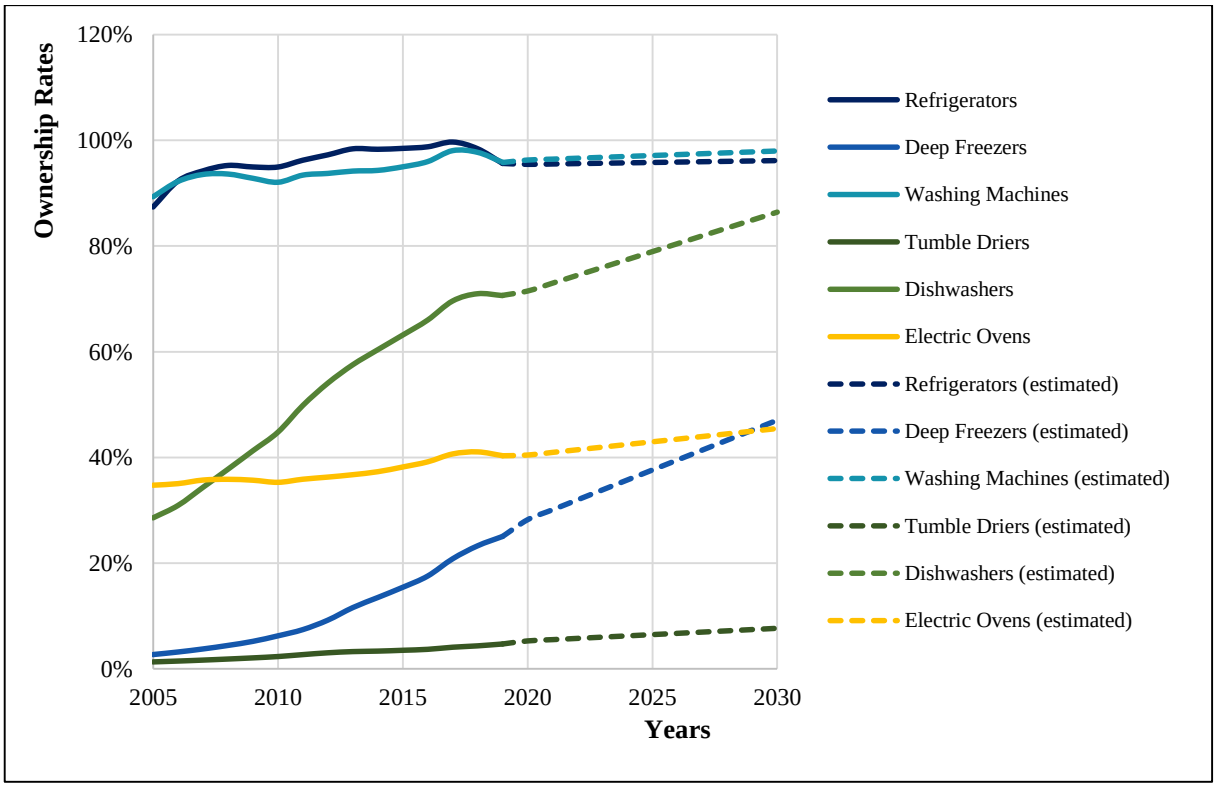


Figure 6. *Development of ownership rates of large household appliances*

Based on these assumptions, Equation (1) is used to calculate the stock amount of large household appliances by multiplying the number of households with the estimated ownership rates. After that, the

annual sales numbers between 2020 and 2030 are estimated. And finally, different scenarios are developed based on the expected sales numbers ± 5%. In addition, two different efficiency scenarios are developed to predict the total electricity consumption of large household appliances stock, assuming that the energy efficiency of the appliances will freeze and will not show any improvements after 2019; and the improvements in energy efficiency will follow the same trend as the improvements presented between 2005 and 2019. Accordingly, the obtained results for forecasted electricity consumption of the appliance stock by 2030 are presented in Table 5, and the electricity consumption projections until 2030 are shown in Figure 7.

Table5. *The forecasted appliance stock and its electricity consumption by 2030 based on the developed scenarios*

Appliances	**Stock in 2019**	**Forecasted Stock in 2030**	**Stock Electricity Consumption in 2019**	**Scenario 1: Sales=Estimated Efficiency=Frozen**	**Scenario 2: Sales=Estimated Efficiency=Past Trend**	**Scenario 3: Sales=Estimated-%5 Efficiency=Frozen**	**Scenario 4: Sales=Estimated-%5 Efficiency=Past Trend**	**Scenario 5: Sales=Estimated+%5 Efficiency=Frozen**	**Scenario 6: Sales=Estimated+%5 Efficiency=Past Trend**
	Units		GWh	GWh (2030)					
Refrigerators	22,953,045	28,992,195	9,630	9,480	7,596	9,087	7,296	9,874	7,895
Deep Freezers	6,018,092	14,187,406	2,012	4,402	3,643	4,215	3,494	4,589	3,792
Washing Machines	22,997,003	29,536,540	4,655	5,126	4,320	4,913	4,148	5,338	4,492
Tumble Driers	1,128,863	2,310,043	422	645	519	617	498	672	540
Dishwashers	16,954,196	26,052,521	4,977	7,152	6,567	6,846	6,290	7,459	6,845
Electric Ovens	9,680,721	13,717,994	1,370	1,847	1,644	1,766	1,573	1,928	1,715
Total Stock Consumption			23,067	28,652	24,289	27,444	23,299	29,860	25,279

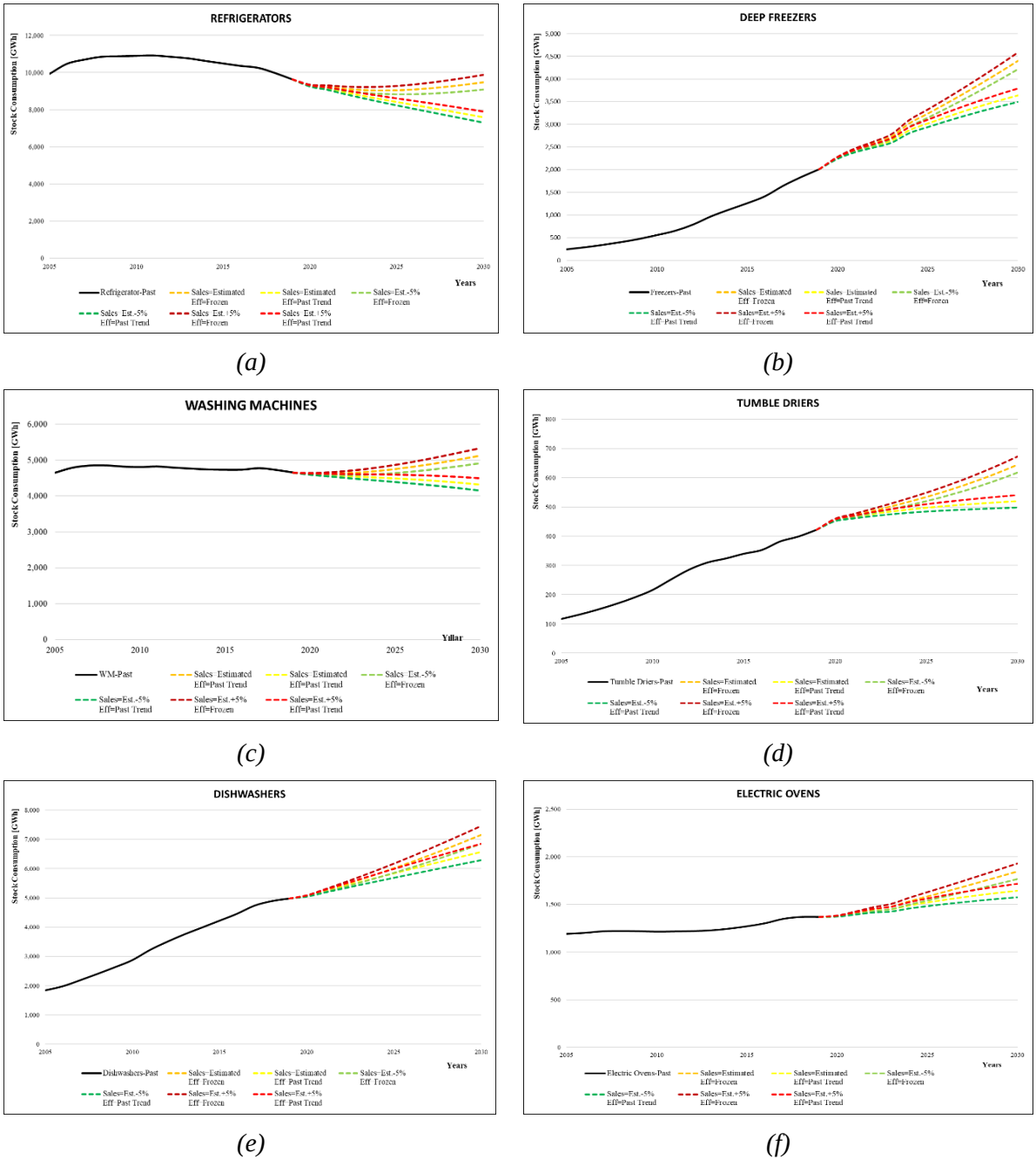


Figure 7. *The projections on the electricity consumption of large household appliances by 2030 (a) Refrigerators (b) Deep freezers (c) Washing machines (d) Tumble driers (e) Dishwashers (f) Electric ovens*

The forecast results on refrigerators show that the electricity consumption of the refrigerator stock will decrease in five scenarios, and a significant savings potential can be achieved through improvements in energy efficiency. With the decline in refrigerator sales and increase in energy efficiency, the stock electricity consumption may decrease to 24% until 2030 compared to the 2019 level.

In line with the projections indicating that deep freezer stock will increase more than twice, the electricity consumption of the deep freezer stock is expected to increase by at least 74% despite the improvements in energy efficiency.

On the other hand, the electricity consumption growth of the washing machine stock is more uncertain over the projection period. Depending on the sales and improvements in energy efficiency, the stock electricity consumption may increase, decrease or reach a plateau until 2030. Even in the scenario in

which the consumption is predicted to be the highest, the increase rate in the electricity consumption of the stock is expected to be 15%.

The electricity consumption of the tumble driers stock is expected to increase due to the rise in ownership rates. However, this rise is also expected to be suppressed by the improvements in energy efficiency. The increase in the rate of the stock electricity consumption is forecasted to be between 18% and 53%.

Based on the expectation of a 54% increase in the dishwasher stock, the electricity consumption is expected to rise by 26-50% until 2030. The decrease in sales and improvements in energy efficiency may pressure the rise in the stock electricity consumption.

The electricity consumption of electric ovens is expected to increase by 41%, depending on the increase in the electric ovens stock. Again, this increase may remain at more modest levels with the annual sales trends or efficiency gains.

6. CONCLUSION

As one of the most important policy tools in combating climate change, energy efficiency plays a significant role in meeting countries' energy demand, which is closely related to the increase in the population and welfare of society. Policymakers need to be supported with the analyses that show the main trends in energy consumption and how the consumption will evolve to determine the most appropriate energy efficiency policies in an environment with limited resources.

This study aims to contribute the analyses and research needed to determine the suitable policy options for the residential sector, representing one-fifth of Turkey’s final energy consumption. For this purpose, a bottom-up approach based on the stock accounting model on large household appliances was implemented since appliances promise significant energy efficiency potential. Firstly, the stock of refrigerators, deep freezers, washing machines, tumble dryers, dishwashers, and electric ovens in use were estimated, and their electricity consumption was determined from 2005 to 2019. Analysis revealed that the stock electricity consumption increased by 42.5% compared to the 2005 level and reached 23,067 GWh in 2019.

The refrigerator and washing machine stock increased by 57% and 54%, respectively, between 2005 and 2019. On the other hand, the energy efficiency of refrigerators and washing machines improved by 20% and 25%, respectively. These activities caused the stock electricity consumption to surpass the upward trend and reach a plateau.

The stock electricity consumption of deep freezers, tumble driers, and dishwashers increased by 1.226%, 415%, and 255%, respectively, due to the rise in household ownership rates. The efficiencies of deep freezers, tumble driers, and dishwashers improved by 38%, 44%, and 19%, respectively. As a result of the rapid escalation in the stock, the stock electricity consumption of appliance groups increased by 1.7 to 7 times.

Consequently, the achieved gains through energy efficiency improvements in refrigerators and washing machines prevent the increase in energy consumption driven by the stock growth. However, the electricity consumption increased significantly for the rest of the appliance groups despite the improvements in energy efficiency since the household ownership rates grew dramatically between 2005 and 2019.

In addition, six different scenarios were developed, and projections were made depending on the estimated annual sales and the improvement in energy efficiency to forecast the development of the electricity consumption of large household appliance stock between 2020 and 2030. The results showed that the electricity consumption of refrigerator stock would decrease in five scenarios, although the refrigerator stock was expected to increase from 23 million in 2019 to 29 million in 2030. These results imply that the market transformation of efficient refrigerator appliances can be achieved without any social intervention, thanks to improvements in energy efficiency. Also, the deep freezer stock is expected to increase from 6 million to 14.2 million in the projection period, which will cause an increase from 2 TWh to over 4 TWh in the electricity consumption of deep freezer stock. Like the path followed by refrigerator stock, washing machine stock is predicted to rise from 23 million to 29.5 million. However,

the trend of the electricity consumption of washing machine stock is more uncertain. The future sales will determine how the electricity consumption of washing machine stock will evolve.

The electricity consumption of tumble dryers, dishwashers, and electric ovens stock is expected to increase in all scenarios during the projection period. The tumble dryer stock will increase from 1.1 million to 2.3 million, the dishwasher stock from 17 million to 26 million, and the electric oven stock from 9.7 million to 13.7 million until 2030. According to the scenario in which estimated sales are used, and energy efficiency follows the past trends, the electricity consumptions of clothes dryers, dishwashers, and electric ovens stock are forecasted to reach 519 GWh from 422 GWh, 6,567 GWh from 4,977 GWh, and 1,644 GWh from 1,370 GWh, respectively. As a result, the total electricity consumption of large household appliances is expected to rise by 5.3% compared to the 2019 level and reach 24,289 GWh in 2030.

The ownership rates of large household appliances are expected to increase with the rise in household welfare. However, the stock electricity consumption is forecasted to increase more modestly than the past trend despite the increasing stock. The tendency of the electricity consumption of large household appliances is tried to be determined with the scenarios developed. In this way, this study aimed to provide the required data sets that policymakers will need to determine suitable policy options. Detailed policy analysis is recommended for promoting the market transformation of efficient appliances for future studies.

ACKNOWLEDGEMENT

The authors would like to thank the experts from the Department of Energy Efficiency and Environment of the Turkish Ministry of Energy and Natural Resources who contributed to the maturation of this study with their valuable comments, and the anonymous referees for constructive criticism of the manuscript. The opinions and comments stated in this study are strictly those of the authors and do not purport to reflect the opinions or views of the institutions they are affiliated with.

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