# Bottom-up scenario calculations for 10 world regions reveal worldwide efficiency potentials of about 50 % for refrigeration and washing

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## Abstract

Domestic refrigerators, freezers and washing machines are among the most widely used electrical appliances all around the world. Currently, about 1.4 billion domestic cold appliances and 840 million washing machines worldwide use about 740 TWh electricity, which is more than Germany's total electricity consumption, cause $CO_2$eq emissions of 500 million tons and use 19 $km^3$ of water a year.

Although the specific electricity consumption per volume of cold appliances or per kg laundry in washing machines has decreased during recent years due to technical progress, total worldwide energy consumption of these appliances is on the increase.

In the framework of a new website "bigEE.net - Your guide to energy efficiency in buildings", which aims to provide information about technical options but also about policies to support the development of energy-efficient appliances, bottom-up scenario calculations were carried out for all 10 IPCC world regions by the Wuppertal Institute. Results show that about half of the specific energy consumption could be saved with the most energy-efficient appliances available today, and even higher savings will be possible with next generation technologies by 2030. According to the model, these savings are usually very cost-effective. The scenario results and policy strategies to address these potentials will be presented in this paper.

## Introduction

Domestic refrigerators, freezers and washing machines are among the most widely used electrical appliances in the residential sector all around the world, contributing significantly by their electricity consumption to the greenhouse effect. Therefore political instruments focus on the introduction of labels, minimum energy performance standards (MEPS) or subsidies in order to improve the efficiency of appliances on the market. In addition, washing machines are related to water consumption, which could cause problems in regions of the world with drinking water shortages.

This raises the question of how high the worldwide electricity and water consumption of household appliances in the different regions of the world is today and how the number of devices and their consumption per unit and so their total consumption for cold appliances and washing machines will develop in the future in the business as usual case.

It is well known from international appliances databases like "Topten" (www.topten.info), which present the most efficient appliances worldwide, that significant differences in consumption between the average and the most efficient appliances exist. Based on this, the questions arise, what is the saving potential if only the most efficient appliances are purchased and what kind of policies and policy instruments are required for such a market transformation.

## Distribution of current worldwide electricity and water consumption of domestic cold appliances and washing machines

### Distribution of current worldwide electricity consumption of domestic cold appliances

Country specific bottom-up analysis – based on several sources[1] all around the world – shows that currently 1.4 billion refrigerators, fridge freezers and freezers are in use in households. The average electricity consumption of these cold appliances amounts to about 450 kWh per year and appliance. With an annual total electricity consumption of 650 TWh, they account for almost 14 % of the electricity consumption of the residential sector and cause worldwide annual greenhouse gas emissions of 440 million tons of $CO_2$eq.

Thereby, the distribution of domestic cold appliances varies widely between the different world regions. In North America (NAM), Western Europe (WEU) and Pacific OECD (PAO) about 1.7 people own one cold appliance, whereas in other world regions the level of ownership is still well below saturation (see figure 1). This is expected to change significantly in the future, especially due to the booming markets in Asia (CLASP / LBNL 2007).

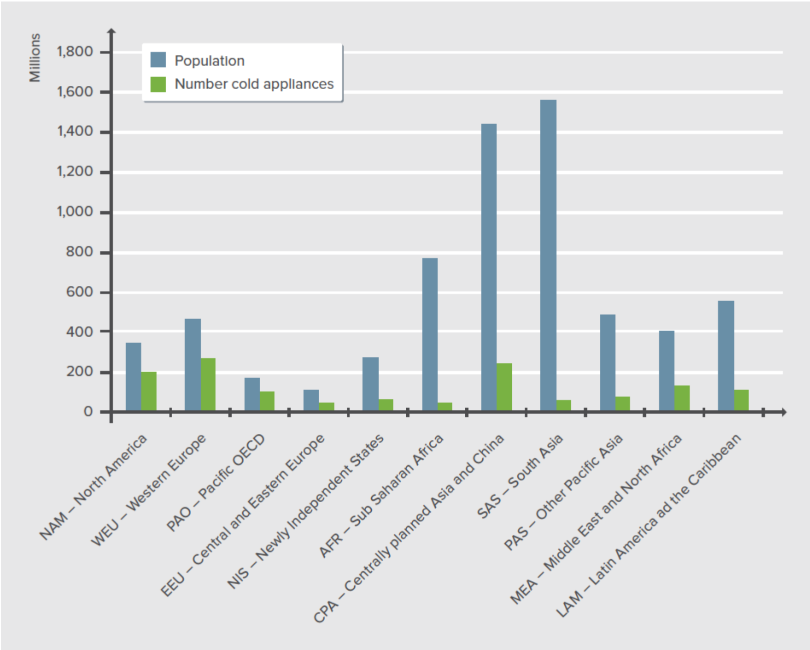


**Figure 1: World population and number of cold appliances in the different world regions according to IPCC systematic in 2010. (Reference: Own calculation based on WEC 2009, IEA 2010 and other reports)**

The worldwide uneven distribution of domestic cold appliances as well as their different size and efficiency levels lead to large differences in electricity consumption of this group of appliances in different world regions.

**Distribution of current worldwide electricity and water consumption of domestic washing machines**

The country specific bottom-up analysis for washing machines[2] shows that about 840 million domestic washing machines are in use worldwide. The average annual consumption of each of these washing

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[1] IEA 2010, WEC 2009, Department of the Environment, Water, Heritage and the Arts 2008, Hollanda 2010, Schaeffer 2008, Vendrusculo 2008, Natural Resources Canada 2010, Fridley 2007, 2008, Lin 2006, Lu 2006, Bertoldi 2006, Ademe 2009, Presutto 2007, Qader 2009, Hagan 2006, The World Bank 2006, 2008, 2009, De la Rue du Can 2009, Letschert 2007, Murakami 2009, Cabanas 2009, WECS 2010, Ministry of Economic Development 2010, Foran 2010, DOE 2009

[2] Based on data by Pakula / Stamminger (2010) and other available reports (e.g. AATCC 2011, ACEEE 2011, Berkholz et al. 2006, Biermayer / Lin 2004, Faberi et al. 2007, GfK 2011, Josephy et al. 2011, RECS 2009, IEA-4E 2011)

machines amounts to about 110 kWh of electricity and 23 $m^3$ of water. With an electricity consumption of 92 TWh per year, they account for about 2 % of the total electricity consumption of the residential sector worldwide. Annually, washing machines also consume about 19 billion $m^3$ of water and cause worldwide greenhouse gas emissions of 62 million tons of $CO_2$eq.

Thereby, the distribution of domestic washing machines is very uneven between different world regions. In the world regions NAM, WEU and PAO, on average 2.9 to 4.4 people own one washing machine (see Figure 2). In other world regions the level of ownership is still well below saturation. For example in Sub Saharan Africa (AFR), there is on average one washing machine per 125 persons. However, this is also expected to change significantly in the future, especially in the booming markets in Asia (CLASP / LBNL 2007).

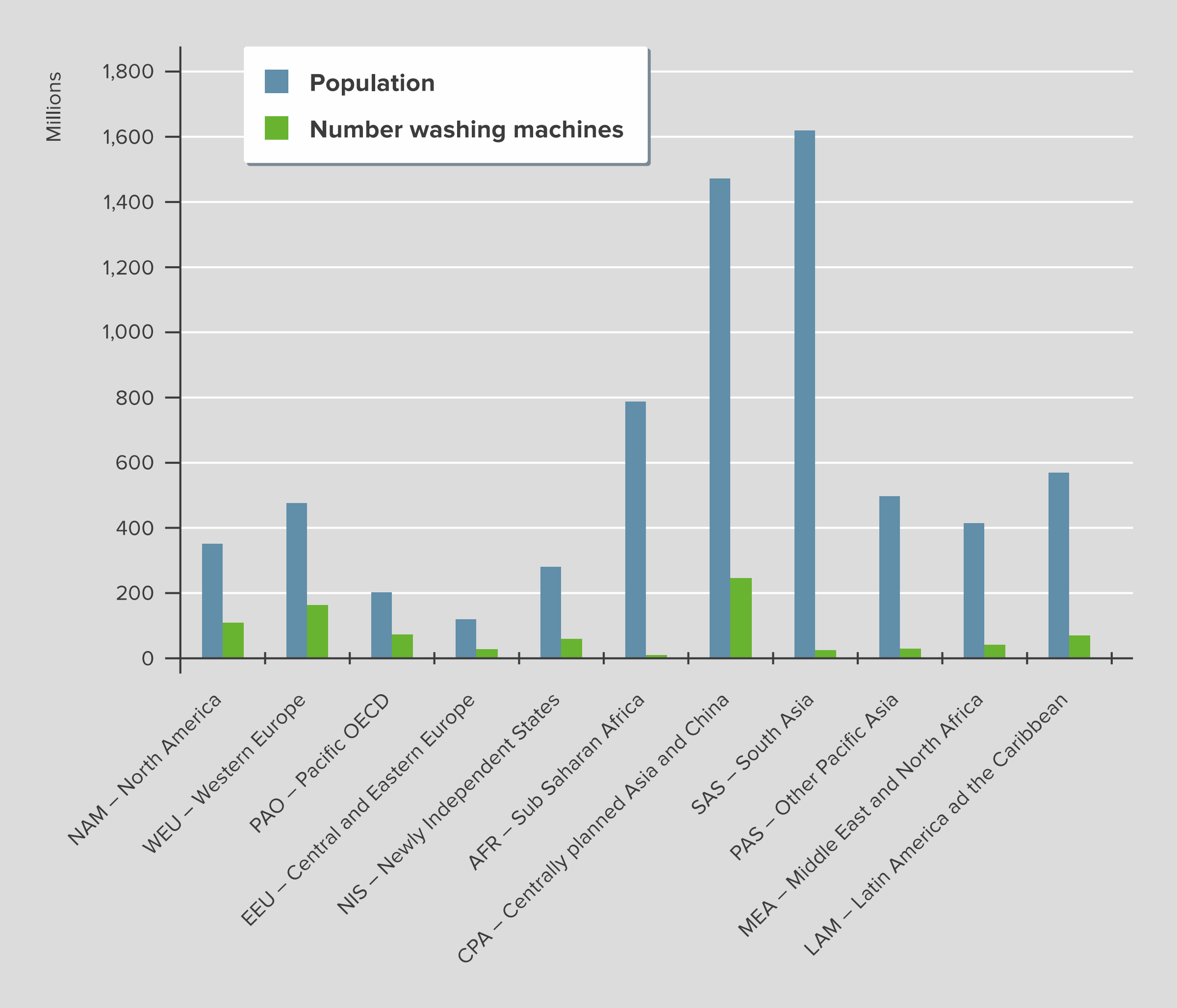


**Figure 2: World population and number of washing machines in the different world regions according to IPCC systematic in 2010 (Reference: Own calculation based on IEA, Pakula / Stamminger (2010) and other reports)**

The uneven distribution of domestic washing machines worldwide, different types of machines (different technologies like horizontal and vertical axis washing machines) and their various efficiency levels, as well as different wash habits and practices (e.g. wash temperatures, number of wash cycles per year) lead to substantial disparities in electricity and water consumption within the different world regions.

**Types of automatic washing machines, main features and geographical distribution**

While the technology for refrigerators, fridge freezers and freezers does not vary significantly worldwide, domestic washing machines can be assigned to two different main categories:

***- Horizontal axis machines***

In horizontal axis machines (Figure 3), only the bottom of the washtub is filled with water. Compared to vertical axis machines, significantly less water per wash cycle is used. Horizontal axis machines are commonly equipped with an internal electric water heating system. Hence, the energy consumption heavily depends on the chosen washing temperature. Modern washing machines with horizontal axis technology have an automatic load sensing function in order to reduce water and electricity consumption in response to consumer loads that are smaller than the rated capacity. Horizontal axis machines are gaining market shares in almost all markets worldwide (Pakula / Stamminger 2010).

**Figure 3: Horizontal axis washing machine, front loader configuration. Source: iStockphoto (2013)**

***- Vertical axis machines***

Traditionally, the tub of vertical axis machines (Figure 4) is entirely filled with water. Although most modern vertical axis machines also have automatic water level settings or the user can set the water level manually, even present-day machines often consume about twice as much water per wash cycle as horizontal axis machines. Vertical axis machines are usually not equipped with an integrated electric water heating system, but warm washes can be done by using hot water from external sources. This additional energy needed to heat up water from the tap is hard to estimate, because it can be done by electricity or other energy sources like gas, coal, oil or solar power (Pakula / Stamminger 2010). Vertical axis machines are still most widespread in America, Australia and Asia.

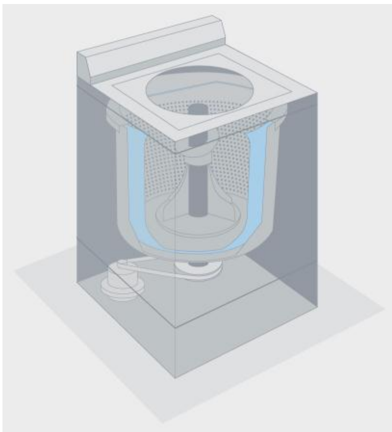

**Figure 4: Vertical axis washing machine (Agitator type). Source: own illustration (www.bigee.net 2013)**

Within these two basic categories, appliances vary in their configurations and the range of options. The most common types of automatic washing machines worldwide are:

***Horizontal axis, front- or top loading washing machine (also known as "front-loader" or "drum type" machines).***

These machines show large energy- and water savings when comparing most efficient to inefficient average models on the market, especially in Europe as such washing machines are most popular in this region. Additionally, the share of horizontal axis machines is also steadily rising in most other markets worldwide. Switching from vertical axis to horizontal axis machines offers another important water and energy saving potential, because horizontal axis machines usually consume significantly less (pre-)heated water per wash cycle than vertical axis machines.

In a horizontal axis washing machine, the textiles are placed in a horizontal drum and partially immersed in the washing water. The mechanical action is provided by the rotation of the drum about its axis. The drum is accessible from one single door on the front (front-loader configuration) or from several adjacent doors on the top of the machine and the drum (top-loader configuration). Many traditional horizontal axis machines have a minimum program temperature of 30°C, which means that these machines use electricity to heat up water even in the coldest program selectable (Pakula / Stamminger 2010). Since the introduction of high efficient low-temperature detergents, many contemporary washing machines have been equipped with 20°C, 15°C and “cold wash” programs to reduce the energy consumption significantly.

Horizontal axis drum type washing machines are used mainly in WEU/EEU, and increasingly in most other markets (Pakula / Stamminger 2010).

***Vertical axis, top loading agitator washing machines***

This type of washing machines shows large energy- and water savings compared to inefficient models on the market, especially in North- and Latin America, as such washing machines are popular in these regions. If cold water is used, the energy consumption per wash cycle is low. But although the majority of washing machines in North America are vertical axis machines without internal heating system, the average washing temperature is reported to be at about 30°C, which causes an electricity consumption of about 0.43 kWh per wash cycle (Pakula / Stamminger 2010). This might include warm water from the tap and thus energy from external resources, which are hard to quantify.

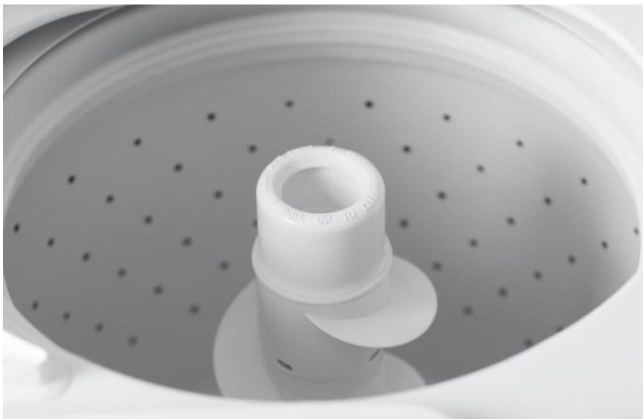

**Figure 5: Vertical axis washing machine, agitator. Source: iStockphoto (2013)**

***Vertical axis, top loading impeller washing machines***

These machines show large energy- and water savings compared to inefficient models on the market, especially in Asia (China, South Korea, Japan) and Australia as such washing machines are popular in these regions. The mechanical swirl-action is produced by a device, which is named by most manufacturers as ‘impeller’, rotating about its axis (Figure 5). During operation, the uppermost point of this device is substantially below the minimum water level (Faberi et al. 2007). This type of washing machines is traditionally designed as top-loading device (accessible from one single door on the top). If cold water is used, the energy consumption per wash cycle is low. However, although vertical axis impeller machines are usually not equipped with an internal water heating system, the usage of preheated water from external sources through a separate hot water inlet is commonly possible and is often reported (Pakula / Stamminger 2010).

**Figure 6: Vertical axis ‘high-efficiency’ washing machine, Impeller, Source: iStockphoto (2013)**

Occasionally, impeller-type washing machines are also referred to as “high efficient washers” (especially in North America) due to an improved washing process and a reduced water usage compared to inefficient agitator-type models. Nevertheless, a higher usage of bleach and other detergents, as well as washing treatments with relevant amounts of water and energy outside the washing machine may indicate only a mediocre level of washing performance provided also by these machines.

## Techno-economical saving potentials

### Description of the model calculations

The bottom-up model used for the purposes of this paper is a simplified version of the DEESY Stock Model developed by the Wuppertal Institute, which assesses scenarios with focus on energy and water consumption as well as costs[3]. According to the development of the stock volume[4] and the typical lifetime of an appliance (15 years for cold appliances and washing machines), the model calculates the per-annum market volume for each year of the covered scenario time period (2010 to 2030), including the first-time acquisition as well as the replacement of end-of-life appliances. The techno-economical characteristics of the typical product purchased in a certain year are dependent on the Base Case and Best Available Technology (BAT) available at the time of purchase and on a weighting factor reflecting the level of energy efficiency for the respective scenario. Future BAT technology, named BNAT (best not yet available technology), is becoming more efficient in terms of electricity and water consumption each year and is regarded in the model as well as additional costs for these product improvements. The modelling of the historical appliance stock purchased within the 15 years in advance of the covered scenario time period (1995 to 2009) is essentially based on the same methodology. However, the development of these preceding years is additionally calibrated for the base year (2010) to meet the expected stock volume in this year[5].

In order to assess the techno-economical saving potential of the most efficient appliances, subsequently two scenarios are compared: a Baseline[6] scenario, in which Base Case products have 100 % market share after 2010, and an Energy Efficiency scenario, assuming a 100 % market share of BAT products. The characteristics of the Base Case and BAT products are based on the country specific bottom-up analysis, which was performed as preparatory work for the modelling. Account has been taken to different regional economic and market specific conditions. Consequently, the savings in terms of energy, water and costs depend on the year and the world region considered respectively.

### Results for domestic cold appliances

As the results from the model calculations show, large efficiency improvements can be achieved globally if the most energy-efficient appliances available on the market are systematically purchased instead of standard technologies. Despite the expected 27 % increase of the worldwide cold appliance stock in use by 2020 and the 62 % increase by 2030, the annual electricity consumption of domestic cold appliances could be reduced from 650 TWh in 2010 to 475 TWh by 2020 and to about 400 TWh by 2030 (see Figure 7) with the best available technologies on the market. The potential would be even larger and achieved faster if old and inefficient cold appliances would be replaced and recycled before they have reached the end of their technical lifetime.

The analysis also shows that the electricity consumption of domestic cold appliances per unit varies very much between the different world regions. As this consumption is not proportional to the typical appliances size in the respective region it can only be explained by different efficiencies.

[3] For more information on the DEESY stock-based bottom-up accounting model see ECN (2011)

[4] Future stock volume (2020, 2030) based on CLASP PAMS2007 model (CLASP / LBNL 2007)

[5] Existing stock volume of domestic cold appliances in 2010 is based on own elaboration by Wuppertal Institute.

[6] The baseline scenario assumes a moderate efficiency improvement according to historical trends

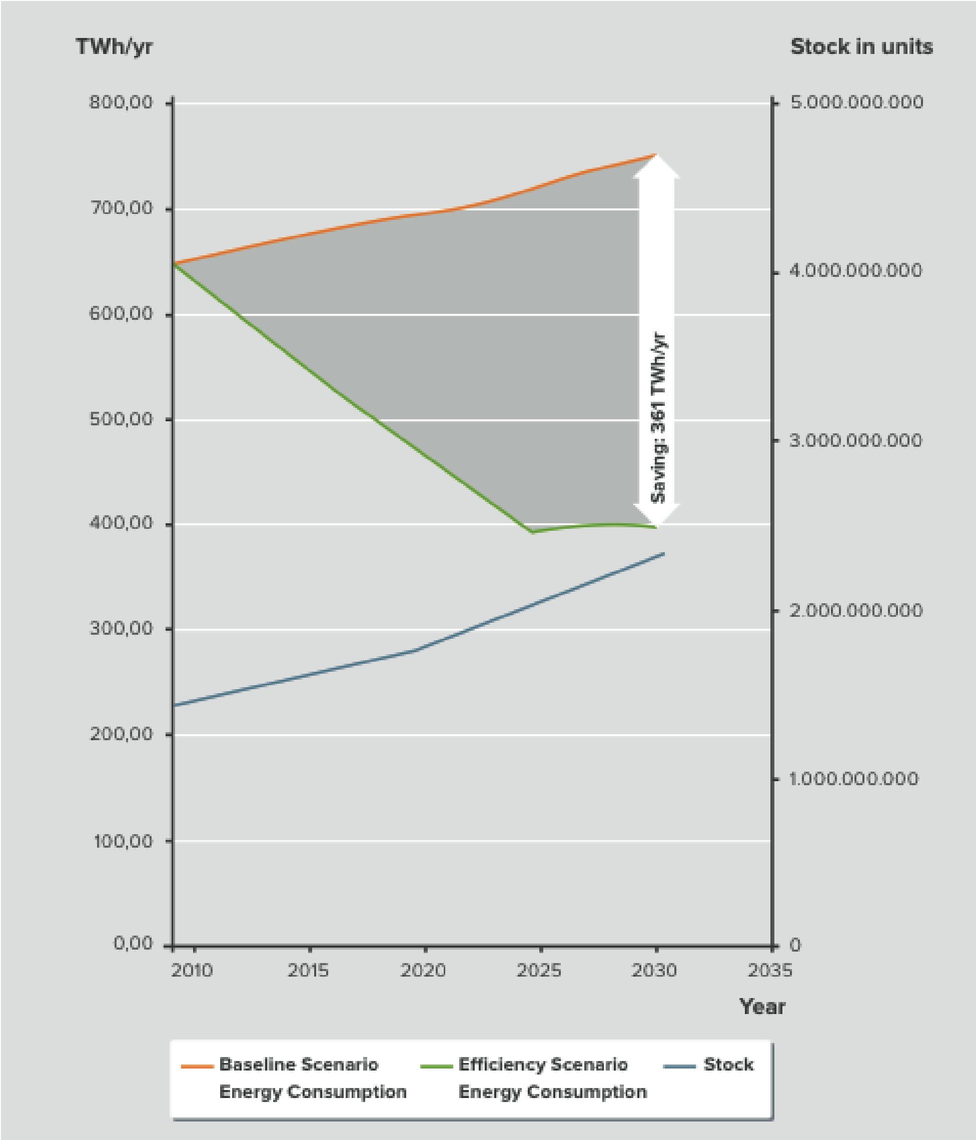


**Figure 7: Development of the worldwide domestic cold appliances stock 2010-2030 and the total electricity consumption in the Baseline Scenario versus the Efficiency (BAT) Scenario. Source: own calculation; WEC 2009 and IEA 2010 for current electricity consumption and population data**

| **World regions** | **Present situation** | | **Results of model calculations for 2030** | | | |
|---|---|---|---|---|---|---|
| | Stock number domestic cold appliances [m] | Electricity consumption [TWh/year] | Stock number domestic cold appliances [m] | Baseline Scenario electricity consumption [TWh/year] | Efficiency Scenario electricity consumption [TWh/year] | Electricity savings Efficiency Scenario vs. Baseline Scenario |
| **NAM** | 209 | 123.3 | 265 | 117.7 | 62.0 | 47 % |
| **WEU / EEU** | 335 | 126.3 | 411 | 111.1 | 59.1 | 47 % |

| | | | | | | |
|---|---|---|---|---|---|---|
| **PAO** | 108 | 48.6 | 137 | 49.6 | 28.0 | 44 % |
| **NIS** | 69 | 28.5 | 125 | 39.2 | 17.8 | 54 % |
| **AFR** | 49 | 20.4 | 107 | 33.7 | 18.1 | 46 % |
| **CPA** | 260 | 108.3 | 570 | 179.7 | 96.5 | 46 % |
| **SAS** | 63 | 40.2 | 138 | 54.5 | 29.4 | 46 % |
| **PAS** | 82 | 31.8 | 148 | 48.1 | 29.2 | 39 % |
| **MEA** | 142 | 60.4 | 256 | 80.9 | 43.5 | 46 % |
| **LAM** | 118 | 61.6 | 175 | 60.2 | 30.1 | 50 % |
| **Total** | **1,435** | **649.4** | **2,332** | **774.8** | **413.8** | **47 %** |

If every time a domestic cold appliance is purchased in the efficiency scenario, the most efficient model is chosen instead of a standard model, 240 TWh of electricity and 158 million tons of $CO_2$-eq can be saved per year in 2020. Moreover, in 2030, even 360 TWh of electricity and 235 million tons of $CO_2$-eq can be saved per year. Based on the assumptions of the performed model calculation[7], over the whole lifetime of the energy-efficient refrigerators and freezers purchased until 2030, the total economic benefit (discounted) is 193 billion EUR[8] for end-user perspective and 105 billion EUR for societal perspective. However, the actually achievable savings are dependent on varying investment costs and electricity prices in the different world regions. For example, the incremental investment costs for BAT could be very low in countries where already high efficiency standards are established and high where no market and no manufacturer of efficient cold appliances exist.

Therefore, regionally optimized policy measures and programs have to address this technical efficiency improvement potential under consideration of cost-effectiveness for society as well as for end-users.

**Results for washing machines**

In order to assess the techno-economical saving potential of the most energy and water efficient washing machines, an identical approach to the domestic cold appliances has been followed. This also includes a comprehensive country specific bottom-up analysis and the same two-scenario comparison based on a typical lifetime of 15 years for washing machines.

As the results from the model calculations show, large efficiency improvements can be achieved globally if the most energy and water efficient washing machines available on the market are systematically purchased instead of standard technologies. By this means, a relative decoupling of the growth of the worldwide annual energy and water consumption and the increasing stock of domestic washing machines can be achieved. While the stock is expected to grow by 36 % until 2020, in the efficiency scenario the energy consumption would only increase by 12 % and the water consumption by 5 %. Although the stock is expected to grow by another 26 % until 2030, the increase of the energy and water consumption would be limited to half of that value (13 %), each for energy as well as water consumption (see Figure 8 and Figure 9). Thereby, higher living standards, represented by increasing appliance ownership rates, a more frequent usage of warm wash cycles as well as a technological change towards more water efficient horizontal axis washing machines already have

[7] Presuming an average worldwide electricity price for all world regions.

[8] For the purposes of the model calculation, all monetary figures are provided in EUR 2010

been anticipated. In contrast, in the baseline scenario, the energy and water consumption would increase by 43 % and 15 % by 2020 and additionally by 35 % and 18 % by 2030.

If every time a washing machine is purchased, the most energy- and water-efficient model is chosen instead of a standard model, 31.5 TWh of electricity, 2.2 billion $m^3$ and 20.8 million tons of $CO_2$-eq can be saved per year in 2020. Moreover, in 2030, even 65 TWh of electricity, 3.6 billion $m^3$ of water and 42.4 million tons of $CO_2$-eq can be saved per year.

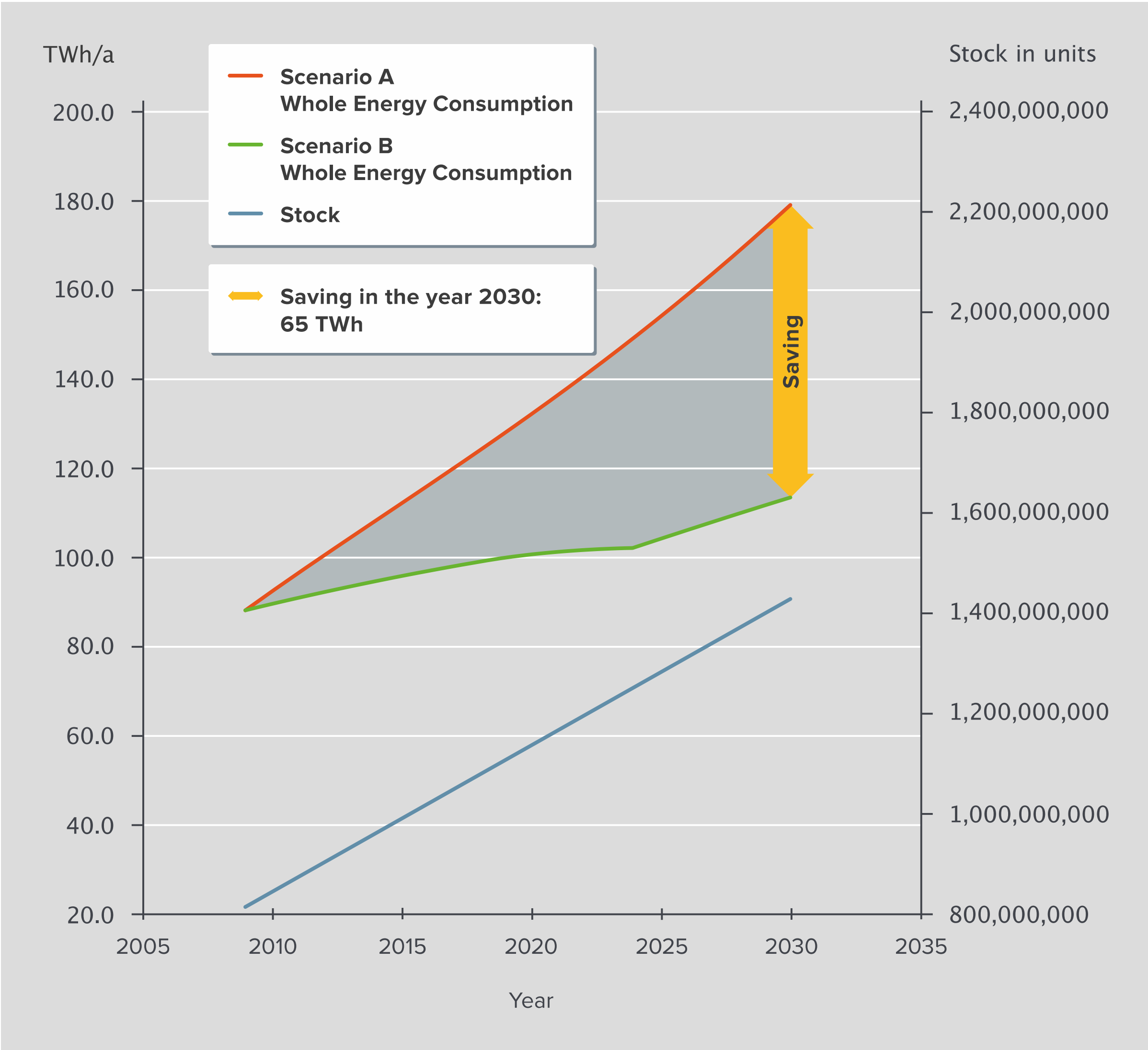


**Figure 8: Total electricity consumption of domestic washing machines, Baseline Scenario compared to the Efficiency Scenario (Source: own calculation; WEC 2009 and IEA 2010 for current electricity consumption and population data)**

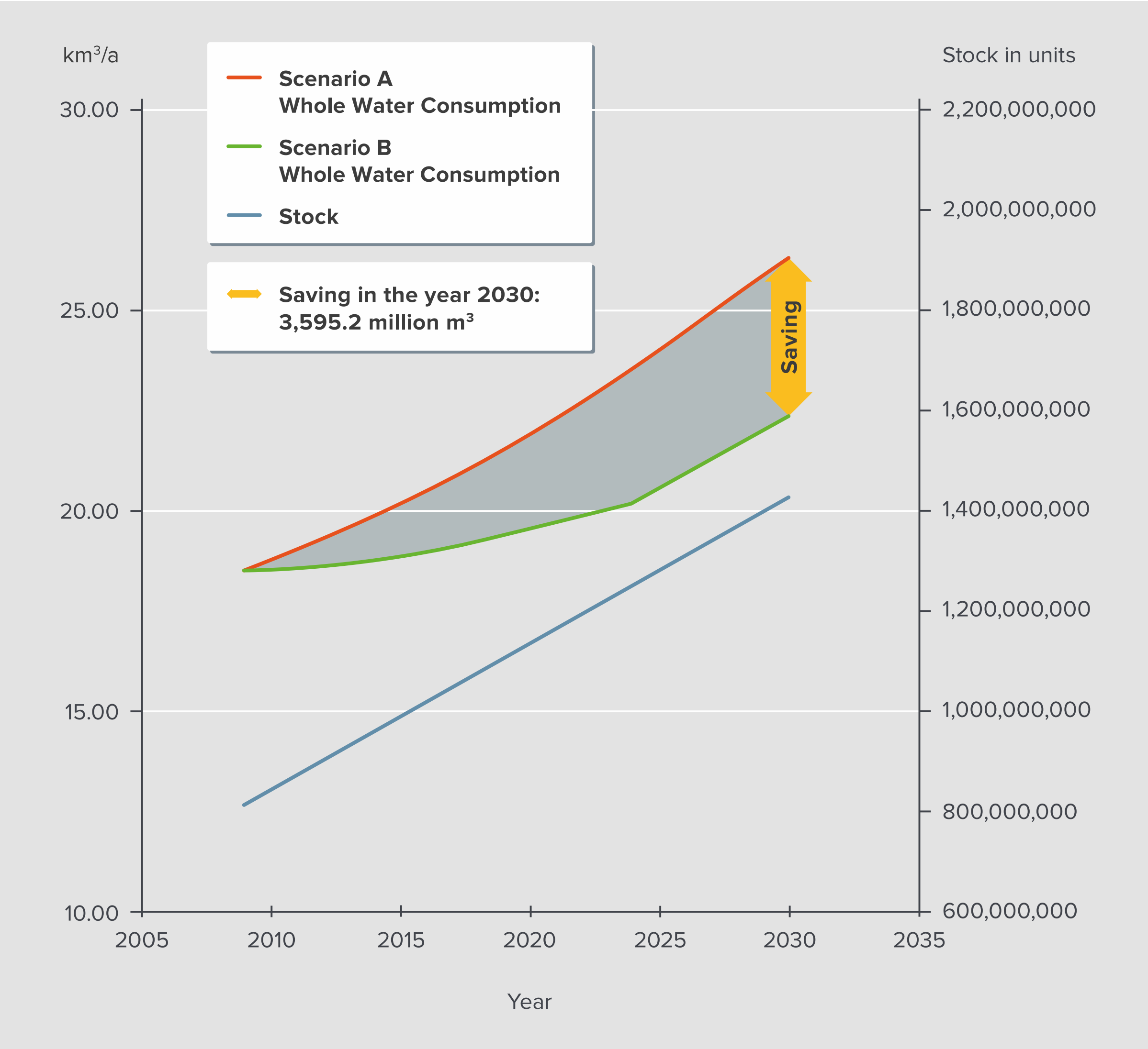


**Figure 9: Total water consumption of domestic washing machines, Baseline Scenario compared to the Efficiency Scenario (Source: own calculation; WEC 2009 and IEA 2010 for population data)**

| World regions | Present situation | | Results of model calculations for 2030 | | | |
|---|---|---|---|---|---|---|
| | Stock number domestic washing machines [m] | Electricity consumption [TWh/year] | Stock number domestic washing machines [m] | Baseline Scenario electricity consumptio n [TWh/year] | Efficiency Scenario electricity consumptio n [TWh/year] | Electricity savings Efficiency Scenario vs. Baseline Scenario |
| **AFR** | 6.4 | 1.3 | 19.9 | 2.63 | 1.78 | 32.2% |
| **CPA** | 247.4 | 7.4 | 462.0 | 67.65 | 34.46 | 49.1% |
| **LAM** | 69.2 | 5.6 | 124.3 | 9.35 | 7.24 | 22.6% |

| | | | | | | |
|---|---|---|---|---|---|---|
| **MEA** | 38.5 | 9.3 | 70.5 | 13.69 | 9.51 | 30.6% |
| **NAM** | 106.8 | 15.9 | 148.6 | 18.87 | 14.56 | 22.8% |
| **NIS** | 58.3 | 11.3 | 65.2 | 8.64 | 5.91 | 31.6% |
| **PAO** | 71.0 | 6.1 | 85.7 | 7.48 | 5.48 | 26.8% |
| **PAS** | 28.4 | 2.7 | 70.9 | 7.25 | 4.80 | 33.8% |
| **SAS** | 20.7 | 1.6 | 151.0 | 13.61 | 8.31 | 38.9% |
| **WEU / EEU** | 192.9 | 31.0 | 239.8 | 29.11 | 21.21 | 27.1% |
| **Total** | **839.6** | **92.2** | **1,437.9** | **178.3** | **113.3** | **36.5%** |

| **World regions** | **Present situation** | | **Results of model calculations for 2030** | | | |
|---|---|---|---|---|---|---|
| | Stock number domestic washing machines [m] | Water consumption [$km^3$/year] | Stock number domestic washing machines [m] | Baseline Scenario water consumption [$km^3$/year] | Efficiency Scenario water consumption [$km^3$/year] | Water savings Efficiency Scenario vs. Baseline Scenario |
| **AFR** | 6.4 | 0.2 | 19.9 | 0.47 | 0.41 | 13% |
| **CPA** | 247.4 | 3.3 | 462.0 | 5.16 | 4.02 | 22% |
| **LAM** | 69.2 | 2.4 | 124.3 | 3.12 | 2.79 | 11% |
| **MEA** | 38.5 | 1.1 | 70.5 | 1.19 | 1.04 | 12% |
| **NAM** | 106.8 | 3.9 | 148.6 | 3.62 | 3.29 | 9% |
| **NIS** | 58.3 | 0.7 | 65.2 | 0.56 | 0.49 | 12% |
| **PAO** | 71.0 | 3.5 | 85.7 | 2.88 | 2.74 | 5% |
| **PAS** | 28.4 | 1.0 | 70.9 | 1.62 | 1.42 | 12% |
| **SAS** | 20.7 | 1.0 | 151.0 | 5.49 | 4.56 | 17% |
| **WEU_EEU** | 192.9 | 2.0 | 239.8 | 1.94 | 1.69 | 13% |
| **Total** | **839.6** | **19.1** | **1,437.9** | **26.0** | **22.4** | **14%** |

## Policy strategies to address the potentials

The previous section has illustrated the possible energy savings of refrigerators and washing machines worldwide and in different world regions. This means that energy efficient appliances can bring large energy savings, while providing the same or better service. The energy efficiency efforts do not only achieve high energy saving potentials. $CO_2$ emissions can also be reduced cost-effectively from a life-cycle perspective and thus provide economic benefits. Furthermore, several other co-benefits like energy security, health and increased competitiveness can be realised. By offering innovative products this can open up new (niche) markets, which will likely have a positive effect on the economy as a whole. Co-benefits increase social and/or individual welfare and come as a free add-on to the direct benefits of energy efficiency for investors.

However, there are still lots of inefficient appliances available on the market and market forces alone are often unlikely to bring a very high energy-efficient market development about (Sorrel et al. 2004; Thomas 2007). There are various barriers to manufacture, sell or buy energy efficient products that hinder a market transformation towards energy efficiency. All elements and levels of the appliances value chain have their own and specific characteristics. Financial, knowledge and technical barriers as well as lack of interest and the investor-user dilemma are some of the major reasons why there is a gap between the saving potentials and the energy savings actually realised by markets alone (Thomas 2006; IEA 2008).

Policy is needed to overcome these respective barriers and to exploit the existing potentials. Policy-makers have to intervene and develop adequate strategies to change this market development. The overall goal for policy makers should be to move the market towards to the best available technology and perspectively to the best not yet available technology (BNAT) with very high energy efficiency levels. Almost half of the energy saving potential could be achieved from the worldwide adoption of the most stringent energy efficiency regulations. Furthermore there are lots of energy efficiency technologies, which are already far beyond existing regulations, so the other half of the potential lies in reaching this “best practice” level. This emphasises that energy efficiency policy is incomplete. Even in economies that already have policies requiring or promoting high energy efficiency levels, significant savings are possible. Where requirements are limited, the savings from accelerated adoption of leading policies would stimulate much larger savings (Wuppertal Institute 2012).

Therefore, it is highly advisable for policy makers all over the world to pay attention to the large potentials and to energy efficiency improvements. It is important to abandon the prevailing approach of ‘as-fast-and-as-cheap-as-possible’ because it will be wasting vast amounts of energy and money throughout their lifetime. To tap this tremendous potential, appropriate and integrated packages of policies and measures are necessary, supporting very efficient appliances.

The first step is to pay attention to every actor in the value chain. By knowing the barriers and incentives of each type of actor, the policy package can be adapted to guarantee desired results and achieve the greatest possible energy savings. In order to be able to adequately design and implement energy efficiency policies and measures, political decision makers must have good knowledge of the concerned market actors and thoroughly analyse the specific incentives and barriers faced by each of them. These market actors are for instance manufactures, whole sales, retailers, investors and users. All of these actors make decisions that can influence the energy performance of appliances in question.

The second step concerns the following question: How can the incentives that market actors have be strengthened, and how can the barriers be overcome. Experience from pro-active countries and an analysis of market barriers show that several instruments need to interact and reinforce each other in a comprehensive policy package (cf. next box). Every policy measure is tailored to overcome one or a few of the mentioned market barriers, but none can address all these barriers (Tholen & Thomas 2011). The impact of well-combined policies is often synergistic i.e. the impact of two or more instruments is often larger than the sum of the individual expected impact. Therefore different policies addressing the demand- and supply side of markets should be properly combined according to regional circumstances. As pro-active countries have demonstrated, a comprehensive and coherent policy package for energy efficiency will usually provide a sound balance between clear ambitious mandatory measures, incentives, information and capacity building. It also needs a governance framework to enable implementation of these policies.

This governance framework includes a concrete and ambitious roadmap, an organisation to design, implement and monitor the policy (like an energy agency), and an independent test procedure. Furthermore a compliance system, and financial mechanisms such as Energy Saving Obligations and Energy Efficiency Funds to realise a successful implementation of specific policies in this package are needed. These specific policies are the following:

Legal provisions on minimum energy performance standards (MEPS) reduce search and transaction costs and partly overcome the investor-user dilemma. They are a cost-effective way to eliminate the segment of the worst energy-performing products from the market. However, they do not harness additional savings potentials due the most energy-efficient products in such cases. Therefore, appliance standards are often combined with labelling and rebates in order to give incentives for investments beyond the level required by the MEPS. Financial or other incentives can give the decisive push that makes people opt for the more energy-efficient investments. In addition, financing instruments such as soft loans can be needed to overcome potential incremental costs for BAT products and to enable investors to make more sustainable upfront investments.

To pull the market even more into an energy efficient direction, information programmes, trainings for sales staff and manufacturers, and especially procurement programmes can influence the market to promote energy efficient appliances. With procurement programmes but also with bulk purchasing projects and competitions it is even possible to go beyond the best available technology and to support a market development towards BNAT with very high energy-efficiency levels.

This general description of a comprehensive policy package should be adapted to national circumstances and to specific appliances. Each appliance and each market has its own specificity and the barriers as well as incentives for the market transformation are also diverse. Therefore the package must be adapted to specific circumstances of single product groups. For examples refrigerators have several specialities like the high energy and cost saving potentials as well as many differing technical characteristics (volume and additional features like climate class, built-in appliance, free-standing freezer, 'no-frost' function, etc). Policy makers should pay attention to all these factors and create policy packages that reach the desired results.

The next box shows how China has implemented an overall policy package to influence the market development of refrigerators and freezers. In some areas China is very successful with its policy package and is on a good way to promote energy efficiency.

China achieved a substantial transformation towards higher energy efficiency in the refrigerator market using a policy package adapted to its national conditions. Along with the rapid economic growth of the country in recent years, the sales figures of appliances also increased. The sales figures of top-rated energy-efficient refrigerators skyrocketed from 360,000 to 46 million units in nine years (from 1999 to 2008). In light of this development, it must be a top priority to the government to phase out the production of the least efficient products while promoting sales of highly efficient ones. Population size and increasing prosperity make China a highly attractive market for appliance manufacturers. This makes energy efficiency policies in the country even more important as policies can have huge impacts on greenhouse gas (GHG) levels. Moreover, China is regarded as the world's workbench. Thus, policy makers can implement regulation targeting the production process of appliances directly. Due to this situation the Chinese government introduced a comprehensive policy package to increase the energy efficiency of appliances.

The 11th Five-Year plan (FYP) was established in 2005 and aimed at reducing energy intensity by 20% up to 2010. For the exemplary product group refrigerators, this meant that their average energy-efficiency indicator was to be reduced to between 62% and 50% by 2010, meaning they would be in the two most energy-efficient classes of the energy label (Zhou et al. 2010, p6442). According to results mentioned in the National 12th Five Year Plan, the actually achieved energy conservation and GHG emission reduction was 49%. The 12th Five-Year plan for 2011 to 2015 targets a total energy and carbon intensity reduction by 17%.

China has committed to achieving these goals through different measures. There has been a minimum energy performance standard (MEPS) since 1990 in order to eliminate very inefficient models from the market. The standards are mandatory, but compliance is sill a big issue and needs to be targeted (Zhou 2010). In addition to this MEPS regulation a mandatory comparative energy labelling system (CELS) was established in 2005. The label is based on the coloured arrows design of the European Union's appliance energy label. However, it uses number 1 to 5 instead of characters A to G. The rating goes from grade 1, which counts for refrigerators having an energy consumption of at most 55% of the MEPS and goes over grade 2: 55-65%, grade 3: 65-80%, grade 4: 80-90%, to grade 5: 90-100%. The mandatory label uses the MEPS as a reference point for the thresholds. Refrigerators not meeting the MEPS will not be labelled, nor even produced (Fridley 2008, p. 6 f). This mandatory label provides market transparency on the energy efficiency of appliances to consumers.

Furthermore, China introduced a voluntary endorsement label, and refrigerators will only be provided with it, if they have an energy performance of at least a grade 2 level of the energy information label. To inform the consumers about the labels and energy efficiency in general several information and education campaigns were implemented. The energy efficiency information week takes place annually and focuses on different themes. A consumer education programme has focused on awareness raising towards energy efficient refrigerator advantages and the willingness of purchasing them. Assistance was also granted to engineers from refrigerator manufacturers who received training in international technology options. The international organisation, Top10 China, establishes an internet-based platform to provide independent and up-to-date information on the best available energy efficient products in the Chinese market.

The Chinese government also established a law obliging state agencies and organisations to purchase only energy-efficient appliances. The "Energy Efficient Products For Government Procurement" law tries to raise awareness of higher standards and the benefits of purchasing energy efficient appliances by setting a good example to the people. A series of energy efficiency appliance lists have been submitted by the Ministry of Finance and the National Development and Reform Commission (NDRC), where all appliances covered by that scheme are listed (State Council Office 2007).

Moreover, in 2012, the Ministry of Finance (MoF) has launched a financial incentive programme offering grants for the purchase of energy saving refrigerators (and other appliances) of up to 70-400 Yuan depending on the product size. Consumers receive the subsidies immediately at the retailers. Funding, which totals 26.5 billion yuan (~3.3 billion EUR), has been provided for the period from June 2012 until May 2013.

## Conclusion

Within the bigEE project, an extensive data gathering was carried out for domestic cold appliances and washing machines worldwide as well as a modeling work, in order to assess the saving potentials in terms of energy, water, GHG emissions and costs. The results show between 2010 and 2030 a stock increase of more than 60 % worldwide for cold appliances and of about 70 % for washing machines. Consequently, in the baseline scenario, which already includes a moderate efficiency improvement, the electricity consumption is to be expected to rise by 20 % for cold appliances. For washing machines, even an increase of 93 % for electricity and 36 % for the water consumption is expected.

However the modeling has also shown that with existing (BAT) and coming (BNAT) technologies, it is almost possible to halve worldwide electricity demand for both, residential cold appliances and washing machines in comparison to this baseline in year 2030. In the efficiency scenario absolute reductions are possible for cold appliances in all regions, even in developing and emerging regions such as CPA with China, where the stock is expected at least to double within 20 years. One additional outcome of this study is that these electricity savings are cost-effective both for end-users and society.

However, this market transformation towards energy efficient appliances is unlikely to happen itself, therefore policy packages are needed. Within the bigEE-project a new theoretical and empirical foundation has been developed that shows what is a necessary and advisable package of policies for energy efficiency in appliances.

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