Technical Report

GBPN
Global Buildings Performance Network

*Building Policies for a Better World*

ABUD
ADVANCED BUILDING & URBAN DESIGN

# MONETARY BENEFITS OF AMBITIOUS BUILDING ENERGY POLICIES

Janurary 2015

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## Principal Investigators

Diana Ürge-Vorsatz, PhD., (3CSEP)
András Reith, PhD. (ABUD)

## Research team

Katarína Korytárová, PhD.
Mónika Egyed (ABUD)
János Dollenstein

## Research Project Manager

András Reith, PhD. (ABUD)

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## Reviewers

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David Legg
Oliver Rapf
Ksenia Petrichenko
Niamh McDonald
Sophie Shnapp
Anne-Claire Bellec
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Thad Mermer
Peter Graham

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# ACRONYMS

| | |
|---|---|
| **3CSEP HEB model** | Center for Climate Change and Sustainable Energy Policy High Efficiency Buildings Model |
| **BAU** | business as usual (scenario) |
| **BID** | building type identification |
| **CCI** | construction cost index |
| **CID** | climate zone identification |
| **CPI** | consumer price index |
| **C&P** | commercial and public buildings |
| **ECS** | total cumulative energy cost savings |
| **EPBD** | Energy Performance of Buildings Directive (Directive 2010/31/EU) |
| **IDP** | Integrated Design Process |
| **INV** | total cumulative additional investment costs |
| **MF** | multi-family buildings |
| **PBID** | identification of public (& commercial) buildings |
| **RID** | regional identification |
| **SF** | single family buildings |
| **SH/C** | space heating or cooling |
| **UID** | urbanization identification |
| **VH/H/M/L HD** | very high/high/moderate/low heating demand |
| **VH/H/M/L CD** | very high/high/moderate/low cooling demand |
| **DH** | dehumidification |
| **new** | new construction |
| **anew** | advanced new construction |
| **ret** | retrofit (retrofitted buildings) |
| **aret** | advanced retrofit (advanced retrofitted buildings) |
| **$N^{LOW}$** | compliance with only already existing local building codes is considered. Update or improvements of the existing building are not considered. The compliance with the currently building codes is assumed rather low |
| **$N^{BC}$** | implementation of currently valid local Building code, including ambitious EPBD implementation in the EU-27[1] and building codes for new buildings in other regions. Codes that are in the policy pipeline or upcoming are also considered (higher compliance than $N^{LOW}$ is considered) |
| **$AN^{70+}$** | up to 15-30 kWh/m$^2$/a for SH/C |
| **$R^{10}$** | complex retrofit, which results in around 10% lower energy consumption as compared to a standard building |
| **$R^{30}$** | complex retrofit, which results in around 30% lower energy consumption as compared to a standard building - or whatever is the prevailing average retrofit |
| **$AR^{70+}$** | around 15-50 kWh/m$^2$/a for SH/C, or >70% reduction in energy consumption as compared to energy consumption before retrofit |
| **NAM** | North America, one of the eleven Word regions considered in the model |

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[1] DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast)

| | |
|---|---|
| **WEU** | Western Europe, one of the eleven Word regions considered in the model |
| **EEU** | Eastern Europe, one of the eleven Word regions considered in the model, |
| **FSU** | Former Soviet Union, one of the eleven Word regions considered in the model |
| **LAC** | Latin America, one of the eleven Word regions considered in the model |
| **PAO** | Pacific OECD, one of the eleven Word regions considered in the model |
| **CPA** | Centrally Planned Asia, one of the eleven Word regions considered in the model |
| **PAS** | Pacific Asia, one of the eleven Word regions considered in the model |
| **SAS** | South Asia, one of the eleven Word regions considered in the model |
| **MEA** | Middle East and Africa, one of the eleven Word regions considered in the model |
| **AFR** | Africa, one of the eleven Word regions considered in the model |
| **EU-27** | EU-27 includes: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden and the United Kingdom |
| **RoW** | Rest of the World, World, except for the four major regions (EU-27, USA, China and India) |

# EXECUTIVE SUMMARY

Several recent reports, (McDonald and Laustsen 2013, Ürge-Vorsatz et al. 2011, 2012a, 2012b, Bin and Jun 2012, Næss-Schmidt et al. 2012) have demonstrated the magnitude of energy and emission saving opportunities that can be realized through advanced and accelerated building energy efficiency retrofits and construction of highly efficient buildings. The aim of this report is to quantify the global and regional cost implications of implementing large-scale energy efficiency improvements in buildings as compared with the status-quo under certain scenarios. The scenarios considered in this study (previously defined by Ürge-Vorsatz et al. (2012b) under GBPN's initiative), focus on the deployment of very advanced (very low energy, passive or nearly zero energy) new construction and retrofits (Deep efficiency scenario), as well as more moderate improvements in building energy performance (Moderate efficiency scenario with less energy saved in retrofits and less ambitious performance levels in new construction).

As mentioned, the current study is a continuation of the GBPN's Best-practices scenario analysis (Ürge-Vorsatz et al. 2012b), and is also based on the 3CSEP HEB model (Center for Climate Change and Sustainable Energy Policy High Efficiency Buildings Model), which was extended to include the Cost analysis module (Module 2). As with the previous study (Ürge-Vorsatz et al. 2012b), this report is focused on the four key regions, including both developed regions (EU-27, USA) as well as emerging economies (China, India). The global costs and benefits for the two outlined scenarios are calculated based on the aggregation of the results for the 11 regions, defined in the Global Energy Assessment (Ürge-Vorsatz et al. 2011).

The 3CSEP HEB model is a sophisticated and complex global building energy model. It distinguishes among the buildings located in urban, rural areas or slums (where applicable), considers 3 building types (single family houses, multi-family buildings, commercial and public buildings, further subdivided into six subcategories: hotels and restaurants, educational buildings, hospitals, offices, retail buildings, and others), 5 building vintages (standard, new, retrofit, advanced new and advanced retrofit buildings), 17 climate zones and 11 world region[2] (Ürge-Vorsatz et al. 2012b) - essentially dividing the world building stock into over 10,000 unique building categories.

Due to the major challenge in accessing accurate and representative construction cost data, this study aims to show a zero order estimate of the financial costs and benefits, providing a preliminary indication of the overall cost-effectiveness of each scenario rather than presenting precise figures. The investment costs are calculated as additional to the baseline cost, which would take place if the current policy and technological trends continue without energy efficiency gains until 2050.

Similar to the scenario report (Ürge-Vorsatz et al. 2012b), the principal pillar of the modelling logic is cost-effective best-practices of building energy performance, which can be replicated for similar climatic conditions and building types. Extensive data on advanced as well as conventional buildings was collected for the four priority regions, and subsequently for other world regions. As the main focus of the study is to investigate the feasibility of a transformative pathway towards a low-energy future of the global building sector, the best-practices were searched and selected from both an energy performance and a cost perspective with a careful consideration regarding scalability. The costs associated with the implementation of the low-energy building scenario were estimated based on the current costs of developing exemplary new and retrofit buildings. The cost data from exemplary projects was included only if it was considered to be possible to upscale the best-practice across similar building types, climate zones and vintages. As consistent and reliable cost data does not exist for all regions, climate zones, building types or building vintages; costs for missing categories were assumed using a cost transfer from another similar category elsewhere in the world with better data, taking into account regional differences in the cost levels and economic conditions, based on an elaborate method (see Section 2.7 and Annex 8: Cost ratio transfer for more details).

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[2] AFR, CPA, EEU, FSU, LAC, MEA, NAM, PAO, PAS, SAS, WEU (for the regional split see Annex 4).

The results of the cost analysis show that for all four major regions (EU-27, USA, China and India), as well as for the world as a whole, the total cumulative energy cost savings under the Deep efficiency scenario exceed the total cumulative additional investment costs (see Table 1 and Figure 1).

Table 1: Total cumulative additional investment costs vs. total cumulative energy cost savings until 2050

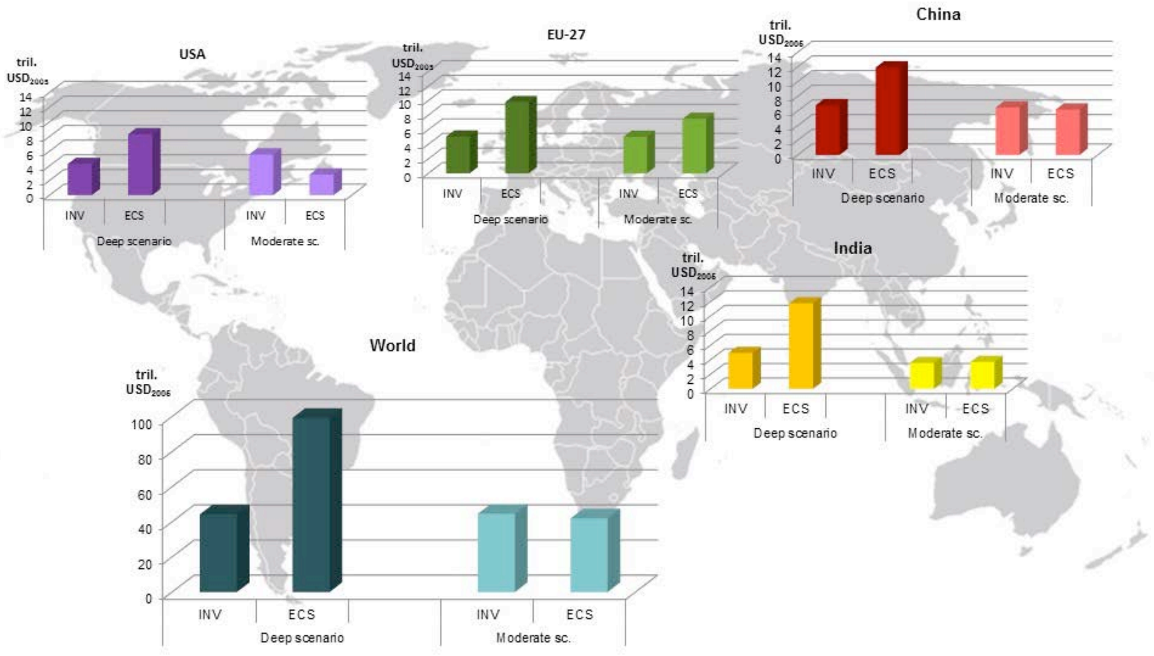
| Region | Deep efficiency scenario | | Moderate efficiency scenario | |
|---|---|---|---|---|
| | Total cumulative additional investment costs | Total cumulative energy cost savings | Total cumulative additional investment costs | Total cumulative energy cost savings |
| | tril. $USD_{2005}$ | tril. $USD_{2005}$ | tril. $USD_{2005}$ | tril. $USD_{2005}$ |
| **EU-27** | 5.1 | 9.8 | 5.0 | 7.5 |
| **USA** | 4.3 | 8.3 | 5.6 | 2.8 |
| **China** | 6.8 | 11.9 | 6.5 | 6.2 |
| **India** | 5.0 | 11.8 | 3.6 | 3.7 |
| **RoW**[1] | 23.3 | 42.2 | 24.00 | 14.8 |
| **World**[2] | 44.3 | 99.2 | 44.6 | 42.0 |

*Notes:* 1 - RoW - Rest of the World; 2 – Note, that the region World is not a simple sum of the four major regions and RoW region, but rather a sum of the 11 world regions. Therefore there are differences in World and sum of the four major regions.

On the other hand, under the Moderate efficiency scenario, for most of the regions (except for EU-27), the total cumulative additional investment costs exceed the total cumulative energy cost savings achieved through such investment. In the EU-27 this is mainly due to rather ambitious assumptions (due to EPBD recast implementation) for the Moderate scenario. Much lower cost-effectiveness (i.e. the difference between energy cost savings and additional investment costs) is achieved under the Moderate efficiency scenario as compared to the Deep efficiency scenario in all regions. In some regions, the cumulative additional investment costs are even higher in the Moderate scenario than in the Deep scenario (World, RoW and the USA). The main reason for this is that the rate of the highly energy efficient buildings – advanced new and advanced retrofit - is fluctuating differently in the different scenarios in the floor area projections. Namely, the share of advanced buildings is significantly higher in the Deep scenario than in the Moderate scenario. The other relevant variable of the calculation is the specific investment costs calculated yearly due to technological learning. Due to the dynamics of these changes, as a result, the cumulative additional investment costs of Moderate scenario exceed that of the Deep scenario for example in case of the USA by 2032. Thus, regarding the period to 2050, the implementation of the Moderate scenario would cause even higher investments in the specific region of the USA as it is shown in the report in detail.

The Moderate efficiency scenario is cost-effective only in EU-27 and India (under the given assumptions). While in EU-27 all building types are cost effective, in India it is only two of them. EU-27 is the only major region where many countries have adopted nearly zero energy targets for new buildings and significant energy savings are mandated in major retrofits. In light of this there is less difference between the Deep and Moderate scenario in this region relative to other world regions. The cost effective potential of the Moderate scenario in India is mainly due to its low specific investment costs in general. Nevertheless, the difference between the total cumulative additional investment costs and the total cumulative energy cost savings is very small.

Figure 1: Total cumulative additional investment costs vs. total cumulative energy cost savings until 2050 under the Deep efficiency and Moderate efficiency scenario



*Note*: INV – total cumulative additional investment costs; ECS - total cumulative energy cost savings

In the rest of the world region (World except for the for the four major regions – EU27, USA, China India) the Deep efficiency scenario is cost-effective, unlike the Moderate efficiency scenario. Similarly, the Deep efficiency scenario is cost-effective for World in total, while the Moderate efficiency scenario is not.

In summary, the results show that in the long term, unlike the Moderate efficiency scenario, the Deep efficiency scenario is cost-effective for all four major regions, as well as for the World. The results also show that for all analyzed regions and the world the Deep efficiency scenario has higher energy cost savings and higher cost-effectiveness (i.e. the larger difference between energy cost savings and investment costs) than the Moderate efficiency scenario.

When we compare these findings with other relevant studies (BPIE 2011), GEA - in Ürge-Vorsatz et al. 2011, McKinsey - 2007, 2009a, 2009b) on cost analysis of low energy transition in the building sector, the results of the cost analysis of the 3CSEP HEB Model are in most cases at the same level of magnitude (GEA, in Ürge-Vorsatz et al. 2011 – e. g. for instance total cumulative energy cost savings in the EU, USA, China), yet there are some differences. For example, the total cumulative additional investment costs calculated in the current study are several times higher than the results of other relevant studies (e.g. Global Energy Assessment - GEA described in Ürge-Vorsatz et al. 2011 and BPIE 2011). This difference in total investment needs is mainly due to much more conservative specific investment costs used for the 3CSEP HEB Model, in a meaning of significantly more thorough and detailed data collection and much more expert reviews where data were not available, which resulted in using higher additional investment costs than in other relevant studies (e.g. in BPIE 2011). However, after careful considerations and careful checks, the authors agreed to use the figures documented in this report despite this discrepancy because the current study is based on a thorough data collection for different climate zones, regions and building types and vintages and cautious cost transfer, combined with a profound multiple-expert review. These efforts constitute the major value added of this study. However, the current study has come to the conclusion, which is in line with the GEA, that further data collection and verification is still necessary in India and other developing regions. Moreover, further data collection would be beneficial for those regions that depend on cost transfer (China and partially also some building vintages in the USA).

A thorough sensitivity analysis was conducted in order to show how different variables influence the overall results of the cost analysis, and which variables have a significant impact on the cost-effectiveness of the two scenarios. The results show that the variables in general do not significantly influence the cost-effectiveness of the two scenarios at the global scale. However, due to changes in certain variables the Deep scenario may no longer be cost-effective for some regions, e.g. when energy prices fall significantly (hypothetically, if energy prices fall by 70% as compared to the default projections, the Deep scenario would not be cost-effective for EU-27, China, USA and World anymore), or when the specific investment costs do not decrease enough, i.e. when the learning factor is not high enough (when specific investment costs of advanced buildings decrease only by 15% by 2050 as compared to their 2005 value as opposed to the default learning factor of 50%, the Deep efficiency scenario would not be cost-effective for the USA). The cost-effectiveness of the Deep scenario does not change for any region even if the specific investment costs increase (both costs of advanced buildings and costs of conventional buildings) by up to 50%. An increase in specific energy consumption does not have a significant influence on the results, as change in this variable is only applied to advanced buildings. A change in specific energy consumption triggers the most significant impact in China and India, where a large number of advanced buildings is expected by 2050.

On the other hand, the results show that cost-effectiveness can be reached under certain circumstances even under the Moderate efficiency scenario in some regions - for example this scenario can become cost-effective in China, India and the World in case energy prices increase by at least 30% by 2050 of their currently projected level. Similarly, this scenario may become cost effective in China and the World region when specific investment costs decrease by at least 25% and in the USA with the decrease of at least 50% of the specific investment costs.

Based on the sensitivity analysis, we can summarize that the variables with the most significant impact on the results and overall cost-effectiveness of the scenarios are energy prices and the learning factor. Thus, these are important variables that need to be taken into account when interpreting the results of the current study. These also point to important policy implications: if a low-energy building future becomes an important policy goal (such as for climate, energy security, improved social welfare or other reasons), its economic efficiency can be best promoted by catalyzing fast and effective technology learning (such as through demonstration projects, well-targeted and designed investment subsidy schemes, etc.), as well as eliminating the distortion of energy prices by subsidies.

## Recommendations

The results of the study show that from the long-term perspective, the "deep" path is much more cost-effective from a societal perspective than the "moderate" scenario. More concretely, it is economically much more efficient to promote the proliferation of very high performance buildings rather than to focus on accelerated investment into “shallow” energy efficiency improvements during the building retrofit or construction. This is valid both for developed countries, where the main construction activity focuses on retrofit of existing buildings, and for emerging economies and developing countries, where significant volumes of new buildings are added every year. Thus, ambitious building codes for new construction and their strong enforcement are necessary in developing and emerging regions. As in China both new and retrofit are expected to be dominant vintages in terms of their share in the Chinese 2050 building stock (see page 55, technical report, Ürge-Vorsatz et al. 2012b), in the long term, well-designed building codes are recommended to cover also retrofit buildings and be strictly enforced.

The study proves that long-term cost analysis of building use scenarios, despite all its uncertainties, is crucial in order to have a comprehensive overview of the financial costs and benefits of alternative pathways in the building sector. The reason is that buildings are structures with a long lifetime, and the full benefit of advanced measures can only be seen after several decades of the building's operation. In addition, it is particularly important to view long-term impacts/benefits in the case of a know-how, such as very highly efficient buildings, because their real economic benefits appear after the learning period. Most of the major regions reach cost-effectiveness between 2030-2040, i.e. beyond the 2030 horizon, which is often used for analysis of energy savings potential in buildings.

In order to avoid the risk of the “lock-in effect” of the energy saving, governments are advised to first develop strategies to increase the minimum requirements of new construction and retrofit towards high energy performance levels. Only then is it recommended to introduce financial mechanisms or policies to accelerate retrofit rates (where applicable) supporting the deployment of advanced buildings on a large scale. This recommendation is very important as financial mechanisms with low energy savings requirements usually lead to the acceleration of "shallow" retrofits with low levels of energy savings (e.g. at the level of Moderate efficiency scenario). Such mechanisms, without a long-term framework strategy and progressive improvement of energy performance requirements as a condition for provision of the financial support, will inevitably lead to a significant "lock-in effect", when a significant portion of potential building's energy savings, and, thus, related emissions reductions, are locked-in for several decades until the next round of renovation becomes economically feasible.[3]

Another important factor crucial for the realization of the full energy efficiency potential, that long-term strategy and ambitious minimum requirements may bring, is education and training. The extent and rate of deployment of advanced buildings depend both on the availability of the high efficiency building elements and the preparedness of the construction industry. Therefore, it is recommended that governments ensure that all construction professionals involved in the construction process of advanced buildings (e.g. architects, planners, engineers, equipment installers, craftsmen, building inspectors, energy auditors, and site managers) have necessary education and training so that advanced buildings can be deployed at a large scale.

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[3] The renovation cycle usually lasts between 30-40 years in OECD countries according to Laustsen (2008), but can be longer in countries with a long period of building stock depreciation (Csoknyai 2009 in Korytarova 2010).

# CHAPTER 1: INTRODUCTION

## 1.1 Background and rationale

Buildings accounted for about one third of the 2009 final energy use globally (IEA 2012) and according to IPCC (2007) they were responsible for approximately one third of global energy-related $CO_2$ emissions in 2009. At the same time, research shows that buildings offer a large-cost-effective potential (IPCC 2007, McKinsey 2009a, 2009b, Ürge-Vorsatz et al. 2011, 2012a, 2012b). Recently, a report prepared for GBPN showed that by applying a rapid transition to highly energy efficient buildings 72 EJ of final energy savings can be achieved by 2050 on the global scale as compared to the frozen efficiency level (Ürge-Vorsatz et al. 2012b). This can be achieved by improving the buildings' efficiency to the levels of nearly zero energy buildings, passive house buildings or very low energy buildings, while considering a building as a system and applying the principles of integrated design, both in terms of new construction and retrofit of existing buildings. As the majority of today's building stock in the developed world will still be present in 2050, retrofit to highly efficient level is of the utmost interest. In contrast, high efficiency new construction is more important in the developing countries due to the large rates of housing construction driven by growing population, urbanisation and migration.

Along with the potential, the building sector poses a high risk of locking-in unsustainable energy consumption patterns for several decades until the next renovation cycle (Ürge-Vorsatz et al. 2012b, 2011, 2010, Korytarova 2010, Petrichenko 2010).[4] Lock-in effect happens due to massive application of only minor (suboptimal) quality of the renovation often accompanied by subsidies provided to wide public disregarding of the ambition of the renovation. The extent of the lock-in effect varies across country studies from 32%-60% of the business-as-usual (BAU) energy use (Ürge-Vorsatz et al. 2010, Ürge-Vorsatz et al. 2011-GEA, Petrichenko 2010, Korytarova 2010). The global lock-in effect could reach up to 80% of 2005 final heating and cooling energy by 2050 (Ürge-Vorsatz et al. 2012b).

However, strikingly, several studies show that lock-in effect happens even if it is not the most cost-effective option to support energy efficiency and to provide comfortable housing or workplace conditions. Lock-in effect can occur when the costs are considered in short term horizon only, when the financial benefit of reduced energy costs are not taken into account over the lifetime of the energy efficiency investment, and/or the wider socio-economic benefits are not taken into account. However, long-term perspective shows that once an ambitious strategy of transition towards highly efficient buildings is chosen, higher energy savings can be achieved at comparable level of initial investment (Korytarova 2010). Moreover, high energy cost savings can be achieved.

Although several studies examined the costs and benefits (e.g. IPCC 2007, Novikova 2008, McKinsey 2009a, 2009b, Korytarova 2010, BPIE 2011, Ürge-Vorsatz et al. 2011, 2012a), as well as risks and opportunities of the transformation towards highly efficient buildings (e.g. Korytarova 2010, Petrichenko 2009, Ürge-Vorsatz et al. 2011 - GEA), a rigorous assessment of the cost-effectiveness of deep transformation scenarios for the global and regional building sectors is still missing. This study aims to contribute to filling in this gap.

Due to severe limitations in the availability of relevant, sufficiently detailed and reliable cost data for various world regions, the current study does not claim to provide precise figures. It rather presents the attempt to provide the best-possible estimates based on throrough data and expert judgements collection, as well as application of the elaborated method for filling in the data gaps. The results give the understanding of the levels of the investments needed for the transition towards building sectors with much higher energy efficiency, as well as the levels of the potential energy cost savings that can be achieved from energy efficiency improvements under different scenarios. In this report the cost-effectiveness of different scenarios is also analysed and its sensitivity for variations in key input parameters is investigated.

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[4] The renovation cycle lasts usually between 30-40 years in the OECD countries according to Laustsen (2008), but can be longer in countries with long period of building stock depreciation (Csoknyai 2009 in Korytarova 2010).

## 1.2 Research aim and objectives

The aim of the study is to analyze the major costs and benefits of the key scenarios presented in the "Best-Practices for Low Carbon & Energy Buildings" GBPN report (Ürge-Vorsatz et al. 2012b).

To fulfil this aim, two objectives were set:

**Objective 1:** To calculate the cumulative additional investment needed until 2050 for the Moderate and Deep efficiency Scenarios as compared to a reference scenario (i.e. Frozen Efficiency Scenarion – see Ürge-Vorsatz et al. 2012b).

**Objective 2:** To calculate the cumulative energy cost savings until 2050 for the Moderate and Deep efficiency scenarios as compared to a reference scenario.

## 1.3 Organization of this report

The report consists of eleven chapters. Chapter 1 provides a brief introduction into the field of the study and the aim and the related objectives of the study. Chapter 2 defines the methodological framework for the undertaken research, including overview of the 3CSEP HEB model, description of the cost analysis calculation process, description of the cost database, climate zone identification, description of the cost transfer, assumptions underlying the technology learning and other modelling assumptions. The chapter concludes with an outline of the data gaps and areas of further research. Chapters 3-8 describe the region-specific modelling assumptions as well as the results for both Deep and Moderate efficiency scenario for the four major regions: EU-27, USA, China and India, and for the World. Chapter 9 provides a comparison of the results of the current study with those of other relevant studies focusing on cost analysis of low energy transition in the building sector. Chapter 10 shows the results of the sensitivity analysis for the following variables: specific investment costs, learning factor, specific energy consumption and energy prices. Last, but not least, Conclusions and recommendations (Chapter 11) summarize the main outcomes of the study and provide recommendations for decision makers.

# CHAPTER 2: METHODOLOGY AND ASSUMPTIONS

In this section, first, a brief overview of the 3CSEP HEB Model (Center for Climate Change and Sustainable Energy Policy High Efficiency Buildings Model) developed under Ürge-Vorsatz et al. (2012b), and here named Module 1: Scenario analysis,[5] is provided, which describes the overall modeling logics, the main variables and categories considered in the model and the scenarios. Second, the methodological framework of the Module 2: Cost analysis, the module developed under the current study, is introduced. This includes description of data collection and the calculation process of total cumulative additional investment costs and total cumulative energy cost savings. Afterwards, the different modeling assumptions are presented, including cost transfer, technology learning, energy price projections and other.

## 2.1 Overview of the 3CSEP HEB model

3CSEP HEB model, presented in detail in Ürge-Vorsatz et al. (2012b), is a bottom-up model, which uses a rather novel, performance-based approach. As opposed to a component-based approach, the performance-based approach does not analyse single building-related measures, but rather utilises a systemic perspective in such a way that the buildings are approached as systems, and measures to reduce their energy consumption are also treated as systemic interventions comprising individually tailored packages of different efficiency and renewable energy options. In such a method the energy performance for space heating and cooling of the different building types is in the center of the modeling logic. Data on energy performance in different regions, climate zones, building vintages and types are key inputs for the scenarios (Ürge-Vorsatz et al. 2012b).

The primary aim of the GBPN scenario analysis is to "illustrate how far the building sector can contribute to ambitious climate change mitigation goals ("Deep efficiency" scenario); how it might be different from a hypothetical reference scenario ("Frozen efficiency" scenario), and how the future of the building sector might look under the intermediate scenario ("Moderate efficiency" scenario) (Ürge-Vorsatz et al. 2012b). Assumptions for the scenarios differ mainly in retrofit rates and deployment of the advanced performance levels (see Table 2)..[6] The Module 2 on the cost analysis provides cost estimations for all three scenarios mentioned above.

The cornerstone model's assumption is that today's existing state-of-the-art best-practices in new construction and retrofit proliferate to the levels of a standard practice after a certain transition period. The energy performance level of advanced buildings (both new construction and retrofit) is set based on the review of the best-practice case studies which can be considered to be potentially replicable in the same climate zone, and for the given building type. These energy performance levels in the Deep efficiency scenario typically range between 15-30 kWh/m$^2$/year, depending on the region (Ürge-Vorsatz et al. 2012b). Advanced buildings "have a state-of-the-art design, which allows for a significant reduction of thermal energy demand in most climate zones" (up to 90%) (Ürge-Vorsatz et al. 2012b). This is in line with the concept of passive house (energy performance level for space heating of 15kWh/m$^2$/year), which has been applied in several countries, especially in Central and Northern Europe (Austria, Germany, Sweden, Denmark), as well as in the USA. Nevertheless, the concept of advanced buildings considered in this report goes beyond that, and includes all high efficiency buildings with very low level of thermal energy use (Ürge-Vorsatz et al. 2012b).

The 3CSEP HEB model considers buildings located in urban or rural area, 4 building types (single family houses, multi-family buildings, slums (where applicable and only in urban areas), commercial and public buildings, which are further subdivided into hotels and restaurants, educational establishments, hospitals, offices, retail buildings, and others), 5 building vintages (standard, new, retrofit, advanced new and advanced retrofit buildings), 17 climate zones, 11 big regions and 4 target (major)

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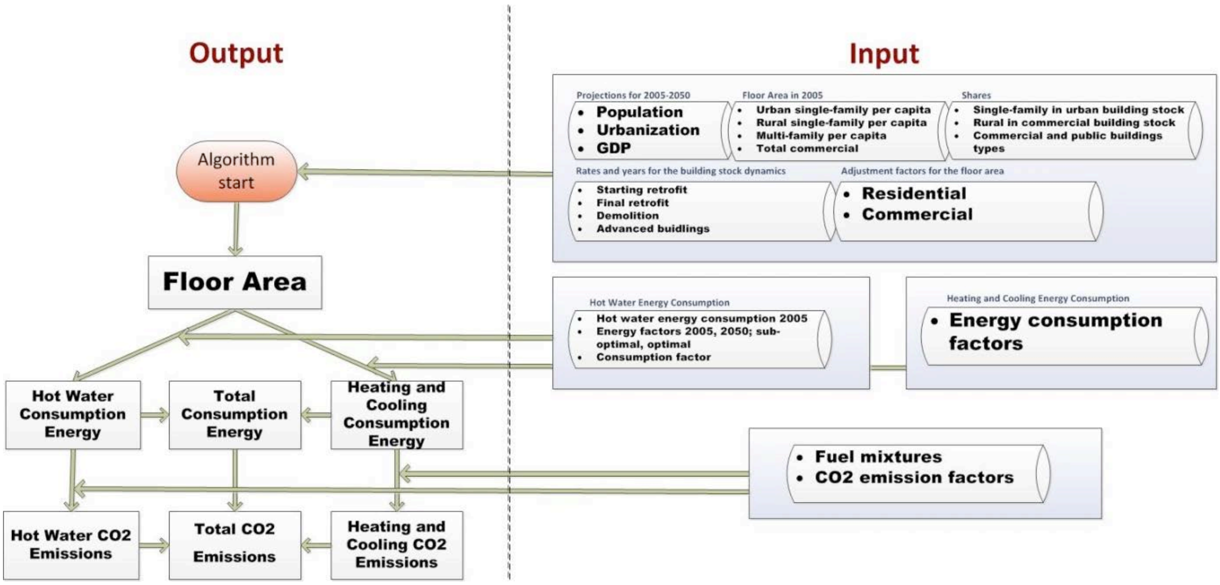
[5] Module 1 of the 3CSEP HEB model includes the Scenario analysis under Ürge-Vorsatz et al. (2012b) and was named Module 1 as to distinguish it from the Cost analysis module of the model (named Module 2), which has been constructed under the current study. See below for further details.

[6] This scenario is based on the Moderate efficiency scenario, where the retrofit rate is increased (up to 3% p.a.) in order to be comparable to the Deep efficiency scenario.

regions (USA, EU-27, China and India) (Ürge-Vorsatz et al. 2012b). Figure 2 shows the modelling logics, the input and output of the 3CSEP HEB model.

Figure 2 Flowchart representing the modeling logic for 3CSEP-HEB (Module 1: Scenario analysis)



Source: Ürge-Vorsatz et al. (2012b)

Table 2 Assumptions behind the scenarios considered in Module 1: Scenario analysis

| Scenario | Description | Rate of retrofit (% p.a.) |
|---|---|---|
| Frozen efficiency scenario | - Hypothetical reference scenario.<br>- Specific energy consumption of new and retrofit buildings does not improve as compared to their2005 levels.<br>- Specific energy consumption of new buildings is higher than that under the Moderate efficiency scenario due to lack of energy efficiency building codes or due to lower level of compliance<br>- Retrofit buildings consume around 10% less energy for SH/C than standard existing buildings<br>- Advanced new buildings are assumed only for Germany and Austria (5% and 10% of the new building stock built after 2005, respectively)<br>- Advanced retrofit not considered in any region | 1.4% p.a. |
| Moderate efficiency scenario | - Implementation of current policies (EPBD in the EU-27[7], building codes for new buildings in other regions)<br>- Accelerated rate of retrofit<br>- New buildings are built to the level of currently valid regional building code<br>- Retrofitted buildings achieve on average energy savings of 30% as compared to the existing buildings built before 2005 | Increases from 1.4% to 2.1% (EU-27, USA), 1.6% (China) and 1.5% (India) by 2020, then remains constant |
| Deep efficiency scenario | - Most ambitious scenario<br>- Best-practices are widely applied in all the regions (both retrofit and new construction).<br>- After 2022, most renovations and newly built structures will be of a very high-energy efficient design as exemplary buildings in the same climate zones and building types. | By 2020 increases from 1.4% to 3%, then remains constant |
| Lock-in effect | - Illustrates the potential lock-in effect, which may occur if non- high performance levels are applied in an accelerated manner.<br>- Based on Moderate efficiency scenario, while applying accelerated retrofit rate (the same as under the Deep efficiency scenario). | Increases from 1.4% to 3% by 2020,, then remains constant |

Source: Ürge-Vorsatz et al. (2012b)

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[7] EU (2010)

Table 3 summarizes the main assumptions for the different building vintages and their energy performance levels (i.e. specific energy consumption per unit of floor area).

Table 3 Assumptions for building vintages and their energy performance levels under different scenarios

| Frozen efficiency scenario | | | | Moderate efficiency scenario | | | | Deep efficiency scenario | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| New | | Retrofit | | New | | Retrofit | | New | | Retrofit | |
| New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit |
| $N^{LOW}$ | $AN^{70+}$ | $R^{10}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ |

Source: based on Ürge-Vorsatz et al. (2012b)

*Notes*:

$N^{LOW}$ - compliance with only already existing local building codes is considered. Update or improvements of the existing building are not considered. The compliance with the currently building codes is assumed rather low

$N^{BC}$ - implementation of currently valid local Building code, including ambitious EPBD implementation in the EU-27[8] and building codes for new buildings in other regions. Codes that are in the policy pipeline or upcoming are also considered (higher compliance than $N^{LOW}$ is considered).

$AN^{70+}$ - up to 15-30 kWh/m$^2$/a for SH/C

$R^{10}$ - complex retrofit, which results in around 10% lower energy consumption as compared to a standard building[9]

$R^{30}$ - complex retrofit, which results in around 30% lower energy consumption as compared to a standard building - or whatever is the prevailing average level of retrofit

$AR^{70+}$ - around 15-50 kWh/m$^2$/a for SH/C, or >70% reduction in energy consumption as compared to energy consumption before retrofit

Complex retrofit means that the building is not renovated partially, but as a whole. Such a renovation includes insulation of building envelope, insulation of roof and ceiling above cellar, replacement of windows/doors, replacement or renovation of space heating system. The aim of complex renovation is maintenance of the building rather than thermal renovation or a focus on energy savings. Although the building is renovated as a whole, it is not considered as a system, and thus it cannot be considered a holistic approach.

Complex retrofit, which results in 10% lower energy consumption as compared to a standard existing building, is a hypothetical benchmark devised for the purpose of comparison to the advanced (and also complex) retrofit. Due to the fact that the data on costs of $R^{10}$ and $R^{30}$ is scarce and often contradictory, their costs are assumed as a ratio of the cost of the advanced retrofit (0.6 and 0.8 respectively).

The three scenarios differ in the rate of renovation and in the proliferation of the advanced buildings on the market. Thus, they vary in floor area per different building vintages and as a result of that they naturally differ in the resulting total energy consumption.

### Regions and climate zones in the model

While the model considers 11 world regions,[10] the main focus is on four "major" regions: EU-27, USA, China and India as these regions altogether account for more than 60% of the 2005 final building energy use (Ürge-Vorsatz et al. 2012b), see Figure 3.

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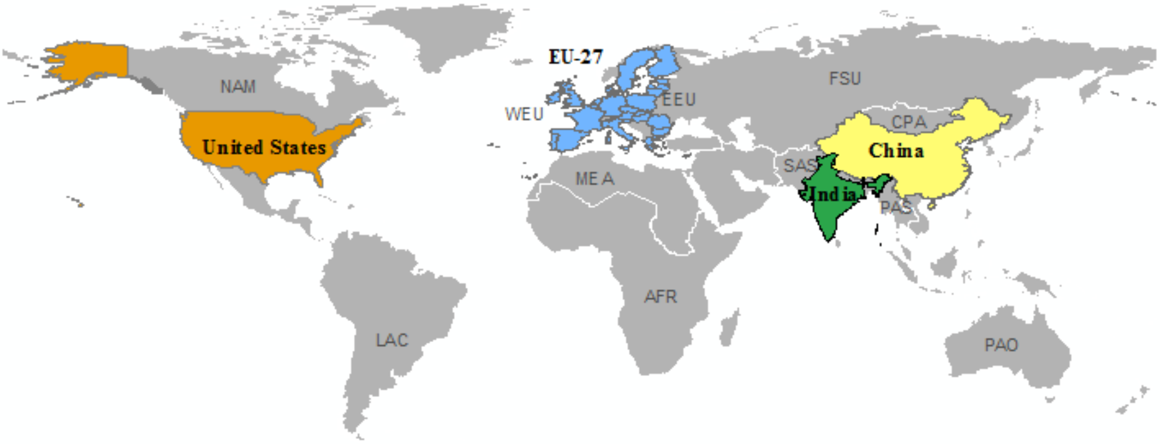
[8] EU (2010)

[9] Standard building - existing building built before 2005.

[10] North America (NAM), Western Europe (WEU), Eastern Europe (EEU), Former Soviet Union (FSU), Latin America and Carribean (LAC), Pacific OECD (PAO), Centrally Planned Asia (CPA), Other Pacific Asia (PAS), South Asia (SAS), Middle East and

Figure 3 Regions analyzed in the model with the focus on four key regions



Source: Ürge-Vorsatz et al. (2012b)

In each region, 17 climate zones are considered in the model. The climate zones (see Table 4 below) are identified for each region based on Heating Degree Days (HDD), Cooling Degree Days (CDD), relative humidity (RH) and average temperature of the warmest month (Ürge-Vorsatz et al. 2012b) – see detailed subchapter 2.5 Climate zone identification: Climate zone identification, Figure 5 for the map of the climate zones considered in the model with the specifications provided in Table 7. For more details see Ürge-Vorsatz et al. (2012b, p. 28-32).

Table 4 The 17 climate zones considered in the 3CSEP HEB model

| Climate ID | Climate description |
|---|---|
| 1 | Only Heating (Very high heating demand) |
| 2 | Only heating (High heating demand) |
| 3 | Only Heating (Low and moderate heating demand) |
| 4 | Heating and Cooling (Very high heating demand and mostly Low cooling demand) |
| 5 | Heating and Cooling (High heating demand and mostly Moderate cooling demand) |
| 6 | Heating and Cooling (High heating demand and Low cooling demand) |
| 7 | Heating and Cooling (Moderate heating demand and Moderate cooling demand) |
| 8 | Heating and Cooling (Moderate heating demand and Low cooling demand) |
| 9 | Heating and Cooling (Low heating demand and Moderate cooling demand) |
| 10 | Heating and Cooling (Low heating demand and Low cooling demand) |
| 11 | Only Cooling (Very high cooling demand) |
| 12 | Only Cooling (High cooling demand) |
| 13 | Only Cooling (Low and moderate cooling demand) |
| 14 | Cooling and Dehumidification (Very high cooling demand) |
| 15 | Cooling and Dehumidification (High cooling demand) |
| 16 | Cooling and Dehumidification (Low and moderate cooling demand) |
| 17 | Heating and Cooling and Dehumidification |

Source: based on Ürge-Vorsatz et al. (2012b)

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Africa (MEA), and Africa (AFR). For more detail see Annex 4 and IIASA website, Energy Modelling Framework description, available at: http://webarchive.iiasa.ac.at/Research/ENE/model/regions.html.

## 2.2 Modelling logic and methodological framework for the cost analysis

The purpose of this study is to provide an indication of the level of main indicators of costs and financial benefits of the scenarios described in Ürge-Vorsatz et al. (2012b) to society. The cost analysis involves an extensive data collection for the main categories (3 building types, 5 building vintages, 11 world regions, 17 climate zones).

The analysis focuses on two main indicators - total cumulative additional investment cost and total cumulative energy cost savings - as these are the main indicators that draw the attention of the decision-makers (households, businesses as well as governments). Total cumulative additional investment costs show how much more investment is needed by 2050 in order to accomplish the transition towards very low energy buildings (either in Moderate or Deep efficiency scenario) as compared to the pathway in the Frozen efficiency scenario, where the investment into refurbishment or new construction is not primarily focused on energy savings and, therefore, energy saving potential cannot be realised to full extent. Total cumulative energy cost savings show the benefits in terms of lowered energy bills this investment brings relative to the development under the Frozen efficiency scenario. The cost data includes construction cost for the advanced and conventional buildings fulfilling criteria mentioned in Subchapter 2.1 Overview of the 3CSEP HEB model. Having the information on the investment needed for instance for the transition towards high efficiency renovation, on one hand, and energy cost savings - on the other, and possibility to compare it to the pathway, in which energy efficiency measures are not implemented, provides a knowledge basis for conscious decision-making.

The complex analysis presented in this report considers only financial aspects of the different renovation scenarios and does not take into account co-benefits related to energy efficiency improvements in buildings such as employment effect, health benefits, gains in productivity for the economy etc.).

In a similar manner as the analysis presented in Ürge-Vorsatz et al. (2012b), the current study assesses improvement of energy efficiency, and not integration of renewable energy sources. The rationale behind it is to assess the cost-effectiveness of the first step on the way towards high performance building sector, which is energy efficiency improvement and the following energy use reduction. A number of studies have claimed that energy efficiency improvements should precede installation of renewable energy technologies (mostly to avoid oversizing of the renewable systems). The analysis of the potential and costs of the renewable energy proliferation in buildings will require the conduction of a separate study. Due time and resource constriaints and the complexity of the research this part has not been included in this report and is considered as an area of further research.

The scenario analysis mentioned above includes estimation of both energy savings and GHG emissions reductions from energy efficiency improvements in buildings, in this study, however, the cost analysis focuses on the energy-related indicators only in order to eliminate the uncertainty in future trends in the $CO_2$ emission factors. Different assumptions about the development of energy supply decarbonisation can result in very different $CO_2$ emissions for the same building energy scenario, and thus the emission results may tell more about the supply side developments than building sector energy changes.

During this study a Cost analysis module (Module 2) has been added to the 3CSEP HEB Model presented in Ürge-Vorsatz et al. (2012b), here named the Scenario analysis module (Module 1). Figure 4 shows the interconnection between the two modules. The main inputs from Module 1 to Module 2 are the floor area ($m^2$) and energy consumption (EJ/year) per category under the three scenarios. Whereas the Scenario analysis (Module 1) is performed for both space heating and cooling, as well as hot water, the Cost analysis (Module 2) focuses merely on space heating and cooling, as this end-use accounts for the majority of total final energy consumption in the building sector and thus also for the related energy savings achievable under the different scenarios. Moreover, cost analysis for water heating will require a different methodology and a separate data collection effort, which would not be possible with the resources allocated for this research. Due to the relatively low share of hot water on total energy consumption in the buildings, it is assumed that its exclusion from Cost analysis would not significantly alter the results in terms of the total investment needs and the total energy cost savings. Moreover, Module 1 distinguishes between urban and rural areas, as well as among various commenrcial and public commercial sub-categories, while Module 2, due to limited data availability, does not consider such divisions, focusing only on three main building types: single-family (SF), multi-family (MF) and commercial & public (C&P) buildings.

For the total cumulative additional investment costs an extensive database has been created (see Annex 7: Example of the cost database), which includes costs of the “best-practices” in different building types, building vintages, regions and climates, as well as costs of their conventional counterparts ($USD_{2005}/m^2$). In this study the best-practice is considered to be the highest building energy performance, which has been achieved or can be potentially achived in a particular region, climate zone and building type at the cost-effective level.

The additional specific investment cost is calculated as a difference between the full specific investment costs under the more ambitious scenarios (Moderate and Deep efficiency scenarios) and the full baseline specific investment costs under the Frozen efficiency scenario per building type, vintage, region and climate. As the main goal of the investment analysis is to show the difference between the investment needs for high efficiency buildings and investment requirements, which do not primarily focus on energy savings, the specific investment costs are compared to a hypothetical benchmark[11] – the baseline costs of new construction or retrofit without significant energy savings gains. Technology learning is applied to the emerging technologies (advanced new and advanced retrofitted buildings). After applying learning factor the reduced specific additional investment costs are applied to the relevant floor area. The outcome, total cumulative additional investment costs, is a sum of all additional investment costs in the different building types and vintages in all climate zones in the given region up to 2050.

In Module 2, technology learning, i.e. a decrease in costs due to the technology diffusion on the market,  is assumed in a way that the specific investment costs of advanced buildings gradually decrease over time. The technology learning is applied only to the advanced buildings when the specific investment costs (i.e. the costs per unit of floor area) of the advanced buildings are higher compared to the baseline costs of conventional buildings. In case the specific additional investment costs (i.e. the difference between specific costs of advanced buildings and the ones of conventional buildings) are negative, it is considered that there are no additional costs for advanced buildings (i.e. that specific additional costs of advanced buildings equal zero). This is because the focus of the study is to find out how much would the transition towards the highly efficient buildings cost in comparison to Frozen efficiency scenario. Including negative costs of advanced buildings, on the other hand, would lower the total cumulative additional investment costs and distort the picture about the overall investment needs. The indication of the extent of the negative values’ effect on the total cumulative additional investment costs is shown in Table 40, Table 41, Figure 51, and Figure 52 in Annex 3: Results of the Module 2: Cost analysis– consideration of the negative values for specific additional investment costs. For regions, climate zones or building types and vintages, where cost data is scarce, cost transfer[12] is used, meaning that special cost ratios of the known cost data is used to calculate the unknown specific investment cost, taking into account regional difference in the costs levels, caused by the local economic conditions. In cost transfer the building type, vintage, region and climate zone are considered.

Total cumulative energy cost savings are calculated as a sum of energy cost savings in all vintages per building type, region and climate zone achieved in the respective mitigation scenario as compared to the Frozen efficiency scenario. Energy cost savings depend on energy savings achieved in each scenario per building type and vintage, and energy prices varying by region (for equations, see Annex 1: Formal equations for cost analysis).

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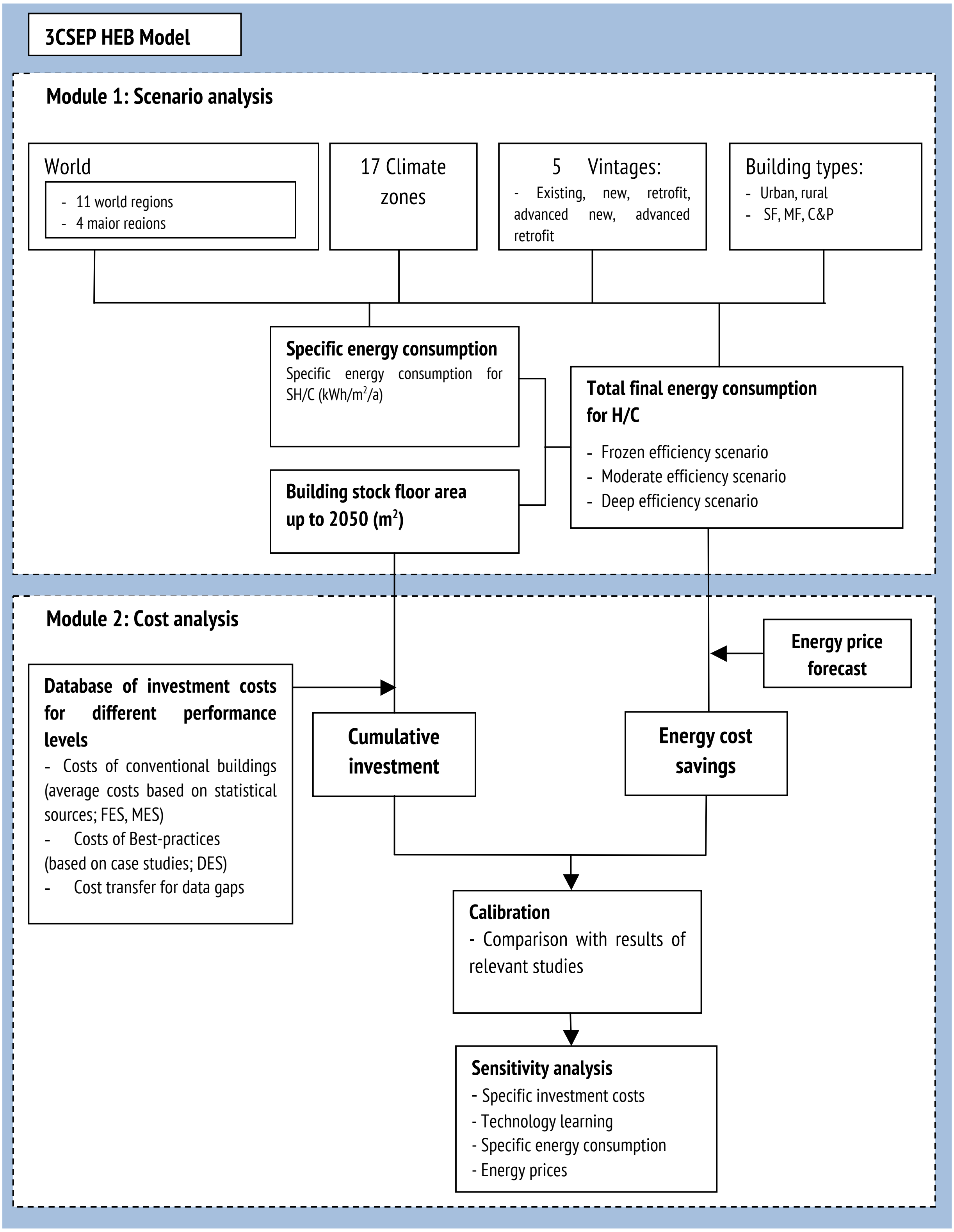
[11] The benchmark in case of retrofit is calculated based on expert judgement as a fraction of the specific investment cost of the advanced retrofit.

[12] The term cost transfer used in this report means transfer of cost ratios, or transfer of a cost through application of a cost ratio. No costs are transferred without consideration of differences in economic conditions of the different regions or climate zones.

Figure 4 Modeling framework for cost analysis of the low energy building scenarios



The methodology for developing Module 2 consists of several steps:

1. Data collection
2. Development of the algorithms for Module 2: Cost analysis and calculation of the results based on the collected cost data
3. Comparison with results of relevant studies
4. Sensitivity analysis

During the first phase (Data collection) data in the following categories have been collected:

- Costs of advanced buildings per building type and building vintage as well as for all world regions, in particular 4 regions – EU-27, USA, India, China. Cost data are collected for each climate zone or in case of data gaps transferred from other regions or climate zones based on the elaborated method discussed below (see Section 2.7).
- Costs of conventional new construction and retrofit per building type and building vintage as well as for all world regions, in particular 4 regions – EU-27, USA, India and China. Costs are collected for each climate zone or in case of data gaps transferred from other regions or climate zones based on the elaborated method discussed below (see Section 2.7).

During data collection, for each region, the major climate zones are identified based on the shares of the population in each climate zones in the total population of a region and the costs are collected only for these climate zones.

In the second phase Module 2 of the 3CSEP HEB model is developed and the total cumulative additional investment costs and total cumulative energy cost savings are computed for the Moderate and Deep efficiency scenarios until 2050. Further, the model results are compared with the results of relevant models/studies (phase 3). Finally, sensitivity analysis is performed for the most important variables (specific investment costs, learning factor, energy prices and specific energy consumption for advanced buildings).

## 2.3 Calculation procedure of the cost analysis

This section describes the calculation procedure in the Module 2 Cost analysis. The formal equations of both calculations can be found in Annex 1: Formal equations for cost analysis.

For the calculation of the **total cumulative additional investment costs** the following steps have been taken:

- First, additional specific investment costs ($USD_{2005}/m^2$) are calculated as a difference between the full specific investment cost of a specific vintage (i.e. advanced new or advanced retrofit) in Moderate/Deep scenario and the full specific investment cost of the corresponding vintage (i.e. new or retrofit) in Frozen efficiency scenario (also called “baseline” costs). For more detail, see equations and Table 39, Annex 1: Formal equations for cost analysis.
- Second, the values new or retrofitted floor area added every year are calculated as a difference between the total floor area per vintage and building type in the actual and previous year. This difference might result in the negative values in the cases, where declining population or certain scenario assumptions cause the decrease in floor area. Decrease in the floor area does not necessarily mean that it has been removed from the building stock, but it rather means that no energy use is taking place on this floor area and, therefore, it is not counted by the model. For the same reason in the calculation of the costs the resulted negative values are not taken into account, i.e. assumed to be zero.
- Third, additional investment costs are calculated by a multiplication of calculated annually added floor area and the corresponding specific full investment cost per floor area ($USD_{2005}/m^2$) for the given region, climate zone, vintage and building type. Learning factor is applied to the specific investment costs of advanced buildings (advanced new buildings and advanced retrofitted buildings) in Deep/Moderate efficiency scenario.
- Fourth, the calculated additional investment costs (tril. $USD_{2005}$) are cumulated for the period until 2050.
- The result of the calculation are the total cumulative additional investment costs per scenario (Deep/Moderate efficiency scenario), as well as vintage, building type and region

For calculation of the **total cumulative energy cost savings** the following steps have been taken:

- First, total energy savings are calculated as a difference between total energy consumption in Frozen and total energy consumption in Deep/Moderate efficiency scenario (EJ) for each region, building type and year. Energy savings are calculated separately for new buildings and retrofitted buildings. Energy savings in new buildings are calculated as a difference between the energy consumption of new buildings built under the Frozen scenario (only new) and energy consumption of new buildings built under Moderate/Deep scenario (both new and advanced new). Energy savings of retrofitted buildings represent the savings stemming from renovating standard buildings to the level of conventional retrofit (under all three scenarios) as well as to the level of advanced retrofit (Moderate/Deep efficiency scenario). Second, the resulting energy savings (EJ) (retrofit and new) per region and building type are converted into TWh and multiplied by the corresponding region-specific energy prices for different fuels.
- The annual energy cost savings for new and for retrofitted buildings are cumulated until 2050 and the result is the cumulative energy cost savings (for new and for retrofitted buildings) in each region, building type and scenario (Deep or Moderate). Total cumulative energy cost savings are calculated as a sum of cumulative energy cost savings for new buildings and cumulative energy cost savings for retrofitted buildings per building type, vintage and region.

## 2.4 Cost database – "Best-Practices" and costs of conventional buildings

The GBPN report (Ürge-Vorsatz et al. 2012b) estimates the energy savings potential in the Deep scenario through large-scale proliferation of highly efficient best-practices, both in new construction and renovation. The Best-practices for new construction can reach up to 90% energy savings as compared to the conventional new construction built according to the country's building code (reaching the energy performance level of approx. 15-30 kWh/m$^2$/year) (Ürge-Vorsatz et al. 2012b). Best-practices for retrofit can achieve up to approximately 70-90% energy savings as compared to conventional retrofit (Ürge-Vorsatz et al. 2012b).

During the phase of data collection, the costs of best-practices of advanced new and retrofit buildings as well as the costs of the conventional ones have been collected and organized in a cost database. The database contains cost data for different building types, regions (11 world regions with a particular focus on four major regions – EU-27, USA, China and India) and climate zones. Main sources used in the database both for the costs of best-practices and for the costs of conventional buildings are summarized in Table 5.

Table 5 Main sources for Cost database

| Data collected | Main sources/Notes | Reference |
|---|---|---|
| **Costs of Best-practices** | Austrian PH database | Courtesy of Gunter Lang (2009) |
| | Austrian PH web-based database | IG Passivhaus Österreich (2012) |
| | German PH database | PHI (2012) |
| | Energy Institute Voralberg, Passive house retrofit kit (collection of case studies for several EU member states) | Energieinstitut (2012) |
| | Paris case studies | Hartkopf et al. (2009) |
| | Finish passive house projects | Energiaviisastalo (2012) |
| | USDoE Building database | USDoE (2012) |
| | Sustainable Habitats | TERI (2012) |
| | Individual studies & projects | Galvin (2010)<br>Voss (2000) |
| **Costs of conventional buildings*** | Hungarian Construction Cost Estimation Handbook | ETK (2009-2011) |
| | Design Cost Data (USA) | DCD (2011) |
| | Quarterly Construction Cost Report (USA) | Rider Levett Bucknall(2012) |
| | International construction cost survey (For different world regions) | Gardiner & Theobald LLP (2009) |
| | International construction cost survey (For major world regions) | Turner & Townsend (2012) |

*Notes*: * Costs of conventional buildings include both "baseline costs", which refer to the cost of the new and retrofitted buildings under the Frozen efficiency scenario ($N^{LOW}$, $R^{10}$), as well as costs of the conventional buildings ($N^{BC}$, $R^{30}$) under the Moderate/Deep efficiency scenario.

In the Cost database a large number of case studies with different types of energy performance have been considered –they range from low-level retrofit through low energy buildings, passive house standard, nearly zero energy buildings to even energy plus buildings. From these cases, only the relevant case studies have been selected for each building type, vintage and climate zone.

For new construction, the advanced buildings must fulfil the threshold of specific energy consumption for space heating of 15-30 kWh/m$^2$/a, or, in regions with low heating requirement, specific energy consumption for space cooling of 15-30 kWh/m$^2$/a.

For advanced retrofit buildings with specific energy consumption for space heating or cooling in range of 15-50 kWh/m$^2$/a are considered. These buildings must show energy savings of at least 70% as compared to their specific energy consumption before renovation.

The costs of conventional buildings are divided into two groups – new ($N^{LOW}$ and $N^{BC}$) and retrofit ($R^{10}$ and $R^{30}$) (for detailed explanation, see Table 3 and related notes). While costs for new construction ($N^{LOW}$ and $N^{BC}$) are collected based on average values for new construction built after 2005 based on international construction cost surveys (e.g. Gardiner & Theobald LLP (2009), Turner & Townsend (2012), the costs of conventional retrofit ($R^{10}$ and $R^{30}$) are mainly based on individual project reports and expert estimates. For $R^{10}$ cases of energy savings of approximately 10-25% as compared to the energy consumption before renovation are considered. For $R^{30}$ cases of energy savings of approximately 25-45% as compared to the energy consumption before renovation are considered. For summary of thresholds see Table 6.

Table 6 Thresholds for selection of case studies for costs of advanced buildings and costs of conventional buildings

| Building vintage/Unit | Specific energy consumption for space heating or cooling kWh/m$^2$/a | Energy savings as compared to the specific energy consumption before renovation % | Source |
|---|---|---|---|
| **Advanced new construction** | 15-30 | 70% | PHI (2010) |
| **Advanced retrofit** | 15-50[13] | 70% | Based on:<br>Ürge-Vorsatz et al. (2012b), PHI (2003), own assumptions |
| **Conventional new construction** | - | 30-50% as compared to comparable new building | Based on:<br>Ürge-Vorsatz et al. (2012b), own assumptions |
| **Conventional retrofit** | - | 30-50% as compared to energy consumption before retrofit | Based on: Ürge-Vorsatz et al. (2012b), own assumptions |

Data of the different cases studies in the database are organized by: regions, climate zones, building types, vintages, energy needs or energy consumption (per space heating, cooling, other and total), depth of energy savings, total construction cost per unit of floor area, additional costs for energy efficiency measures and additional costs for RES measures. The cost of construction is calculated as total construction cost per unit of floor area (USD$_{2005}$/m$^2$).

It must be noted that a wide variety of data was collected. The costs vary across regions due to different levels of construction costs, which is partly reflected by applying country-specific construction cost index - CCI.[14] The costs and cost availability

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[13] The figures for renovation refer to aiming towards the above mentioned thresholds.

differs across building types due to the number of buildings constructed in the specific building vintage and performance level, as well as due to a higher learning effect in particular building type. The costs also differ due to different extent of inclusion of the measures related to utilization of renewable energy sources, their combination and their costs (e.g. heat pumps, PV panels, solar thermal panels, biomass boiler etc.). Despite the effort not to include prohibitively large costs due to large application of renewable measures, the impact of the measures based on renewables often cannot be separated or estimated, and thus the construction cost may be influenced by installation of such technologies. The building is considered as a whole, including both energy efficiency measures as well as the renewable-based measures, and the construction cost reflects this approach.

## 2.5 Climate zone identification

Climate zone identification is a two-way process:

1. Initially, for any given region the case studies are collected, and the climate zone (named as “climate identification”, CID) of each case study must be identified. Then a so called “availability map” is developed per region showing available case studies for different climate zones, building types and vintages.
2. Major climate zones are identified per region based on their population shares in the total region’s population.[15] During the second round of data collection, the cost data have been searched for the major climate zones and if the reliable data was not available the cost transfer has been applied in order to fill the data gaps based on the obtained data (for more details see Section 2.7). Further, cost transfer has been applied for the missing data points in the minor climate zones as well.

Below the process of CID identification is described for the case studies. The region-specific identification of the major climate zones can be found in the region-specific chapters.

The climate zone (CID) categorization used in the model as defined in Ürge-Vorsatz et al. (2012b), uses 17 zones according to the heating- and cooling energy demand and the need for dehumidification. The zones are specified based on the values of cooling degree days (CDD), heating degree days (HDD), relative humidity of the warmest month (RH) and average temperature of the warmest month (AT) (Ürge-Vorsatz et al. 2012, page 28). Although the CID could have been identified for some case studies according to the location of the case study on a climate zone map (Ürge-Vorsatz et al. 2012, see Figure 5), in the majority of the case studies the CID identification is not as straightforward (e.g., when the city is located on the boarder between two climate zones). Thus, for most of the cases their location is identified on each of the CDD, HDD, RH and AT maps (Ürge-Vorsatz et al. 2012, Figure 6), based on which the actual climate zone of the case was identified. For the rest of the cases located on boarders between different climate zones with significantly different features, the available information on CDD, HDD, RH and the AT were taken into consideration[16], based on which the appropriate CID can be identified using the tresholds presented in Table 7. For the most unclear cases the CID categorization was estimated taking into account the diversity of the heating and cooling habits of different cultures/regions and other influencing factors.

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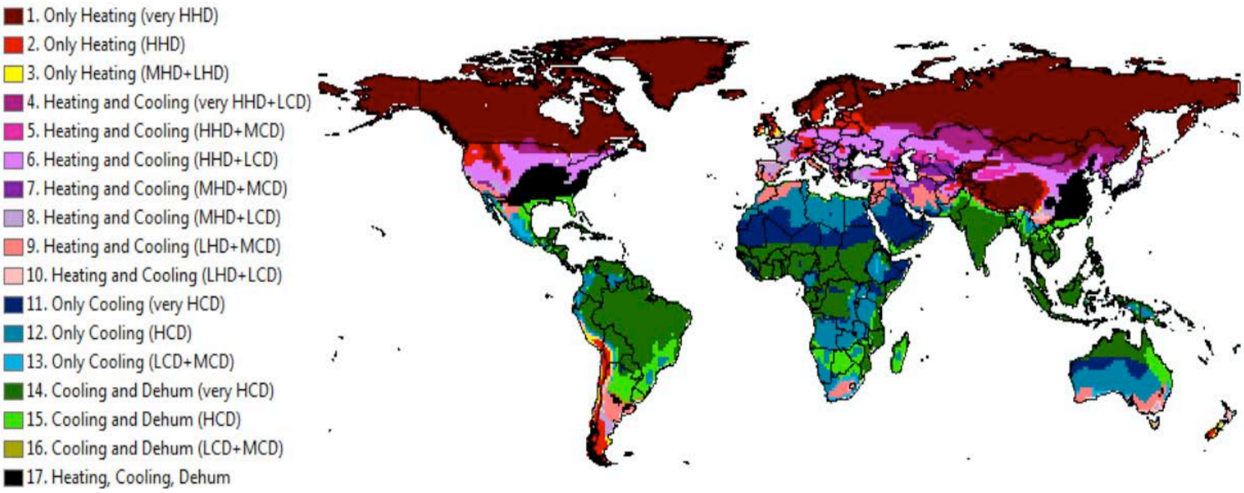
[14] In case construction cost index is not available for the given region (e.g. in case of China, India etc.), the region specific CCI is estimated based on the consumer price index (CPI) applying the ratio between CCI and CPI for EU-27 (OECD 2012).

[15] Major climate zone is defined here as a climate zone comprising at least 10% of the total region’s population.

[16] Sources used:
California Climate Zones and Bioclimatic design, 2006. The Pacific Energy Center, available at:
http://www.pge.com/includes/docs/pdfs/about/edusafety/training/pec/toolbox/arch/climate/california_climate_zones_01-16.pdf,
NCDC National Climatic Data Center, available at: http://www7.ncdc.noaa.gov/IPS/cd/cd.html,
http://www.thinkkentucky.com/edis/cmnty/QltyLife.aspx?cw=098,
http://www.ccenrg.com/cce_handy_data.html,
http://en.wikipedia.org/wiki/Heating_degree_day.

Figure 5 Composite climate split used in the 3CSEP HEB Model



Source: Ürge-Vorsatz et al. (2012b)

Table 7 Input parameters for climate zones

| | Climate Zone | CDD10 | HDD18 | RH | Ave. T | Colour Code |
|---|---|---|---|---|---|---|
| 1 | Only Heating (Very high heating demand) | <1000 | >=5000 | <50 | Or =<23 | 🟥 |
| 2 | Only heating (High heating demand) | <1000 | >=3000 and <5000 | <50 | Or =<23 | 🟥 |
| 3 | Only Heating (Low and moderate heating demand) | <1000 | >= 1000and <3000 | <50 | Or =<23 | 🟨 |
| 4 | Heating and Cooling (Very high heating demand and mostly Low cooling demand) | >=1000 and <2000* | >=5000 | <50 | Or =<23 | 🟪 |
| 5 | Heating and Cooling (High heating demand and mostly Moderate cooling demand) | >=2000 and <3000** | >=3000 and <5000 | <50 | Or =<23 | 🟪 |
| 6 | Heating and Cooling (High heating demand and Low cooling demand) | >=1000 and <2000 | >=3000 and <5000 | <50 | Or =<23 | 🟪 |
| 7 | Heating and Cooling (Moderate heating demand and Moderate cooling demand) | >=2000 and <3000*** | >=2000 and <3000 | <50 | Or =<23 | 🟪 |
| 8 | Heating and Cooling (Moderate heating demand and Low cooling demand) | >=1000 and <2000 | >=2000 and <3000 | <50 | Or =<23 | 🟪 |
| 9 | Heating and Cooling (Low heating demand and Moderate cooling demand) | >=2000 and <3000*** | >=1000 and <2000 | <50 | Or =<23 | 🟥 |
| 10 | Heating and Cooling (Low heating demand and Low cooling demand) | >=1000 and <2000 | >=1000 and <2000 | <50 | Or =<23 | ⬜ |
| 11 | Only Cooling (Very high cooling demand) | >=5000 | <1000 | <50 | Or =<23 | 🟦 |
| 12 | Only Cooling (High cooling demand) | >=3000 and <5000 | <1000 | <50 | Or =<23 | 🟦 |
| 13 | Only Cooling (Low and moderate cooling demand) | >=1000 and <3000 | <1000 | <50 | Or =<23 | 🟦 |
| 14 | Cooling and Dehumidification (Very high cooling demand) | >=5000 | <1000 | >=50 | And >23 | 🟩 |
| 15 | Cooling and Dehumidification (High cooling demand) | >=3000 and <5000 | <1000 | >=50 | And >23 | 🟩 |
| 16 | Cooling and Dehumidification (Low and moderate cooling demand) | >=1000 and <3000 | <1000 | >=50 | And >23 | 🟩 |
| 17 | Heating and Cooling and Dehumidification | >=1000 | >=1000 | >=50 | And >23 | ⬛ |

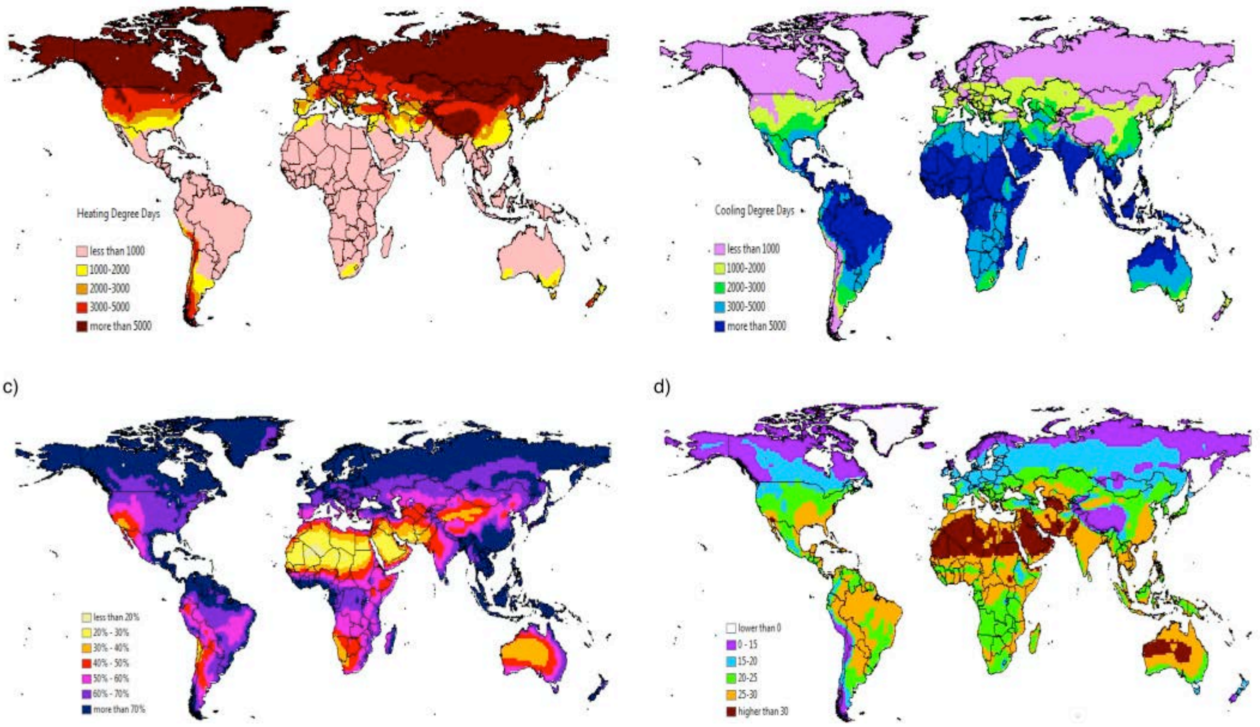
Source: Ürge-Vorsatz, D. et al. (2012b)

*Notes:*

* There might be some areas in this subcategory, where value of CDD is higher than 2000, but their number is insignificant

** There are some areas in this subcategory, where value of CDD is higher than 3000, but their number is insignificant

Figure 6 Maps of HDD, CDD, average temperature and relative humidity



Source: Ürge-Vorsatz et al. (2012b)

## 2.6 Cost identification

Based on the collected data, the most relevant cost figures are identified for each building type and vintage, region and climate zone. For the costs of conventional buildings (new, retrofit), averages of low and medium standards of the building's design and equipment are considered (i. e. the costs of luxury design buildings are excluded) and based on international construction cost surveys, such as Gardiner & Theobald LLP (2009), Turner & Townsend (2012). For the advanced buildings (advanced new, advanced retrofit) the leading principle for the cost identification is to identify the average investment cost for a given region, climate zone, building type and vintage, which is based on the case studies in the low end of the collected data on specific investment costs.

For the given region, the priority is always to find genuine cost data from that region and for the relevant building type. For those building types in different climates where no best-practices with the relevant data on costs or no data on costs of conventional buildings are found, the costs are transferred through the use of cost ratios from similar regions and/or climate zones for the same building type. The priority of genuine data over the lowest cost figures for the neighbouring climate zones may lead to a situation where even though a certain country in general (e.g. Austria) is assumed to have low costs of advanced buildings, the difference in the specific investment costs per unit of floor area ($USD_{2005}/m^2$) between two different climate zones may be significant. Thus, cost identification for a given region, building type and climate zone depends significantly on the availability of cost data and must be considered on the case-by-case basis. In such cases as described above, i.e. in case of certain climate zone, for which only a case study with unreasonably high costs is available (e.g. two or more times higher than the average specific investment cost for similar building type and vintage) the costs have been transferred through so-called cost ratios from a climate zone with a lower cost.

The major general assumptions for cost identification can be summarized as follows:

- Genuine cost data for the given region, its climate zone and building types are identified. Priority is given to original regional data over cost transfer.

- In each region, major climate zones are identified (usually the identified major climate zones account for about 80-90% of the total region's population in total), and cost data for these major climate zones are searched for. A major climate zone is defined here as a climate zone with a share of 10% or higher in the total population of a region. Nevertheless, if data exists in minor climate zone, it can be used as a basis for cost transfer to the major climate zone of similar characteristics or to a climate zone for which no reliable cost data exist.
- If costs of the available case studies are extremely low or extremely high, these cases are examined, and if they prove non-reliable, cost transfer is applied from a different climate zone or even region. In case costs are extremely high, costs from different regions may be transferred as to reflect the possibility to build or retrofit the building towards the advanced level of energy performance at even lower cost level (e.g. in India in some climate zones only case studies with very high costs are available, and thus, cost transfer from the EU-27 is applied in these cases).
- Due to lack of reported and detailed cost data from rural and urban areas of the same region and climate, it is assumed that there is no significant difference between the urban and rural areas in terms of specific investment costs.
- In the cost analysis the category of commercial and public (C&P) buildings is an aggregate of its subcategories (educational buildings, hotels & restaurants, hospitals, other, retail and offices) due to the lack of data for each C&P category.
- Slums are not considered in the cost analysis due to several reasons: the data for these areas are usually unavailable, specific energy consumption in slums is not significant, their share in the total floor area is very small, and energy savings potential is considered limited. Therefore, the impact of slums on the related total investment costs and financial benefits is assumed to be negligible.

Tables with cost identification for all world regions can be found in Annex 4: Specific investment costs per region and building type for all climate zones.

## 2.7 Cost transfer methods and assumptions

There were several cases where reported cost data were not available or could not be used due to consistency issues (e.g. were unrealistically low or high as compared to other relevant cost data). In such cases a calibrated data transfer methodology was used to fill in the data gaps. During the transfer, reliable and referenced data, or its proportionality, from one region is applied to another region where data gaps exist, using a transfer factor (Ürge-Vorsatz et al. 2012a). The data transfer must be performed with care due to differences in economic circumstances of the regions, which are the main issues to address during the transfers (Ürge-Vorsatz et al. 2012a).

Working in the absence of reliable data leaves few options to still be able to build models. The cost transfer methodology is one of the very few, if not the only, methods that can provide a best estimate for filling in the data gaps when a modelling is still desired in the data gap situation. The method of cost transfer has been used in several studies. This incluces recent work on computing the employment effect of renewable and energy efficient investment, such as for the world (Greenpeace 2009) and for Hungary (Ürge-Vorsatz et al. 2012a). The GBPN scenario study, Module 1: Scenario analysis (Ürge-Vorsatz et al. 2012b) used data transfer to fill the gaps in energy intensity values for space heating and cooling (kWh/m$^2$/year) based on empirical data for similar building types, regions or climates. Cost transfer has been used in several other studies (such as Novikova 2008, Korytarova 2010), where costs were transferred mainly between different regions, as well as between different building types. For instance, Korytarova (2010) transferred specific additional investment costs (€/m$^2$) of nearly passive SOLANOVA multi-apartment retrofit (Hermelink 2007) to public buildings of the same specific energy demand, similar size and energy use pattern, which are located in the same region and climate zone (i.e. transfer across building types). Similarly, costs of conventional buildings, which were available only for educational and administration buildings were transferred to other public building types (health care buildings, social and cultural buildings) by using different transfer ratios reflecting the building's functionality and size (Korytarova 2010).

In this study the following principles of the cost transfer have been applied. The Best practices are well-established practices in several parts of the world (Austria, Germany, some parts of the USA), however, reliable cost data of such Best practices are not available in every region and every climate zone of a given region. Therefore, the cost data for both Best practices, as well as costs of conventional building vintages is applied:

- Priority is given to the **genuine cost data** from a given region over the transfer from another region.
- In case of non-availability of cost data within the region, **region-to-region** cost transfer can be conducted for corresponding climate zones.
- Cost transfer can be applied between **two different climate zones** (preferably for the given building type) provided these climate zones have similar climatic features.

In case of cost transfer within a given region, between two different climate zones or two different building types, the **advanced-to-conventional-buildings cost ratio** is applied in some cases. These can be applied for region-to-region cost transfer as well, as the ratio reflects the difference in the purchasing power parity. The advanced-to-conventional-buildings cost ratio is an expression of the relation between the cost of the advanced new /retrofit buildings (i.e. $AR^{70+}$, $AN^{70+}$) and the respective cost of conventional new/retrofit building (either $R^{30}$ or $N^{BC}$). If necessary, a transfer between **two building types** is possible based on the cost ratio reflecting cost ratio between known and unknown vintages, with the consideration of the climate zone and regional specifics.

In regions with major lack of genuine cost data (such as China and India, and regions within the aggregate group Rest of the World), a **combined cost transfer ratio** had to be applied (for more see Annex 8: Cost ratio transfer). With the help of such ratio, cost data is transferred across regions based on the limited reliable data points available in the given region. For further information on cost ratio transfer please, see Annex 8: Cost ratio transfer.

## 2.8 Technology learning

Technology learning is an important factor to consider in any cost analysis of emerging technologies and know-how (Fleiter et al. 2009). Technology learning[17] - a decrease in the cost once the production doubles, occurs due to two reasons – economy of scale and the learning effect. In this study this concept is used in the following way: while the number of advanced new and retrofit buildings is growing and their market uptake is on increase, but a large market penetration is still far from being achieved, the costs of such buildings are expected to be decreasing over time during wider technology diffusion and acceptance.

Neij (1998, cited in Fleiter et al. 2009 and Korytarova 2010) categorized technology learning effect for different types of building components and technologies on the scale of 5-30% when the production doubles. Novikova (2008) includes technology learning for both building components and for the passive standard technology for new construction. Korytarova (2010) applies technology learning also for passive house standard technology for retrofit (assuming that the difference in additional cost (%) between the ones for passive houses and conventional buildings would halve by 2020 for both new construction and retrofit). BPIE (2011) assumes different learning factors varying by ambition of the performance level (cost reduction from 1% p.a. for minor renovation, to cost reduction of 4% p.a. per nZEB). Harvey (2013) notes that in Europe the additional cost of (new) Passive house standard level has decreased by factor of 4 within 14 years. In the research on employment effects of large-scale energy efficient renovation in Poland (Ürge-Vorsatz et al., 2012a) cost reduction is assumed in such a way that the costs of deep renovation decreases to the doubled level of the base renovation costs by 2070, and then becomes relatively stable. Specifically, the cost of deep renovation falls down from approximately 330 €/m$^2$ in 2011 to approximately 80 €/m$^2$ in year 2070 (Ürge-Vorsatz et al. 2012a), i.e. more than factor of four in 60 years. A similar study for

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[17] "For many products and services, unit costs decrease with increasing experience. The idealized pattern describing this kind of technological progress in a regular fashion is referred to as a learning curve, progress curve, experience curve, or learning by doing" (Dutton and Thomas 1984, Argote and Epple 1990, Argote 1999, Galvin 2010).

Hungary assumed that the cost of deep renovation gradually decreases to the doubled level of the cost for base retrofit by 2040, i.e. from the level of about 320 €/m$^2$ in 2011 to the level of about 100 €/m$^2$ in 2040 (Ürge-Vorsatz et al. 2011), resulting in. more than factor of three in 30 years.

One of the reasons why the assumed learning effects are so large is the limited experience with deep renovations worldwide (except for countries with a long tradition of passive energy standard, such as Austria, Germany) (Ürge-Vorsatz et al. 2011), including the lack of skilled construction professionals.

The current study assumes that the specific investment cost of the advanced new construction as well as that of advanced retrofit decreases by 50% by 2050 as compared to their 2005 values. Due to the large variety of approaches to technology learning factor in different studies, variety of learning factors and their effect on the total cumulative additional investment costs are examined further in the sensitivity analysis.

Another important reason for the learning effect is a major change in the design methodology, which means moving away from the conventional, linear approach to building design towards the integrated design process (IDP). IDP means that different processes of design, planning, construction and commissioning are closely interlinked (Zimmerman 2006, Poirier 2008).[18] Zimmerman also mentions a case study about a completed design and construction project where ten percentage of constructions cost has been saved thanks to IDP.

The extent of the cost difference depends on the technology learning driven by demand for new construction and retrofits. In case there is enough demand for new construction, the requirements of the Directive 2010/31/EU on Energy Performance of Buildings (EU 2010) could drive the demand for nearly zero energy buildings in Europe, and thus may influence the cost of high-efficiency buildings at least on this continent. Moreover, this learning effect may partially spill over to other continents as well.

## 2.9 Energy price projections

Energy prices are based on the assumptions of energy prices and their development presented in Global Energy Assessment (Ürge-Vorsatz et al. 2012a) and updated for EU-27 and USA for natural gas and electricity. For these fuels and regions the energy prices are assumed to increase by 1.5% p.a. Table 8 shows the sources of energy prices in the model.

Table 8 Assumptions and sources for energy price projections

| Region | Source |
|---|---|
| **EU-27** | Electricity and Natural gas:<br>Eurostat (2012a-e) |
| | Wood, lignite, coal, district heating:<br>Simple weighted average of energy prices for regions of EEU and WEU (GEA in Ürge-Vorsatz et al. 2011) |
| **USA** | Electricity and Natural gas:<br>DoE (2012), DoL (2012) |
| | Wood, lignite, coal, district heating:<br>Simple weighted average of energy prices for regions of EEU and WEU (GEA in Ürge-Vorsatz et al. 2011) |
| **China** | Simple weighted average of energy prices for regions of China (GEA in Ürge-Vorsatz et al. 2011) |
| **India** | Simple weighted average of energy prices for regions of India (GEA in Ürge-Vorsatz et al. 2011) |
| **Rest of the World regions (RoW)** | Based on energy prices and their projections in GEA in Ürge-Vorsatz et al. (2011) |

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[18] Integrated design process is “a process in which all of the design variables that affect one another are considered together and resolved in an optimal fashion” (Lewis 2004 cited in Harvey 2006). Integrated design process includes minimizing loads, sizing and selecting best-HVAC equipment, optimizing equipment operation, commissioning of the building (Todesco 2004 cited in Harvey 2006).

## 2.11 Data gaps and study limitations

### 2.11.1 Data gaps

This section summarizes the main data gaps and provides suggestions for the areas of further research. During the data collection phase, the following gaps were identified (see Table 9):

**EU-27:** As in the EU-27 there is a number of advanced new buildings and renovated buildings, data are available for most of the categories (building types and vintages) in the major climate zones. In general, there are some data gaps regarding advanced new buildings (MF and C&P) and advanced retrofit (SF) for one or two major climate zones.

**USA:** In the USA, several cases are available for the major climate zones (CID 6, 9, 15, 17). The main gaps concern conventional retrofit ($R^{30}$) for the residential building types (SF, MF), advanced retrofit ($AR^{70+}$) for the residential building types (SF, MF) and some single data points of advanced new buildings (SF, C&P).

**China:** The data on advanced buildings is very limited, except for some C&P buildings. Cost data for conventional buildings have not been found except for new buildings, for which the data have been collected for most of the building types and major CIDs).

**India:** Similarly to China, for India very limited data is available. Main gaps exist in the data for advanced new and advanced retrofit buildings in the residential building types (SF, MF), while limited number of case studies are available for C&P buildings. Cost data for conventional buildings have been obtained only for new buildings in two major CIDs.

Table 9 Summary of the main data gaps for the major regions

| Region | Building type | Main data gaps |
|---|---|---|
| **EU-27** | SF | CID 8: advanced retrofit |
| | MF | CID 2, 6: advanced new |
| | C&P | CID 8: advanced new |
| **USA** | SF | CID 9: Advanced new, advanced retrofit<br>CID 15: advanced new<br>CID 17: advanced retrofit |
| | MF | CID 6, 9: advanced retrofit<br>CID 15: advanced retrofit |
| | C&P | CID 6, 17: advanced retrofit<br>CID 9: advanced new |
| **China** | All building types | All building types lack data on advanced new and advanced retrofit, except for C&P, where data on advanced new exists for CID 15. Cost data of conventional buildings are also missing except for new, which are available for most of the building types and major CIDs. |
| **India** | All building types | All building types lack data on advanced new and advanced retrofit, except for C&P, where data on advanced new exists for CID 14 and CID 15. Cost data of conventional buildings are also missing except for new, which are available only for CID 14 and CID 15. |

### 2.11.2 Limitations of the study

Due to the limited scope and time frame for the study, the following limitations are identified:

- Availability of the cost data is limited for a number of regions, climate zones and building types. The major data gaps are described above (section 2.11.1 Data gaps) and mainly refer to such regions as China and India.
- Not all the data, which is available could have been used in the model. The key reason for that is that there is no statistically representative, uniform and detailed data collection practice on the costs for construction and retrofit.

Therefore, the data used for this study is only a fraction of a large body of construction costs, which could have been accessed and based on the expert judgments is considered to be representative.

- A large portion of the data does not provide the necessary level of detail in order to be comparable to other cases, which aggravates data selection process.
- The study focuses only on space heating and cooling. Other end-uses are not considered for a number of reasons. Lighting and appliances have not been analysed, as they are not included in the scenarios for energy use discussed above. Hot water end-use is not considered from two reasons: first, the energy saving potential from hot water systems improvements is quite limited, as related energu consumption accounts for only about 10-20% of the thermal energy consumption in the buildings (Ürge-Vorsatz et al. 2012b); second, hot water consumption measures are not considered to have a relatively low impact on the total investment costs and the energy cost savings relative to those related to space heating and cooling.
- Energy price projections are simplified (i.e. the standard assumption of annual energy price increase has been used), based on the prices for certain fuels or on the weighted average of energy projections per region from the Global Energy Assessment model.

# CHAPTER 3: FINDINGS: THE EUROPEAN UNION-27

Based on the background provided in the previous sections this chapter focuses on the input data and results applicable for EU-27. The modelling assumptions for this region are documented in Annex 2: Assumptions for the cost analysis by region, Section A2.1. The European Union-27.

## 3.1 Summary of the input data

Several European countries have a long tradition in high efficiency buildings, both new construction and retrofit. Therefore, there is a significantly larger basis for data collection (which gives the possibility to choose the lowest achieved costs of best-practices) as compared to other world regions. In addition, the costs of advanced buildings have decreased over decades through technology learning. This is especially due to the long traditions in such countries as Austria, Germany, Switzerland, Sweden, Denmark and Finland. However, not all EU member states have the same history in advanced building construction or retrofit, and thus, this region shows a wide variety of costs.

The process of the cost identification includes the following steps: first, the major climate zones of the region are identified. Second, the climate zones are identified for the studies that are available. The collected case studies are then distributed into the relevant climate zones in a so called availability map, according to which further case studies are searched for in order to fill in the gaps of the missing data points. Finally, the costs in minor climate zones or those climate zones or other categories (such as building vintage or building type), for which there are no relevant and reliable cost data, are based on the cost transfer from other category or region (for more details on the exact assumptions see Annex 2: Assumptions for the cost analysis by region, for example of cost transfer see Annex 8: Cost ratio transfer).

### 3.1.1 Cimate zones

The Section 2.5 Climate zone identification describes a general approach to the climate zones (CID) identification. Similarly to other regions, the case studies all over the region EU-27 were searched for, with special attention paid to the major climate zones. Major climate zone is defined here as a climate zone comprising at least 10% of the total region's population, the 3CSEP HEB model provides these shares for the EU-27. The population shares of the climate zones in the EU's total population are shown in Table 10, where the major climate zones are shaded with light blue.

Table 10 Average shares of climate zones in the region’s total population, EU-27 in 2005 and 2050

| **CID** | **2005** | | | **2050** | |
|---|---|---|---|---|---|
| | **Description of the climate zone (CZ)** | **Average share of the climate zone in the region’s total population** | **Population in the climate zone** | **Average share of the climate zone in the region’s total population** | **Population in the climate zone** |
| | | **%** | **million** | **%** | **million** |
| **CID 1** | vHHD | 1.4% | 8.2 | 1.5% | 9.1 |
| **CID 2** | HHD | 23.8% | 140.8 | 24.5% | 152.7 |
| **CID 3** | MHD + LHD | 4.0% | 23.4 | 4.1% | 25.8 |
| **CID 6** | HHD + LCD | 30.1% | 178.1 | 28.4% | 176.7 |
| **CID 7** | MHD + MCD | 2.3% | 13.7 | 2.4% | 15.1 |
| **CID 8** | MHD + LCD | 25.9% | 152.9 | 26.2% | 163.3 |
| **CID 9** | LHD + MCD | 6.3% | 37 | 6.6% | 40.8 |
| **CID 10** | LHD + LCD | 1.7% | 9.8 | 1.7% | 10.9 |
| **CID 12** | HCD | 0.3% | 1.7 | 0.3% | 1.8 |
| **CID 15** | HCD | 1.0% | 5.6 | 1.0% | 6.2 |
| **CID 16** | LCD + MCD | 0.7% | 4 | 0.7% | 4.5 |
| **CID 17** | H+C+DH | 2.6% | 15.4 | 2.6% | 15.9 |

Table 10 shows that the EU-27 has 3 key climate zones (highlighted) meeting the 10% threshold: CID 2 (Only heating), CID 6 (High Heating Demand and Low Cooling Demand) and CID 8 (Medium Heating Demand and Low Cooling Demand). According to the table above, 80% of the EU-27 population live in the three major climate zones, while most of these require mainly heating and do not have high cooling demand.

### 3.1.2 Costs of advanced and conventional buildings

The cost database contains data for both advanced buildings (advanced retrofit and advanced new) used in the Moderate and Deep efficiency scenarios and conventional ones (new and retrofit) utilised in the Frozen efficiency scenario. The performance levels of advanced buildings are considered the same for the Deep efficiency and Moderate efficiency scenarios (for detail see Section 2.4 Cost database – “Best-Practices” and costs of conventional buildings).

The costs of advanced buildings are based on an extensive collection of over 200 case studies, mainly based on Austrian Passive House database (Lang 2009), German Passive House database (PHI 2012), UNEP Paris case studies (Hartkopf et al. 2009) as well as individual reports or publications (such as Galvin 2010, Voss 2000, Harvey 2006). For advanced buildings, the cases with the lowest construction cost per unit of floor area ($USD_{2005}/m^2$) have been identified per climate zone, building type and building vintage.

The costs of conventional new buildings are based mainly on International construction cost survey of Gardiner & Theobald LLP (2009) and Turner and Townsend (2012), which provides costs for a wide range of building types and comfort standard (low, medium, high) and gives cost variations for different EU-27 member states. For each available climate zone, an average was calculated based on cost figures excluding high standard, premium and luxury standard buildings. The resulting averages are used for the relevant climate zones, building types and vintages.

The costs of conventional renovation are based on individual case studies and expert estimates (Reith 2012). Table 11 provides a list of the main sources for costs of advanced and conventional buildings for EU-27.

The cost of construction, here also called “specific investment cost”, means full investment cost per unit of floor area ($USD_{2005}/m^2$). Full investment cost mean the total costs of construction including both the costs of construction of the building as well as the cost of energy efficiency measures, as opposed to additional investment costs, which include only costs related to the improvement in energy efficiency of the building. All cost data are converted from national currencies to USD using ECB's exchange rates (ECB 2012), while for the conversion into $USD_{2005}$ the construction cost index (CCI) for different member states is used (Eurostat 2012e, OECD 2012).

Table 11 Main sources for cost database in the EU-27

| Data collected | Main sources/Notes | Reference |
|---|---|---|
| **Best-practices** | Austrian PH database | Courtesy of Gunter Lang (2009) |
| | Austrian PH web-based database | IG Passivhaus Österreich (2012) |
| | Energyinstitut Voralberg, Passive house retrofit kit (collection of case studies for several EU member states) | Energieinstitut (2012) |
| | German PH database | PHI (2012) |
| | Paris case studies | Hartkopf et al. (2009) |
| | Finish passive house projects | Energiaviisastalo (2012) |
| | Individual studies & projects | Galvin (2010)<br>Voss (2000)<br>Josep Bunyesc (2012)<br>Kazinczy (2012)<br>Hermelink (2005-2007)<br>Haus der Zukunft (2012)<br>Harvey (2006)<br>Lain et al. (2001)<br>Edwards (2006)<br>Dascalaki et al. (2010) |
| **Cost of conventional buildings*** | Hungarian Construction Cost Estimation Handbook | ETK (2009-2011) |
| | International Construction Cost Survey (for different world regions) | Gardiner & Theobald LLP (2009) |
| | International Construction Cost Survey | Turner & Townsend (2012) |

*Notes*: * Cost of conventional buildings include both "baseline costs", which refer to the cost of the new and retrofitted buildings under the Frozen efficiency scenario ($N^{LOW}$, $R^{10}$), as well as costs of the conventional buildings ($N^{BC}$, $R^{30}$) under the Moderate/Deep efficiency scenario.

The specific (full) investment costs per unit of floor area in the EU-27's major CIDs pre building type are shown in Table 12.

Table 12 Specific investment costs per unit of floor area in EU-27, major CIDs

| **EU-27** | | | | SF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Frozen efficiency scenario | | | | Moderate efficiency scenario | | | | Deep efficiency scenario | | | |
| | | | | New | | Retrofit | | New | | Retrofit | | New | | Retrofit | |
| | | | | New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit |
| RID | CID | % CID | Climate | $N^{LOW}$ | $AN^{70+}$ | $R^{10}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ |
| 4+14 | 2 | 24% | HHD | 1112 | 1571 | 561 | 935 | 1390 | 1571 | 748 | 935 | 1390 | 1571 | 748 | 935 |
| 4+14 | 6 | 30% | HHD + LCD | 576 | 1198 | 613 | 1021 | 827 | 1198 | 817 | 1021 | 827 | 1198 | 817 | 1021 |
| 4+14 | 8 | 26% | MHD + LCD | 831 | 887 | 545 | 909 | 855 | 887 | 727 | 909 | 855 | 887 | 727 | 909 |

| | | | | MF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Frozen efficiency scenario | | | | Moderate efficiency scenario | | | | Deep efficiency scenario | | | |
| | | | | New | | Retrofit | | New | | Retrofit | | New | | Retrofit | |
| | | | | New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit |
| RID | CID | % CID | Climate | $N^{LOW}$ | $AN^{70+}$ | $R^{10}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ |
| 4+14 | 2 | 24% | HHD | 1223 | 1342 | 361 | 601 | 1223 | 1342 | 481 | 601 | 1223 | 1342 | 481 | 601 |
| 4+14 | 6 | 30% | HHD + LCD | 465 | 995 | 206 | 344 | 888 | 995 | 275 | 344 | 888 | 995 | 275 | 344 |
| 4+14 | 8 | 26% | MHD + LCD | 769 | 1643 | 206 | 344 | 1467 | 1643 | 275 | 344 | 1467 | 1643 | 275 | 344 |

| | | | | C&P | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Frozen efficiency scenario | | | | Moderate efficiency scenario | | | | Deep efficiency scenario | | | |
| | | | | New | | Retrofit | | New | | Retrofit | | New | | Retrofit | |
| | | | | New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit |
| RID | CID | % CID | Climate | $N^{LOW}$ | $AN^{70+}$ | $R^{10}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ |
| 4+14 | 2 | 24% | HHD | 1711 | 1391 | 332 | 553 | 1711 | 1391 | 443 | 553 | 1711 | 1391 | 443 | 553 |
| 4+14 | 6 | 30% | HHD + LCD | 1082 | 1939 | 493 | 821 | 1711 | 1939 | 657 | 821 | 1711 | 1939 | 657 | 821 |
| 4+14 | 8 | 26% | MHD + LCD | 1248 | 2073 | 493 | 821 | 1974 | 2073 | 657 | 821 | 1974 | 2073 | 657 | 821 |

*Note*: green – genuine data from the CID and region; white – cost transfer

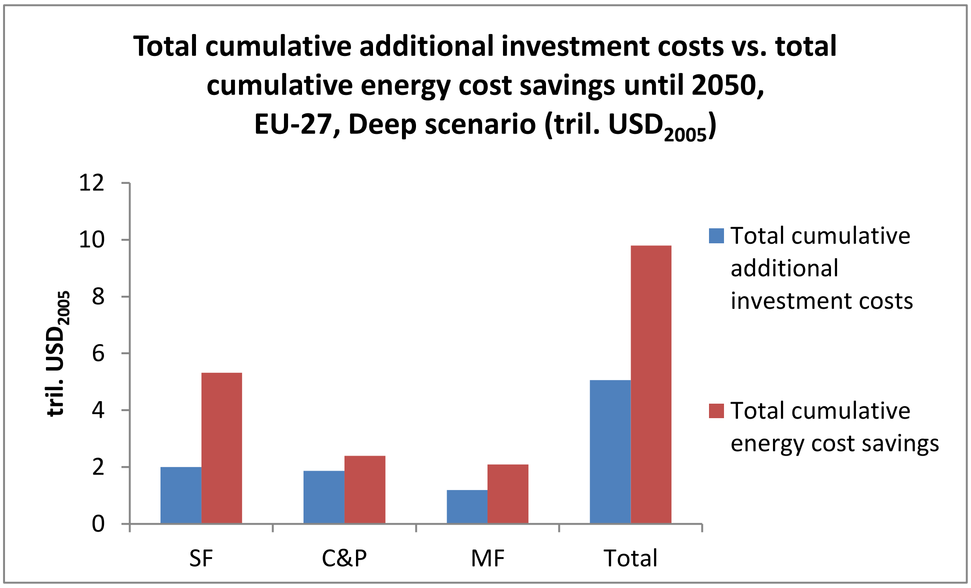
## 3.2 Results for EU-27 – Deep efficiency scenario

Table 13 shows the total cumulative additional investment costs and total cumulative energy cost savings for EU-27 under the Deep efficiency scenario.

Table 13 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in the EU-27 under the Deep efficiency scenario

| **Building type** | **Total cumulative additional investment costs until 2050** | **Total cumulative energy cost savings until 2050** |
|---|---|---|
| | **tril. $USD_{2005}$** | **tril. $USD_{2005}$** |
| **Single-family buildings (SF)** | 2.0 | 5.3 |
| **Commercial & public buildings (C&P)** | 1.9 | 2.4 |
| **Multi-family buildings (MF)** | 1.2 | 2.1 |
| **Total** | 5.1 | 9.8 |

Figure 7 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in the EU-27 under the Deep efficiency scenario



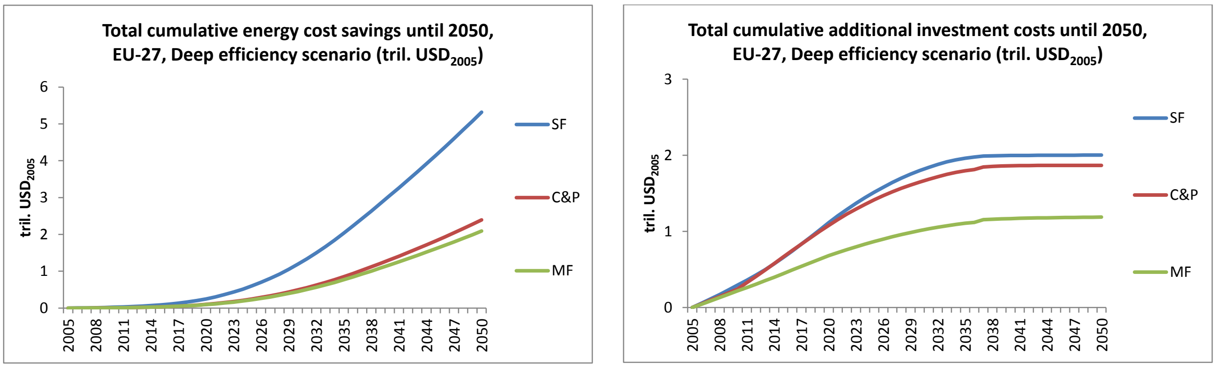
*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

Figure 7 shows that for all building types the total cumulative energy cost savings exceed the total cumulative additional investment costs until 2050, which implies that the Deep efficiency scenario is cost-effective for all three building types by the end of the analysed period.

The SF shows the highest total cumulative additional investment costs, exceeding those of C&P . This can be explained by the SF's largest share in the advanced retrofit floor area by 2050 (Figure 55, Annex 6: Floor area for specified regions and building vintages). The high investment needs of the C&P is due to its largest share in the advanced new construction floor area by 2050 (Figure 54, Annex 6: Floor area for specified regions and building vintages) and its relatively high specific additional investment costs for advanced new as compared to SF. Nevertheless, the volume of the SF's share on floor area of advanced retrofit is larger than that of C&P's share on floor area of advanced new construction (8 bil.$m^2$ of SF's advanced retrofit as compared to 5 bil.m$^2$ of C&P's advanced new construction).[19] At the same time, the SF's largest share in the advanced retrofit floor area is the main factor behind its highest total cumulative energy cost savings achieved under this scenario.

Development of the total cumulative additional investment costs and total cumulative energy cost savings per building type over the projection period is shown in Figure 8. Total cumulative additional investment costs grow steadily until about 2035, by when most of the existing buildings will have been renovated; after this point the total cumulative additional investment costs remain relatively constant.

Figure 8 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in the EU-27 under the Deep efficiency scenario



*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

While SF shows the highest total cumulative additional investment costs (followed by C&P and MF), SF also shows the highest total cumulative energy cost savings among the three building types, followed by C&P and MF (Figure 8).

## 3.3 Results for EU-27 - Moderate efficiency scenario

Table 14 and Figure 9 show the total cumulative additional investment costs and total cumulative energy cost savings under the Moderate efficiency scenario.

Table 14 Total cumulative additional investment costs and total cumulative energy cost savings in the EU-27 under the Moderate efficiency scenario

| **Building type** | **Total cumulative additional investment costs until 2050** | **Total cumulative energy cost savings until 2050** |
|---|---|---|
| | **tril. USD$_{2005}$** | **tril. USD$_{2005}$** |
| **Single-family buildings (SF)** | 2.0 | 4.0 |
| **Commercial & public buildings (C&P)** | 1.9 | 1.8 |
| **Multi-family buildings (MF)** | 1.2 | 1.6 |
| **Total** | 5.0 | 7.5 |

Similarly to the Deep scenario, SF buildings show both the highest total cumulative additional investment costs and total cumulative energy cost savings under the Moderate efficiency scenario. Both the highest investment needs as well as the total cumulative energy cost savings are driven by the SF's by-far largest share on the advanced new and advanced retrofit floor area. The investment is also driven by the SF's relatively higher advanced retrofit costs as compared to C&P.

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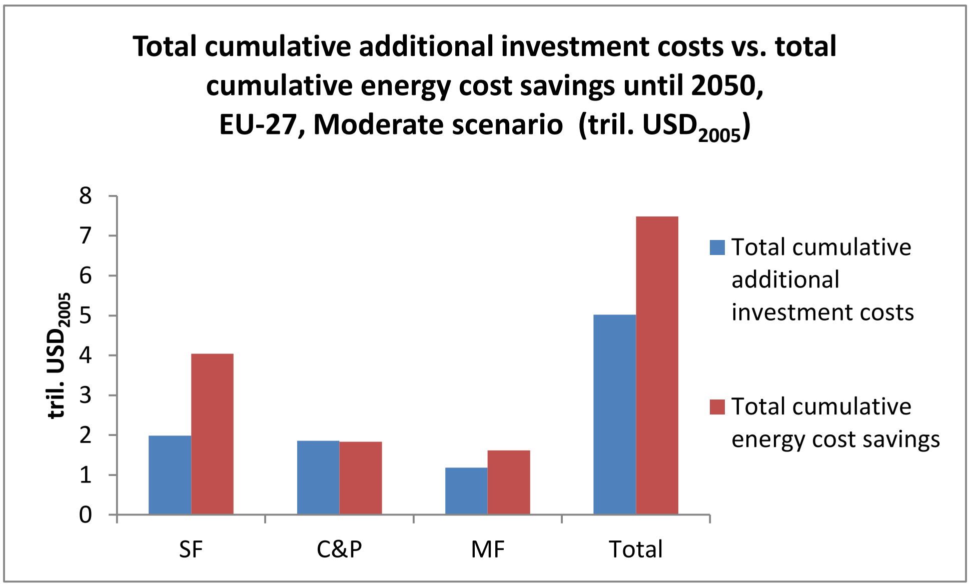
[19] Advanced retrofit buildings account for 49% of the total EU's 2050 floor area, while advanced new account for 26%.

Despite its smaller share on the the advanced new floor area (see Figure 56 and Figure 57, Annex 6: Floor area for specified regions and building vintages) C&P shows the second highest total investment needs, mainly due to its relatively higher specific additional costs for new construction.

Figure 9 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in the EU-27 under the Moderate efficiency scenario



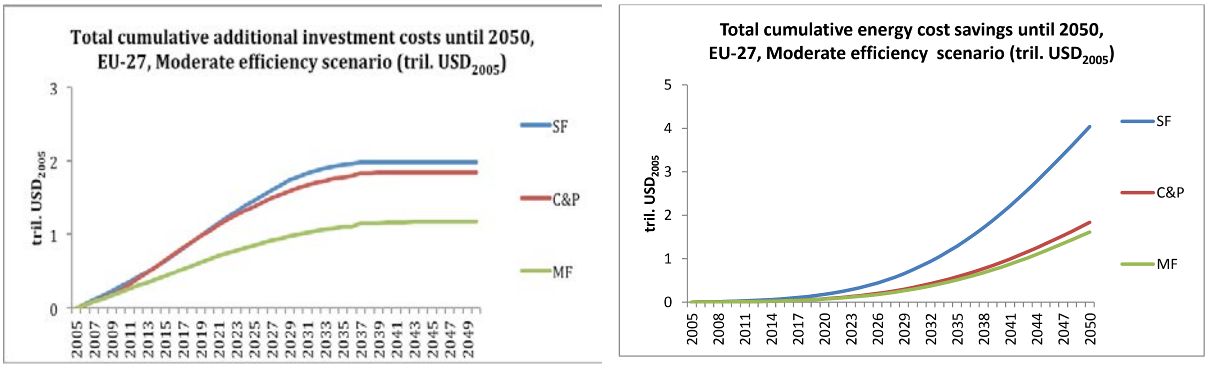
*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

Among the three building types, both SF and MF are cost effectivecost-effective by the end of the analysed period (see Figure 9). Although the total cumulative additional investment costs by 2050 are comparable for both SF and C&P, only SF generates enough energy savings through SF's highest share on the total advanced retrofit floor area in order to exceed the investment needs.

The fact that C&P does not show cost effective under Moderate scenario can be explained both by the significantly higher C&P's additional specific additional investment costs for advanced new buildings as compared to those of SF and MF buildings, as well as their significant share in the advanced new floor area (see Figure 56, Annex 6: Floor area for specified regions and building vintages). The cost-effectiveness of the investments under the Moderate scenario is lower than that under the Deep efficiency scenario.

Development of the total cumulative additional investment costs and total cumulative energy cost savings per different building types over time is shown in Figure 10.

Figure 10 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in the EU-27 under the Moderate efficiency scenario

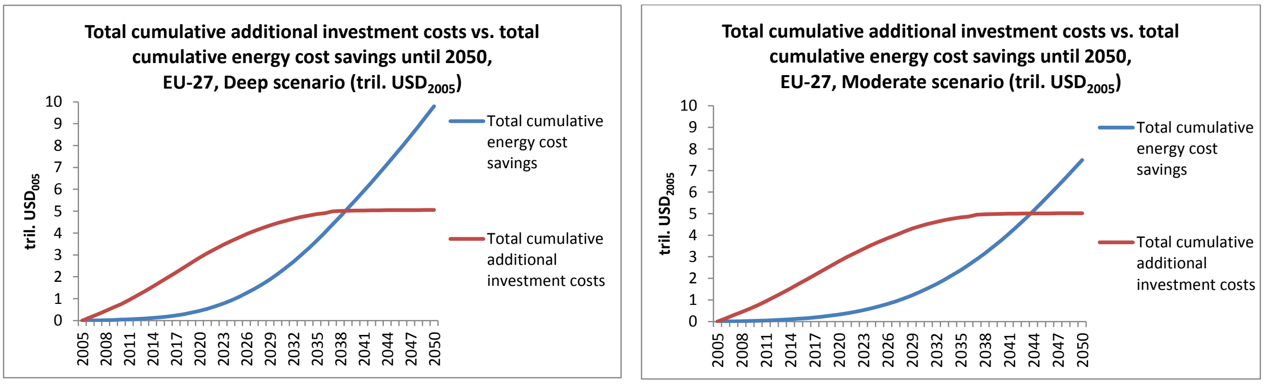


*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

## 3.4 Comparison Deep and Moderate efficiency scenario

The EU-27 is the only major region, which shows that both Deep and Moderate efficiency scenarios can be cost-effective for the total building stock by 2050. There are two main reasons for that: first of all, the EU-27 is the only region, which, has a noticeable share of advanced buildings in its building stock, and, secondly, Moderate scenario for this region has the assumption on the growing share of low-energy new buildings (around 25 kWh/$m^2$/a) due to presumably good compliance with EPBD. The cost-effectiveness is lower under the Moderate efficiency scenario (where C&P is not cost-effective at all) due to the lower share of advanced retrofit buildings in the total region's floor area in 2050 as compared to the Deep efficiency scenario, and, thus, lower energy cost savings. As the total cumulative additional investment costs are comparable between the two scenarios, it is, indeed, the total cumulative energy cost savings, which are responsible for the difference in the scenarios' cost-effectiveness. This implies that investment into accelerated retrofit to the level of non-advanced buildings prevents substantial decrease in energy consumption and on the top of that worsens the long-term cost-effectiveness.

Figure 11 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in EU-27 under the Deep and Moderate efficiency scenario



# CHAPTER 4: FINDINGS: THE USA

This section provides information about the data collection and the results for total cumulative investment costs and total cumulative energy cost savings for the USA. The modelling assumptions for this region are documented in Annex 2: Assumptions for the cost analysis by region, Section A2.2 The United States of America.

## 4.1 Summary of the input data

This section explains the process of CID identification for the different case studies and provides information on the sources for the cost data collection.

The process of the cost identification includes the same steps, as the ones described for the EU (see Section 3.1 Summary of the input data). Each step is discussed below in more details.

### 4.1.1 Identification of climate zones

Like in other regions, the case studies for the USA in the major climate zones were searched for (for the definition of the major climate zone see section 3.1.1 Cimate zones).
Table 15 presents the shares of USA population in each climate zone, according to the 3CSEP HEB model; the identified major climate zones are shaded.

Table 15 Average shares of climate zones in the region's total population for the USA in 2005

| CID | Description of the climate zone (CZ) | Average share of the climate zone in the region's total population | CZ population [million] |
|---|---|---|---|
| **CID 1** | Only H (vhd) | 1.3% | 4.0 |
| **CID 2** | Only H (hd) | 4.4% | 13.5 |
| **CID 4** | H (vhd) and C (ld) | 0.6% | 1.8 |
| **CID 6** | H (hd) and C (ld) | 26.3% | 79.5 |
| **CID 7** | H (md) and C (md) | 1.3% | 3.9 |
| **CID 8** | H (md) and C (ld) | 3.2% | 9.6 |
| **CID 9** | H (ld) and C (md) | 8.5% | 25.7 |
| **CID 10** | H (ld) and C (ld) | 0.2%. | 0.6 |
| **CID 12** | Only C (hd) | 0.1%. | 0.6 |
| **CID 15** | C (hd) and DH | 8.8% | 26.5 |
| **CID 17** | H + C + DH | 45.4% | 137.4 |

*Notes*: H – heating; C – cooling; DH – dehumidification; v – very; h – high; m – moderate; l – low; d - demand

### 4.1.2 Costs of advanced and conventional buildings

Advanced costs for both new construction and retrofit are based on EERE database (USDoE 2012) and WBDG database (2012). For new construction, the advanced buildings specific energy consumption for space heating or cooling ranges between 15-30 kWh/m$^2$/a. Specific energy consumption for space heating and cooling considered for advanced retrofit buildings is 15-50 kWh/m$^2$/a, corresponding to the energy savings of 70% and more as compared to the energy consumption before the retrofit.

Similarly to the EU-27 the costs of conventional new buildings are based on the International construction cost survey (Turner & Townsend, 2012), which provides costs for a wide range of building types and comfort standard and gives cost variations for different US regions. High standard, premium and luxury standard buildings were not considered when calculating averages for each available climate zone. The results of the calculations are used for the respective climate zones and building types.

The costs of conventional retrofit are collected from the EERE (EERE 2012) and WBDG databases (WBDG 2012). Appropriate cases for energy performance and cost data were found only for C&P buildings and only for a limited number of climate zones.

Therefore, conventional costs for the other building types had to be estimated through the cost transfer from the EU-27. Table 16 lists the main sources for cost data of advanced and conventional buildings in the USA.

Table 16 Main sources for cost database in the USA

| Data collected | Main sources/Notes | Reference |
|---|---|---|
| **Best-practices** | Energy Efficiency and Renewable Energy (EERE) Building database | USDoE (2012) |
| | Architecture 2030 database | Architecture 2030 (2011) |
| | NRDC database | NRDC (2012) |
| | The Research Triangle Park - database | RTP (2011) |
| | Engineering News-Record - database | ENR (2012) |
| | Energy Outreach Colorado case studies | Energy Outreach (2012) |
| | BASF, Energy Efficiency in Buildings | BASF (2012) |
| | Paroc Project Database/case studies | Paroc (2012) |
| | UNEP Paris case studies | Hartkopf et al. (2009) |
| | WDBG Database | WBDG (2012) |
| | Individual studies & projects | Parker (2009) |
| | 1000 Home Challenge database | 1000 Home Challenge (2013) |
| **Costs of conventional buildings*** | International construction cost survey (for different world regions) | Gardiner & Theobald LLP (2009) |
| | International construction cost survey (for major world regions) | Turner & Townsend (2012) |
| | Design Cost Data (USA) | DCD (2011) |
| | Quarterly Construction Cost Report (USA) | Rider Levett Bucknall (2012) |

*Notes*: * Cost of conventional buildings include both "baseline costs", which refer to the cost of the new and retrofitted buildings under the Frozen efficiency scenario ($N^{LOW}$, $R^{10}$), as well as costs of the conventional buildings ($N^{BC}$, $R^{30}$) under the Moderate/Deep efficiency scenario.

The specific (full) investment costs per unit of floor area in the major CIDs of the USA per building type are shown in Table 17.

Table 17 Specific investment costs per unit of floor area in the USA, major CIDs

**USA**

| | | | | SF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Frozen efficiency scenario | | | | Moderate efficiency scenario | | | | Deep efficiency scenario | | | |
| | | | | New | | Retrofit | | New | | Retrofit | | New | | Retrofit | |
| | | | | New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit |
| RID | CID | % CID | Climate | $N^{LOW}$ | $AN^{70+}$ | $R^{10}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ |
| 9 | 6 | 26.27% | HHD + LCD | 1450 | 1588 | 610 | 1017 | 1509 | 1588 | 813 | 1017 | 1509 | 1588 | 813 | 1017 |
| 9 | 9 | 8.49% | LHD + MCD | 1390 | 2124 | 584 | 974 | 1446 | 2124 | 779 | 974 | 1446 | 2124 | 779 | 974 |
| 9 | 15 | 8.76% | HCD | 1163 | 1778 | 489 | 816 | 1211 | 1778 | 652 | 816 | 1211 | 1778 | 652 | 816 |
| 9 | 17 | 45.38% | H, C, D | 1465 | 1604 | 441 | 736 | 1092 | 1604 | 589 | 736 | 1092 | 1604 | 589 | 736 |

| | | | | MF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Frozen efficiency scenario | | | | Moderate efficiency scenario | | | | Deep efficiency scenario | | | |
| | | | | New | | Retrofit | | New | | Retrofit | | New | | Retrofit | |
| | | | | New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit |
| RID | CID | % CID | Climate | $N^{LOW}$ | $AN^{70+}$ | $R^{10}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ |
| 9 | 6 | 26.27% | HHD + LCD | 1551 | 1928 | 699 | 1216 | 1619 | 1928 | 973 | 1216 | 1619 | 1928 | 973 | 1216 |
| 9 | 9 | 8.49% | LHD + MCD | 1403 | 1848 | 699 | 1165 | 1551 | 1848 | 932 | 1165 | 1551 | 1848 | 932 | 1165 |
| 9 | 15 | 8.76% | HCD | 1123 | 1247 | 472 | 786 | 1241 | 1247 | 629 | 786 | 1241 | 1247 | 629 | 786 |
| 9 | 17 | 45.38% | H, C, D | 1012 | 1450 | 549 | 914 | 1119 | 1450 | 731 | 914 | 1443 | 1450 | 731 | 914 |

| | | | | C&P | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Frozen efficiency scenario | | | | Moderate efficiency scenario | | | | Deep efficiency scenario | | | |
| | | | | New | | Retrofit | | New | | Retrofit | | New | | Retrofit | |
| | | | | New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit | New | Advanced new | Retrofit | Advanced retrofit |
| RID | CID | % CID | Climate | $N^{LOW}$ | $AN^{70+}$ | $R^{10}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ |
| 9 | 6 | 26.27% | HHD + LCD | 1361 | 1845 | 733 | 1222 | 1382 | 1845 | 995 | 1222 | 1382 | 1845 | 995 | 1222 |
| 9 | 9 | 8.49% | LHD + MCD | 1378 | 1772 | 554 | 924 | 1390 | 1772 | 739 | 924 | 1390 | 1772 | 739 | 924 |
| 9 | 15 | 8.76% | HCD | 1148 | 1706 | 938 | 1563 | 1242 | 1706 | 1250 | 1563 | 1242 | 1706 | 1250 | 1563 |
| 9 | 17 | 45.38% | H, C, D | 1346 | 1685 | 1040 | 1733 | 1377 | 1685 | 1386 | 1733 | 1377 | 1685 | 1386 | 1733 |

*Note*: green – genuine data from the CID and region; white – cost transfer

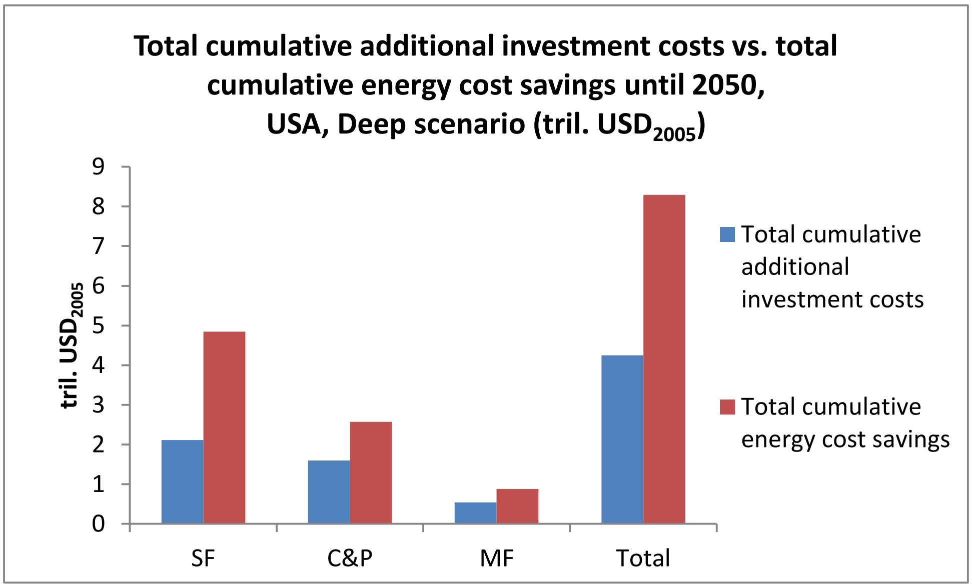
## 4.2 Results for the USA – Deep efficiency scenario

Table 18 shows the total cumulative additional investment costs and total cumulative energy cost savings under the Deep efficiency scenario.

Table 18 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in the USA under the Deep efficiency scenario

| **Building type** | **Total cumulative additional investment costs until 2050** | **Total cumulative energy cost savings until 2050** |
|---|---|---|
| | **tril. USD$_{2005}$** | **tril. USD$_{2005}$** |
| **Single-family buildings (SF)** | 2.1 | 4.8 |
| **Commercial & public buildings (C&P)** | 1.6 | 2.6 |
| **Multi-family buildings (MF)** | 0.5 | 0.9 |
| **Total** | 4.3 | 8.3 |

Figure 12 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in the USA under the Deep efficiency scenario



*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings \

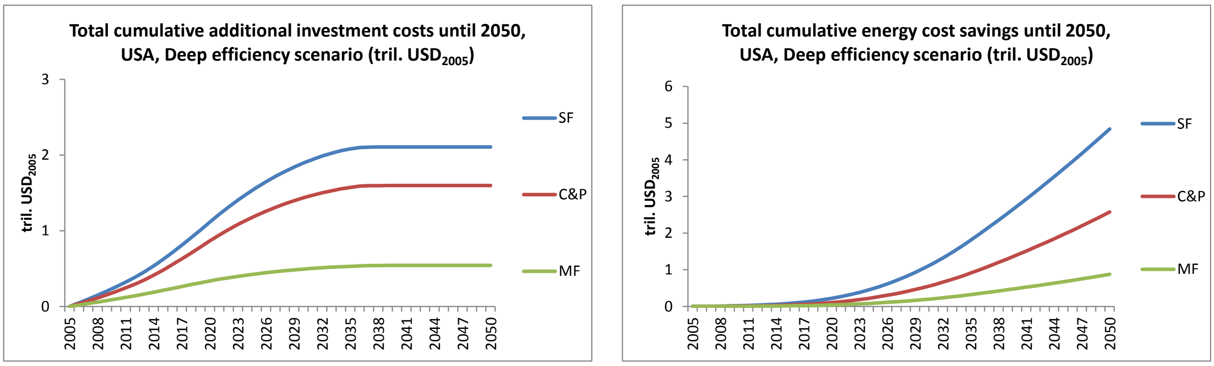
Figure 12 shows that all building types are cost-effective under the Deep efficiency scenario by 2050, while SF buildings have the highest cost-effectiveness, followed by C&P and then MF ones.

SF buildings show the highest values both for the total cumulative investment costs and the total cumulative energy costs savings. The main reason for it is that the share of the floor area of advanced new and advanced retrofitted single-family buildings is the largest in comparison to other building types in the US total building stock (see Figure 58 and Figure 59, Annex 6: Floor area for specified regions and building vintages).

The relatively large share of C&P buildings in the total US 2050 floor area (approx. 30%) helps this category to rank second in terms of cost-effectiveness.

Development of the total cumulative additional investment costs and total cumulative energy cost savings per building type over projection period is shown in Figure 13.

Figure 13 Total cumulative additional investment cost and total cumulative energy cost savings per building type in the USA under the Deep efficiency scenario until 2050



*Notes:* SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

## 4.3 Results for the USA - Moderate efficiency scenario

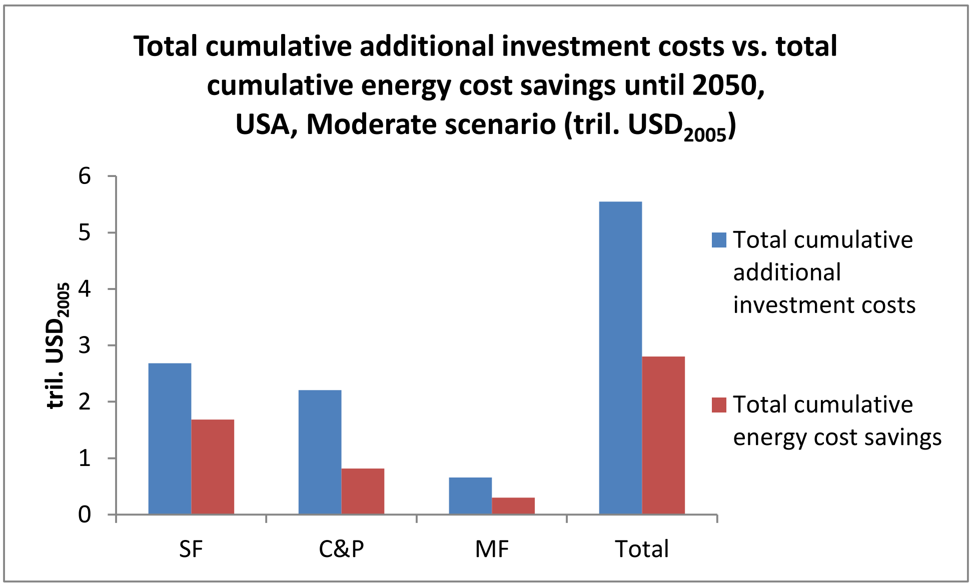
Table 19 shows the total cumulative additional investment costs and total cumulative energy cost savings under the Moderate efficiency scenario for the USA.

Table 19 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in the USA under the Moderate efficiency scenario

| **Building type** | **Total cumulative additional investment costs until 2050** | **Total cumulative energy cost savings until 2050** |
|---|---|---|
| | **tril. USD2005** | **tril. USD2005** |
| **Single-family buildings (SF)** | 2.7 | 1.7 |
| **Commercial & public buildings (C&P)** | 2.2 | 0.8 |
| **Multi-family buildings (MF)** | 0.7 | 0.3 |
| **Total** | 5.6 | 2.8 |

Figure 14 shows that for all building types the total cumulative additional investment costs exceed the total cumulative energy cost savings over the projection period.

Figure 14 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in the USA under the Moderate efficiency scenario



*Notes:* SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

SF buildings show both the highest total cumulative additional investment costs as well as the highest total cumulative energy cost savings because of its overall dominance in US floor area. The difference in the total cumulative additional investment costs between Deep and Moderate efficiency scenario is not drastic (about 0.6 tril $USD_{2005}$) , nevertheless, SF building type shows higher investment needs even despite the relatively higher additional specific investment costs of C&P as compared to SF (SF shows even negative additional specific investment costs for the most important CID).[20]

The relatively low total cumulative energy cost savings under the Moderate scenario as compared to the Deep scenario can be explained by the fact that there are no advanced buildings (both advanced new and advanced retrofit) assumed for the USA under the Moderate efficiency scenario, and thus, the energy savings are significantly lower than those under the Deep efficiency scenario.

Development of the total cumulative additional investment costs and total cumulative energy cost savings per building type over projection period is shown in Figure 15.

Both SF and C&P buildings show high total cumulative additional investment costs. The costs of the SF buildings, however, are higher than those of C&P ones due to the SF's larger share in the total 2050 US floor area in spite of higher specific additional investment costs of C&P buildings, especially in case of conventional retrofit. This is important for the USA under the Moderate efficiency scenario, where conventional retrofit accounts for 73% of the total US 2050 floor area.

The total cumulative additional investment costs are steadily increasing even after 2037 (by when all standard buildings are either retrofitted or demolished), although at a slower rate than before. This is caused by renovation of the buildings that were built early after 2005 during the learning period and needed another renovation at the end of the modelling period.

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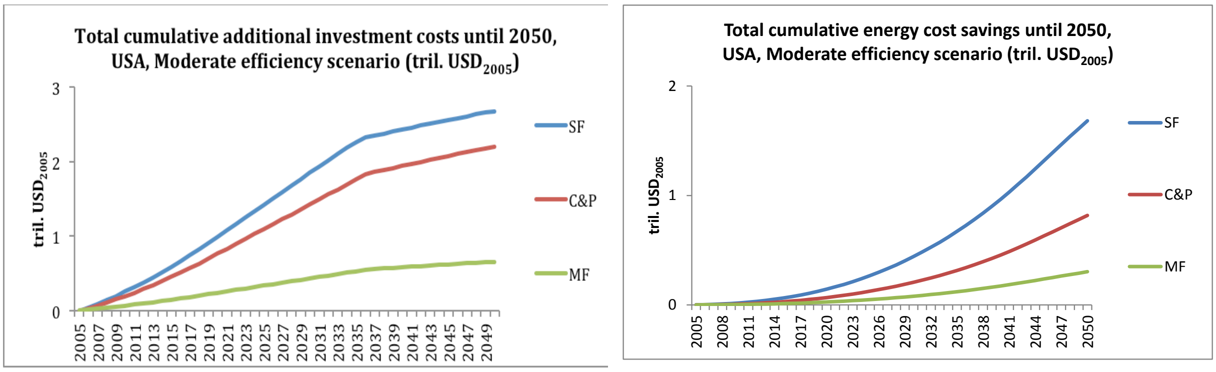
[20] The negative values are mentioned in order to provide a picture on the differences in specific investment costs among the building types. In the calculation of the total cumulative investment costs the negative values are disabled and instead, zero value is used. The reason for that is to show the total real investment needs that will have to be invested under each scenario.

Figure 15 shows that SF buildings have the highest cumulative energy cost savings among three building types, which can be explained by the largest share of SF buildings in the total floor area.

Figure 15 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in the USA under the Moderate efficiency scenario



*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

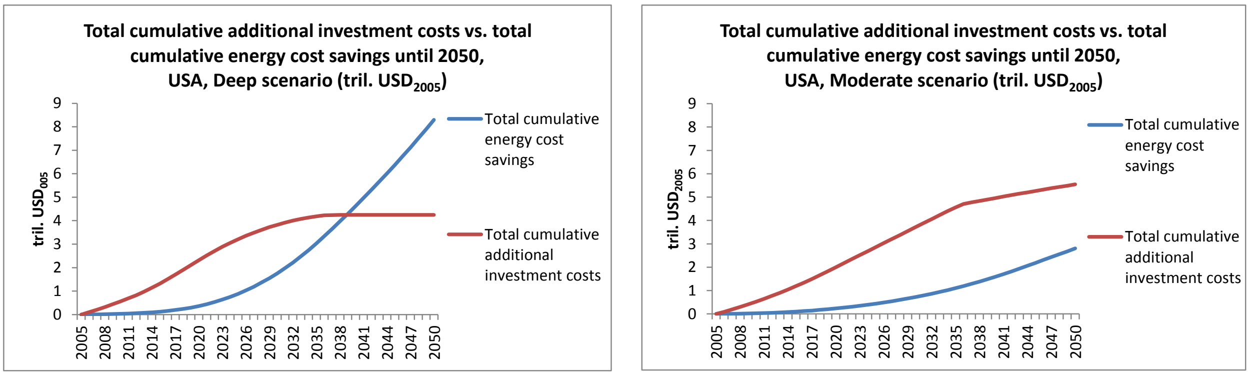
## 4.4 Comparison – Deep and Moderate efficiency scenario

In summary, the potential transition to advanced buildings in the USA is cost-effective under the Deep efficiency scenario. While the total cumulative energy cost savings are much higher than those under the Moderate efficiency scenario, the total cumulative additional investment costs are lower.

The significantly higher savings in energy costs are due to the deployment of the advanced buildings under the Deep efficiency scenario. The lower investment needs under the Deep scenario are due to the fact that the specific investment costs ($USD_{2005}/m^2$) of the advanced buildings in the Deep scenario decrease gradually to half of their 2005 level over time (technology learning) while the costs of the conventional buildings in the Moderate scenario remain the same up to 2050. While the investment costs under the Deep scenario stay relatively stable after 2035, under the Moderate scenario they are steadily increasing even after this year. This is because the rate of retrofit under the Moderate scenario after 2037 is higher than the rate of retrofit under the Deep scenario as described in detail in section 4.3 Results for the USA - Moderate efficiency scenario.

Due to both higher energy costs savings and lower investment costs the energy saving potential in the USA under the Deep scenario can be realised in a cost-effective way, while under the Moderate scenario achieving cost-effectiveness by 2050 does not seem to be possible.

Figure 16 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in the USA under the Deep and Moderate efficiency scenario



# CHAPTER 5: FINDINGS: CHINA

This section provides information about the data collection, the modelling assumptions for China and the results for total cumulative additional investment costs and total cumulative energy cost savings applicable to China. First, the process of identification of the major climate zones (CIDs) in China is described. Second, the data collection and the main sources of cost data are described. Third, the process and main assumptions for cost transfer are presented for those categories where relevant or reliable cost data is not available.

## 5.1 Cost database - summary of input data

This section provides information on the sources and assumptions for the cost data collection and explains the process of CID identification for the collected case studies.

The process of the cost identification includes the same steps, as the ones described for the EU (see Section 3.1 Summary of the input data) and the USA (see Section 4.1 Summary of the input data). Each step is discussed below in more details.

### 5.1.1 Identification of climate zones

Section 2.5 Climate zone identification describes the general approach to the CID identification. Like in other regions, first the major climate zones[21] were identified for China and then the case studies for these major climate zones were searched for. The 3CSEP HEB model provides shares of each climate zone on total population for China, shown in

Table 20, where the major climate zones are shaded.

Table 20 Average shares of climate zones in the region's total population for China in 2005

| CID | Description of the climate zone (CZ) | Average share of the climate zone in the region's total population | CZ population [million] |
|---|---|---|---|
| **CID 1** | Only H (vhd) | 1.9% | 25.0 |
| **CID 2** | Only H (hd) | 1.3% | 17.3 |
| **CID 3** | Only H (md + ld) | 0.2% | 2.7 |
| **CID 4** | H (vhd) and C (ld) | 5.9% | 77.9 |
| **CID 5** | H (hd) and C (md) | 0.2% | 2.3 |
| **CID 6** | H (hd) and C (ld) | 11.4% | 149.0 |
| **CID 7** | H (md) and C (md) | 0.2% | 2.1 |
| **CID 8** | H (md) and C (ld) | 4.5% | 59.3 |
| **CID 9** | H (ld) and C (md) | 0.8% | 10.9 |
| **CID 10** | H (ld) and C (ld) | 1.7% | 22.6 |
| **CID 12** | Only C (hd) | 0.0% | 0.0 |
| **CID 13** | Only C (ld + md) | 0.2% | 2.2 |
| **CID 14** | C (vhd) and DH | 0.2% | 2.4 |
| **CID 15** | C (hd) and DH | 9.1% | 119.9 |
| **CID 17** | H + C + DH | 62.4% | 818.6 |

*Notes*: H – heating; C – cooling; DH – dehumidification; v – very; h – high; m – moderate; l – low; d - demand

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[21] Major climate zone is defined here as a climate zone, the share of which exceeds 10% on the total region's population.

In China the major climate zones are: CID 6 (high heating demand and low cooling demand) with the share of 11%, CID 15 (high cooling demand and dehumidification) with the share of 9%, and CID 17 (heating, cooling and dehumidification) with the share of 62.4% of the total region's population. In total, majority of the Chinese population (82%) live in these three major climate zones.

### 5.1.2 Costs of advanced and conventional buildings

Different case studies were used as sources for the construction costs of the advanced (new and retrofit) buildings, such as REEP (2009), PHI (2012), Hartkopf et al. (2009). Conventional new construction costs are based on international construction cost surveys. See

Table 21 for the main sources used for both cost database of advanced and conventional buildings.

Table 21 Main sources for cost database for China

| Data collected | Main sources/Notes | Reference |
|---|---|---|
| **Best-practices** | Using Financial and Market-based Mechanisms to Improve Building Energy Efficiency in China | REEP (2009) |
| | PH database | PHI (2012) |
| | Case-studies of High-performance Sustainable Buildings | Hartkopf et al. (2009) |
| | Individual studies & projects | Broad town building studies (2009) |
| | | Xuan (2011) |
| | | Dascalaki et al. (2010) |
| **Costs of conventional buildings*** | International construction cost survey (for different world regions) | Gardiner & Theobald LLP (2009) |
| | International Construction Cost Survey | Turner & Townsend (2012) |
| | Independent Real Estate Analysis On China | RET (2006) |

*Notes*: * Cost of conventional buildings include both "baseline costs", which refer to the cost of the new and retrofitted buildings under the Frozen efficiency scenario ($N^{LOW}$, $R^{10}$), as well as costs of the conventional buildings ($N^{BC}$, $R^{30}$) under the Moderate/Deep efficiency scenario.

The cost of construction is calculated as total full construction cost per unit of floor area ($USD_{2005}/m^2$). All cost data are converted from national currencies to USD, while for the conversion into $USD_{2005}$ the estimated construction cost index (CCI) for China is used. As for China only the consumer price index (CPI) is available (OECD 2012), the CCI for China was calculated based on the China's CPI and the ratio between CCI and CPI for EU-27 (OECD 2012).[22]

In summary, very little data is available for this region and if available, the cost data show a large deviation. The major gaps exist for advanced buildings of all building types. Most of the case studies for advanced buildings in China are available only for commercial and public buildings. The main sources are: German PH Database (2012), Hartkopf et al. (2009), and individual case studies. Costs of conventional new construction are based on Turner & Townsend (2012), as well as Real Estate Tech (2012). Due to the lack of cost data for single-family and multi-family buildings, these costs are calculated through cost transfer using cost transfer ratios. The cost transfer is based on the very limited number of reliable available case studies to

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[22] The basic assumption for calculation of the estimate of the $CCI_{China}$ is that the ratio of CCI and CPI in China is approximately similar to such a ratio in EU-27. Therefore, from the assumption $CCI_{China}/CPI_{China} \sim = CCI_{EU27}/CPI_{EU27}$,the following can be established: $CCI_{China} = CPI_{China} * CCI_{EU27}/CPI_{EU27}$.

which the cost ratios based on the cost data for EU-27 and the USA are applied. Ultimately, the specific investment costs used as input for the model were reviewed by an international group of experts (for example of using cost transfer ratio, see Annex 8: Cost ratio transfer).

The specific (full) investment costs per unit of floor area in China's major CIDs by building type are shown in Table 22.

Table 22 Specific investment costs per unit of floor area in China, major CIDs

| China | | | | SF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Frozen | | | | Moderate | | | | Deep | | | |
| | | | | New | | Retrofit | | New | | Retrofit | | New | | Retrofit | |
| | | | | New | Adv. New | Retrofit | Adv. Retrofit | New | Adv. New | Retrofit | Adv. Retrofit | New | Adv. New | Retrofit | Adv. Retrofit |
| **RID** | **CID** | **% CID** | **Climate** | $N^{LOW}$ | $AN^{70+}$ | $R^{10}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ |
| 3 | 6 | 11% | HHD + LCD | 353 | 635 | 291 | 485 | 508 | 635 | 388 | 485 | 508 | 635 | 388 | 485 |
| 3 | 15 | 9% | HCD + DH | 436 | 511 | 205 | 342 | 508 | 511 | 274 | 342 | 508 | 511 | 274 | 342 |
| 3 | 17 | 62% | H + C + DH | 461 | 511 | 205 | 342 | 508 | 511 | 274 | 342 | 508 | 511 | 274 | 342 |
| | | | | MF | | | | | | | | | | | |
| | | | | Frozen | | | | Moderate | | | | Deep | | | |
| | | | | New | | Retrofit | | New | | Retrofit | | New | | Retrofit | |
| | | | | New | Adv. New | Retrofit | Adv. Retrofit | New | Adv. New | Retrofit | Adv. Retrofit | New | Adv. New | Retrofit | Adv. Retrofit |
| **RID** | **CID** | **% CID** | **Climate** | $N^{LOW}$ | $AN^{70+}$ | $R^{10}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ |
| 3 | 6 | 11% | HHD + LCD | 325 | 473 | 137 | 228 | 441 | 473 | 182 | 228 | 441 | 473 | 182 | 228 |
| 3 | 15 | 9% | HCD + DH | 325 | 361 | 206 | 279 | 441 | 361 | 223 | 279 | 441 | 361 | 223 | 279 |
| 3 | 17 | 62% | H + C + DH | 325 | 465 | 169 | 225 | 441 | 465 | 180 | 225 | 441 | 465 | 180 | 225 |
| | | | | C&P | | | | | | | | | | | |
| | | | | Frozen | | | | Moderate | | | | Deep | | | |
| | | | | New | | Retrofit | | New | | Retrofit | | New | | Retrofit | |
| | | | | New | Adv. New | Retrofit | Adv. Retrofit | New | Adv. New | Retrofit | Adv.Retrofit | New | Adv. New | Retrofit | Adv. Retrofit |
| **RID** | **CID** | **% CID** | **Climate** | $N^{LOW}$ | $AN^{70+}$ | $R^{10}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ |
| 3 | 6 | 11% | HHD + LCD | 491 | 881 | 217 | 362 | 667 | 881 | 290 | 362 | 667 | 881 | 290 | 362 |
| 3 | 15 | 9% | HCD + DH | 722 | 1276 | 237 | 396 | 842 | 1276 | 316 | 396 | 842 | 1276 | 316 | 396 |
| 3 | 17 | 62% | H + C + DH | 769 | **1424** | 181 | 302 | 842 | **1424** | 242 | 302 | 842 | **1424** | 242 | 302 |

*Note*: green – genuine data from the CID and region; white – cost transfer

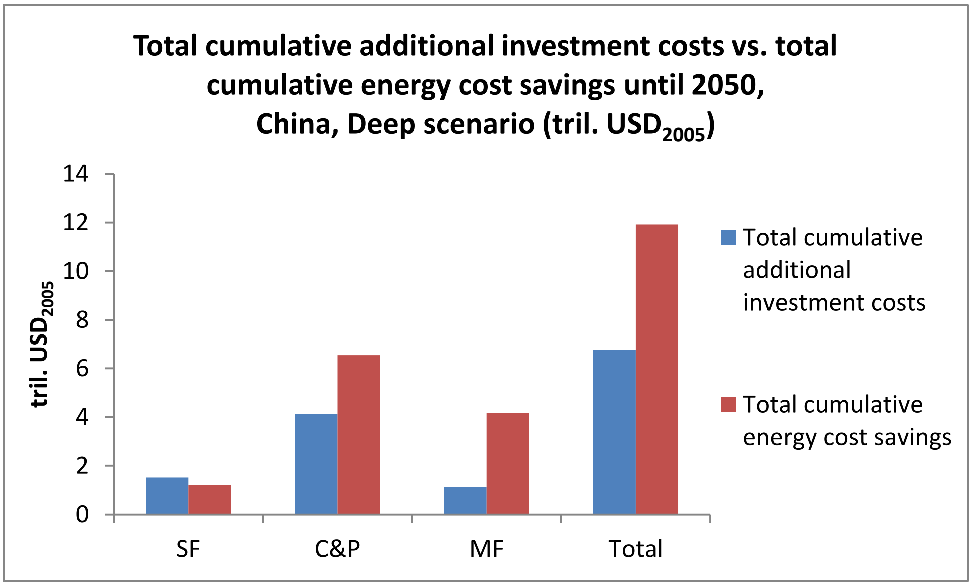
## 5.2 Results for China – Deep efficiency scenario

Table 23 shows the total cumulative additional investment costs and total cumulative energy cost savings for China under the Deep efficiency scenario.

Table 23 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in China under the Deep efficiency scenario

| **Building type** | **Total cumulative additional investment costs until 2050** | **Total cumulative energy cost savings until 2050** |
|---|---|---|
| | **tril. $USD_{2005}$** | **tril. $USD_{2005}$** |
| **Single-family buildings (SF)** | 1.5 | 1.2 |
| **Commercial & public buildings (C&P)** | 4.1 | 6.6 |
| **Multi-family buildings (MF)** | 1.1 | 4.2 |
| **Total** | 6.8 | 11.9 |

Figure 17 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in China Deep efficiency scenario per building type



*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

Figure 17 shows that investments for all building types except for SF can be cost-effective under the Deep efficiency scenario, with the multifamily buildings showing the highest cost-effectiveness.

C&P shows the highest total cumulative energy cost savings due to relatively high floor area of advanced new (second largest after MF, see Figure 60 Annex 6: Floor area for specified regions and building vintages) and advanced retrofit (the highest share of advanced retrofit (after SF, comparable, Figure 61, Annex 6: Floor area for specified regions and building vintages). The C&P's highest total investment needs can be explained by the highest additional specific investment cost of C&P's advanced new construction as compared to other building types (4-5 times higher than those of SF and MF). The specific investment cost for C&P advanced new construction is higher with a factor about 2-3 compared to that of SF and MF.[23]

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[23] Such a large difference of the specific investment costs and the additional specific investment costs among the three building types is due to both relatively higher specific costs for both C&P's advanced and baseline costs for the major CIDs.

Another important reason for the highest total investment needs of C&P is that the C&P buildings account for the largest share on the total floor area among all building types in China. The largest share of the C&P buildings on the total Chinese floor area is also the reason behind the highest total cumulative energy cost savings of the C&P buildings. This leads to the fact that the total cumulative energy cost savings of the C&P buildings is significantly higher than that of the residential buildings (factor of 2-3) despite the lower specific energy saving potential of the C&P buildings as compared to the residential buildings. The C&P's high total cumulative energy cost savings explain the cost effectiveness of the C&P's buildings despite their high additional specific investment costs.

The attractive cost-effectiveness of MF can be explained by its highest share of advanced new floor area (42.9% of 2050 MF's floor area) as well as significant share of MF on floor area of advanced retrofit buildings (although it is the lowest among the building types, its share is still significant – 29.7% of the 2050 Chinese floor area). On the other hand, the MF's total investment needs are the lowest among the building types due to relatively low additional specific investment costs for advanced new buildings, which is the dominating vintage for MF buildings under this scenario. Moreover, MF buildings have the largest share in the Chinese advanced new floor area and the lowest additional specific investment costs for advanced retrofit.

As noted above the only building type in China, where energy efficiency improvements are not cost-effective under Deep scenario is single-family buildings. One of the possible reasons for that is that in the future the floor area of advanced new SF buildings is projected to be less than a half of those of C&P and MF buildings, which means that not enough energy savings are generated in order to compensate the investment needs. On the other hand, the relatively higher investment needs as compared to energy cost savings can be explained by the fact that the additional specific investment costs of advanced retrofit buildings, which is the dominating vintage among single-family buildings by 2050 (51% of the total SF 2050 floor area), are the highest among the three building types. In addition, conventional retrofit accounts for one fifth of the SF 2050 floor area (23%), where the SF's additional specific investment costs are also the highest among the three building types. The relatively high share of conventional retrofit and low share of conventional new buildings in China's building stock (23% and 0,8% of the total SF's 2050 floor area, respectively) as compared to other building types (new buildings account for 12-19%, retrofit accounts for 7-10% of MF and C&P, respectively) are further factors playing a role in much lower energy savings as compared to other building types.

Development of the total cumulative additional investment costs and total cumulative energy cost savings per building type over time is shown in Figure 18.

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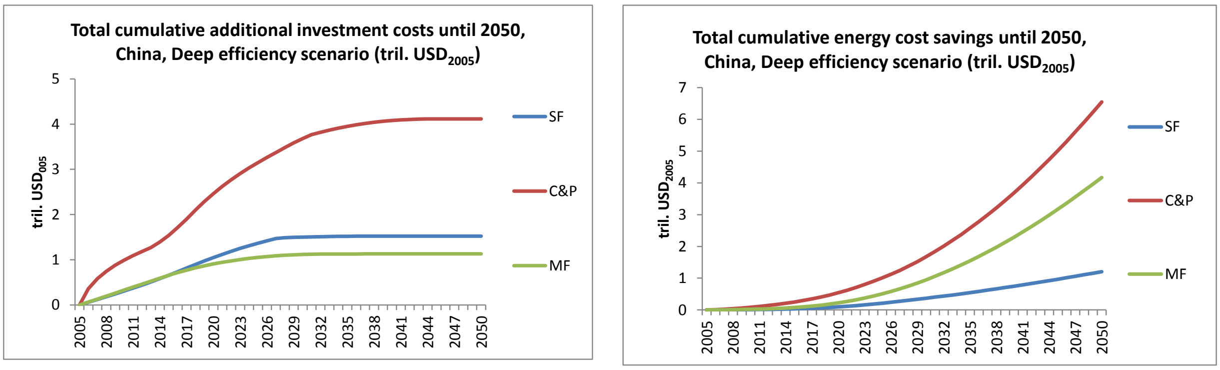
This is especially so in the case of the most populous climate zone – CID 17 (62% of the China's 2005 population), for which also the main data exist. The specific investment costs for advanced new construction (AN$^{70+}$) is based on an average of genuine cost data of the only two available and reliable case studies of commercial office buildings (source: Hartkopf et al., 2009 and German PH database - www.passivehouseprojekte.de). This average represents the highest specific investment costs for advanced new construction (AN$^{70+}$) among all buiding types for this vintage, as well as for all specific investment costs in China and is about higher with a factor of three than the specific investment costs of AN$^{70+}$ for SF and MF (see **Erreur ! Source du renvoi introuvable.**Table 22).

Figure 18 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in China under the Deep efficiency scenario



*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

As it can be seen for the figure above, C&P buildings show both the highest investment costs as well as the highest cumulative energy cost savings both due to their high share of the advanced buildings in the total China's 2050 floor area as well as their highest additional specific investment costs for advanced new buildings. The total cumulative additional investment costs of the SF buildings are even higher as compared to MF buildings. This is due to the higher share of the SF buildings floor area, as well as the higher specific additional investment costs of the SF as compared to MF buildings.

## 5.3 Results for China- Moderate efficiency scenario

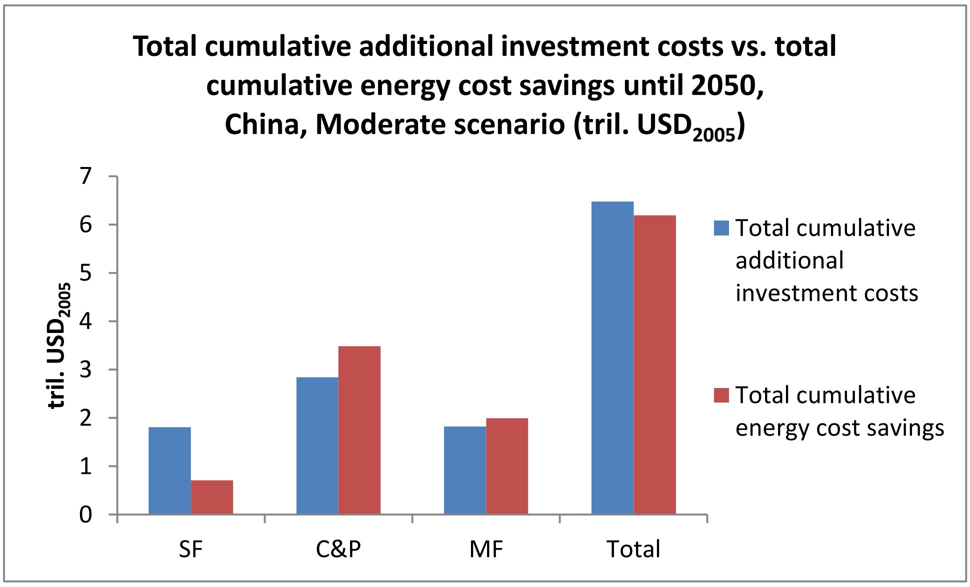
Table 24 shows the total cumulative additional investment costs and total cumulative energy cost savings under the Moderate efficiency scenario.

Table 24 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in China under the Moderate efficiency scenario

| **Building type** | **Total cumulative additional investment costs until 2050** | **Total cumulative energy cost savings until 2050** |
|---|---|---|
| | **tril. $USD_{2005}$** | **tril. $USD_{2005}$** |
| **Single-family buildings (SF)** | 1.8 | 0.7 |
| **Commercial & Public buildings (C&P)** | 2.8 | 3.5 |
| **Multi-family buildings (MF)** | 1.8 | 2.0 |
| **Total** | 6.5 | 6.2 |

Figure 19 shows that for the total building stock, Moderate efficiency scenario is not cost-effective in China. Nevertheless, it is cost-effective for two out of three building types – C&P and MF.

Figure 19 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in China under the Moderate efficiency scenario per building type



*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

The low total cumulative energy cost savings under this scenario as compared to the Deep scenario can be explained by the fact that there are no advanced buildings (neither new nor retrofit) in China under the Moderate efficiency scenario, and thus, the energy cost savings are significantly lower as compared to the Deep efficiency scenario.

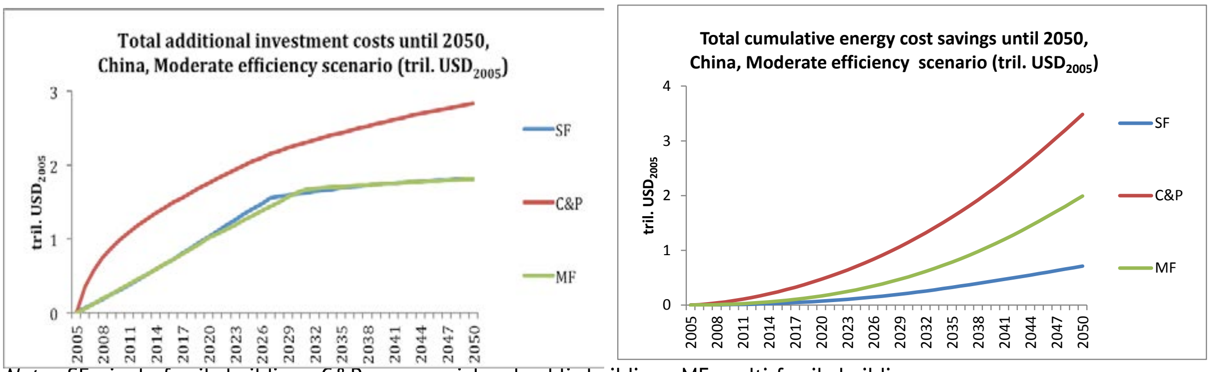
C&P buildings show both the highest total energy cost savings as well as the highest investment needs. The high energy cost savings are due to the C&P sector's largest share in the Chinese 2050 new floor area (C&P accounts for 50% of the 2050 Chinese new floor area). The high total cumulative additional investment costs of C&P can also be explained primarily by their largest share in new floor area in combination with its relatively high additional specific investment costs for this vintage. The additional specific investment costs of conventional new construction are relatively higher than those of the conventional retrofit buildings and thus, despite the dominance of conventional retrofit in the total floor area under the Moderate efficiency scenario (retrofitted buildings account for 67% of the total floor area in 2050, while the distribution of the building types within the 2050 retrofitted floor area is relatively even), conventional new buildings have the highest investment requirement .

Both SF and MF buildings show comparable levels of total investment needs, which can be explained by the largest share of SF buildings in the retrofitted floor area (39% of 2050 Chinese new floor area) and a large share of MF buildings in new building stock (42% of 2050 Chinese new floor area, which is the second largest share in the new floor area after C&P), combined with relatively high additional specific investment costs for both building types (SF has relatively low additional specific investment costs for conventional new buildings and MF has very low additional specific investment costs for the conventional retrofit.)

Nevertheless, contrary to SF, MF generates enough energy cost savings in order to exceed the investment needs for this building type. The main reason for this is a larger portion of multifamily buildings in the new floor area: MF buildings account for approx. 42% of the total Chinese new floor area, while SF buildings - only for 7.8%.

Development of the total cumulative additional investment costs and total cumulative energy cost savings per building type over time is shown in Figure 20, where C&P buildings show both the highest investment needs and cumulative energy cost savings.

Figure 20 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 er building type in China under the Moderate efficiency scenario



*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

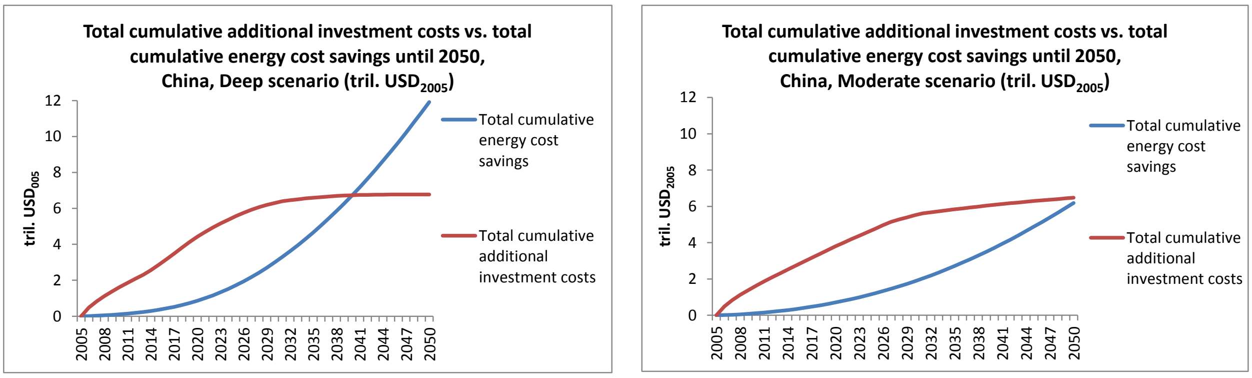
## 5.4 Comparison – Deep and Moderate efficiency scenario

Although the total cumulative additional investment costs under the Deep efficiency scenario are only slightly higher than those under the Moderate efficiency scenario, the total cumulative energy cost savings under the Deep scenario are almost twice as high as those under the Moderate efficiency scenario. This implies that for comparable costs the Deep efficiency scenario generates twice as much energy savings, and the related financial benefits and thus, is more cost-effective. Therefore, it clearly shows that China as well should follow the path of ambitious new construction and retrofit.

The lower total investment costs under the Deep scenario is due to the fact that the additional specific investment costs of advanced buildings in many cases are at the same level of magnitude as conventional buildings, and these costs of the advanced buildings are further lowered by the application of the learning factor (decrease in specific investment cost by 50% by 2050), while the costs of the conventional buildings remain constant throughout the modeling period. The higher energy cost savings under the Deep scenario are caused by the growing share of advanced buildings throughout the analysed period (advanced new and retrofit buildings are projected to account for 36% and 39% of the 2050 total region's floor area, respectively), while their share under the Moderate efficiency scenario remains insignificant.

Under both scenarios C&P buildings show the highest results for both cost indicators, which is caused by C&P buildings' large floor area for both advanced (C&P has the second largest share in the 2050 advanced new floor area and the largest advanced retrofit area among the three building types) and conventional buildings (the largest share in the 2050 new floor area).

Figure 21 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in China under the Deep and Moderate efficiency scenario



# CHAPTER 6: ASSUMPTIONS AND FINDINGS: INDIA

This section provides information about data collection, modeling assumptions and results for total cumulative investment costs and total energy cost savings for India. Following the same logic as in other regions, first, the process of identification of the major climate zones (CIDs) in India is described. Then, data collection and the main sources of cost data are presented. Finally, the process and main assumptions of cost transfer are explained for those categories where relevant or reliable cost data is not available.

## 6.1 Cost database - Summary of the input data

The process of the cost identification includes the same steps, as the ones described for the EU-27 (see Section 3.1 Summary of the input data), the USA (see Section 4.1 Summary of the input data) and China (see Section 5.1 Cost database - summary of input data). Each step is discussed below in more details.

### 6.1.1 Identification of climate zones

Section 2.5 Climate zone identification describes the general approach to the CID identification. Like in other regions, the most important step has been to collect case studies for India for its major climate zones[24]. The 3CSEP HEB model provides shares of each climate zone in total population of India, which are shown in Table 25 (the major climate zones are shaded in light blue).

Table 25 Average shares of climate zones in the region's total population for India in 2005

| CID | Description of the climate zone (CZ) | Average share of the climate zone in the region's total population | CZ population [million] |
|---|---|---|---|
| **CID 1** | Only H (vhd) | 1.0% | 11.6 |
| **CID 2** | Only H (hd) | 2.0% | 22.7 |
| **CID 3** | Only H (md + ld) | 0.4% | 4.6 |
| **CID 8** | H (md) and C (ld) | 1.1% | 12.4 |
| **CID 9** | H (ld) and C (md) | 1.5% | 16.9 |
| **CID 10** | H (ld) and C (ld) | 0.9% | 10.4 |
| **CID 11** | Only C (vhd) | 0.6% | 6.8 |
| **CID 12** | Only C (hd) | 1.0% | 10.8 |
| **CID 13** | Only C (ld + md) | 1.9% | 20.9 |
| **CID 14** | C (vhd) and DH | 72.8% | 823.5 |
| **CID 15** | C (hd) + DH | 16.1% | 182.5 |
| **CID 16** | C (ld + md) and DH | 0.7% | 7.4 |

*Notes*: H – heating; C – cooling; DH – dehumidification; v – very; h – high; m – moderate; l – low; d - demand

In India the major climate zones are CID 14 (very high cooling demand and dehumidification) with the population share of 73% and CID 15 (high cooling demand and dehumidification) with the share of 16%. This means that a great majority of the current Indian population (89%) lives in these two climate zones and, thus, cost data for these climate zones have the greatest impact on the overall results.

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[24] Major climate zone is defined here as a climate zone, the share of which exceeds 10% of the total region's population.

### 6.1.2 Costs of advanced and conventional buildings

This section provides information on the sources and assumptions for the cost data collection and explains the process of climate identification for different case studies. The construction costs for advanced (new and retrofit) buildings are based on various case studies and online databases. Costs of conventional new construction are based mainly on international construction cost surveys. Table 26 summarizes the main data sources for the costs of both advanced and conventional buildings.

Table 26 Main sources for cost database for India

| Data collected | Main sources/Notes | Reference |
|---|---|---|
| **Best-practices** | Green Rating for Integrated Habitat Assessment | GRIHA (2012) |
| | Case-studies of High-performance Sustainable Buildings | Hartkopf et al. (2009) |
| | Individual studies & projects | C40 (2011) |
| **Costs of conventional buildings*** | International construction cost survey (for different world regions) | Gardiner & Theobald LLP (2009) |
| | International Construction Cost Survey | Turner & Townsend (2012) |
| | Individual studies and projects, expert estimates | Rajan Rawal |

*Notes*: * Cost of conventional buildings include both “baseline costs”, which refer to the cost of the new and retrofitted buildings under the Frozen efficiency scenario ($N^{LOW}$, $R^{10}$), as well as costs of the conventional buildings ($N^{BC}$, $R^{30}$) under the Moderate/Deep efficiency scenario.

The costs of construction are calculated as total full construction costs per unit of floor area ($USD_{2005}/m^2$). All cost data are converted from the national currency to USD, while for the conversion to $USD_{2005}$ an estimated construction cost index (CCI) for India is used. As for India only the consumer price index (CPI) is available (OECD 2012), the Indian CCI was calculated based on the India’s CPI and the ratio between CCI and CPI for EU-27 (OECD 2012).[25]

The specific (full) investment costs per unit of floor area in India’s major CIDs and building types are shown in Table 27.

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[25] The basic assumption for calculation of the estimate of the $CCI_{India}$ is that the ratio of CCI and CPI in India is approximately similar to such a ratio in EU-27. Therefore, from the assumption $CCI_{India}/CPI_{India} \approx CCI_{EU27}/CPI_{EU27}$,the following can be established: $CCI_{India} = CPI_{India} * CCI_{EU27}/CPI_{EU27}$.

Table 27 Specific investment costs per unit of floor area in India, major CIDs

India

| | | | | SF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Frozen | | | | Moderate | | | | Deep | | | |
| | | | | New | | Retrofit | | New | | Retrofit | | New | | Retrofit | |
| | | | | New | Adv. New | Retrofit | Adv. Retrofit | New | Adv. New | Retrofit | Adv. Retrofit | New | Adv. New | Retrofit | Adv. Retrofit |
| **RID** | **CID** | **% CID** | **Climate** | $N^{LOW}$ | $AN^{70+}$ | $R^{10}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ |
| 13 | 14 | 73% | VHCD + DH | 300 | 604 | 135 | 225 | 375 | 604 | 180 | 225 | 375 | 604 | 180 | 225 |
| 13 | 15 | 16% | HCD + DH | 300 | 604 | 135 | 225 | 375 | 604 | 180 | 225 | 375 | 604 | 180 | 225 |
| | | | | MF | | | | | | | | | | | |
| | | | | Frozen | | | | Moderate | | | | Deep | | | |
| | | | | New | | Retrofit | | New | | Retrofit | | New | | Retrofit | |
| | | | | New | Adv. New | Retrofit | Adv. Retrofit | New | Adv. New | Retrofit | Adv. Retrofit | New | Adv. New | Retrofit | Adv. Retrofit |
| **RID** | **CID** | **% CID** | **Climate** | $N^{LOW}$ | $AN^{70+}$ | $R^{10}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ |
| 13 | 14 | 73% | VHCD + DH | 165 | 332 | 105 | 174 | 275 | 332 | 139 | 174 | 275 | 332 | 139 | 174 |
| 13 | 15 | 16% | HCD + DH | 165 | 332 | 105 | 174 | 275 | 332 | 139 | 174 | 275 | 332 | 139 | 174 |
| | | | | C&P | | | | | | | | | | | |
| | | | | Frozen | | | | Moderate | | | | Deep | | | |
| | | | | New | | Retrofit | | New | | Retrofit | | New | | Retrofit | |
| | | | | New | Adv. New | Retrofit | Adv. Retrofit | New | Adv. New | Retrofit | Adv. Retrofit | New | Adv. New | Retrofit | Adv. Retrofit |
| **RID** | **CID** | **% CID** | **Climate** | $N^{LOW}$ | $AN^{70+}$ | $R^{10}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ | $N^{BC}$ | $AN^{70+}$ | $R^{30}$ | $AR^{70+}$ |
| 13 | 14 | 73% | VHCD + DH | 450 | 796 | 150 | 250 | 525 | 796 | 200 | 250 | 525 | 796 | 200 | 148 |
| 13 | 15 | 16% | HCD + DH | 450 | 539 | 148 | 247 | 525 | 539 | 197 | 247 | 525 | 539 | 197 | 247 |

*Note*: green – genuine data from the CID and region; white – cost transfer

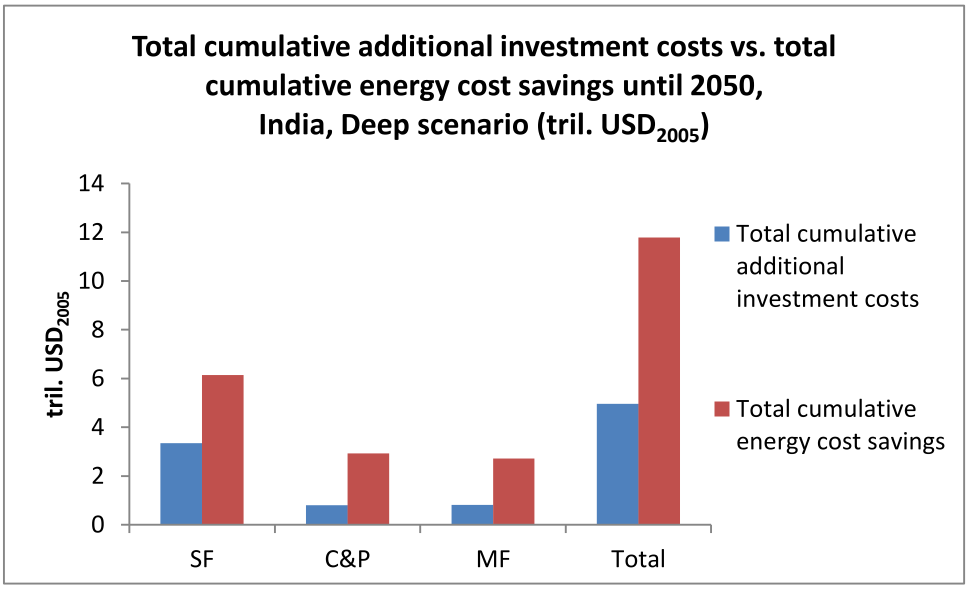
## 6.2 Results for India – Deep efficiency scenario

Table 28 shows the total cumulative additional investment costs and total cumulative energy cost savings under the Deep efficiency scenario.

Table 28 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in India under the Deep efficiency scenario

| **Building type** | **Total cumulative additional investment costs until 2050** | **Total cumulative energy cost savings until 2050** |
|---|---|---|
| | **tril. USD$_{2005}$** | **tril. USD$_{2005}$** |
| **Single-family buildings (SF)** | 3.3 | 6.2 |
| **Commercial & public buildings (C&P)** | 0.8 | 2.9 |
| **Multi-family buildings (MF)** | 0.8 | 2.7 |
| **Total** | 5.0 | 11.8 |

Figure 22 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in India under the Deep efficiency scenario



*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

Figure 22 shows that for all building types the total cumulative energy cost savings exceed the total cumulative additional investment costs by the end of the projection period.

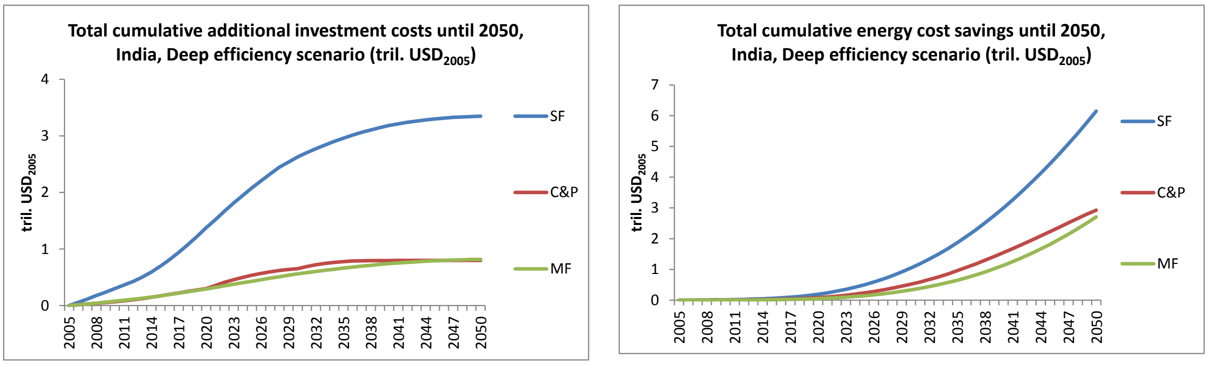
SF buildings show the highest total cumulative energy cost savings, which can be explained by the largest advanced retrofitted area and the largest advanced newly built area of single-family buildings among the building types (see Figure 62 and Figure 63, Annex 6: Floor area for specified regions and building vintages). In both cases SF buildings account for the largest share on the advanced buildings among the other building types (SF accounts for 57% of the total Indian 2050 advanced new floor area and for 76% of the total Indian 2050 advanced retrofitted floor area).

SF buildings also demonstrate the highest total cumulative additional investment, which constitute more than half of the total cumulative additional investment costs. The reason for primacy of the SF buildings in the total cumulative additional investment costs is their largest floor area in advanced new construction (which is important as advanced new buildings are the dominant building vintage under the Deep scenario; for example, in 2050 the floor area of this vintage is projected to be almost 3 times higher than the one of advanced retrofit - see Figure 62 and Figure 63), in combination with the SF buildings' relatively higher additional specific investment costs for advanced new construction as compared to C&P and MF buildings.

The C&P is the most cost-effective of the three building types, however, it is closely followed by the MF buildings. . Although the total cumulative additional investment costs are almost the same for both C&P and MF, the C&P can secure relatively higher energy cost savings (although the specific energy savings per building are comparable for advanced new buildings for both MF and C&P, in case of retrofit C&P achieves several times higher specific energy savings per building due to higher energy intensity of the existing C&P buildings).

Development of the total cumulative additional investment costs and total cumulative energy cost savings per building type over time is shown in Figure 23.

Figure 23 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in India under the Deep efficiency scenario



*Notes: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings*

SF show the highest total cumulative additional investment costs due to the largest new as well as retrofitted floor area, followed by C&P and MF, as well as the highest total cumulative energy cost savings due to the SF's largest floor area used for advanced retrofit. The total additional investment costs grow at a much slower rate after about 2032, which is due to slower rate of deployment of the advanced buildings as well as the decreasing specific investment cost of these buildings.

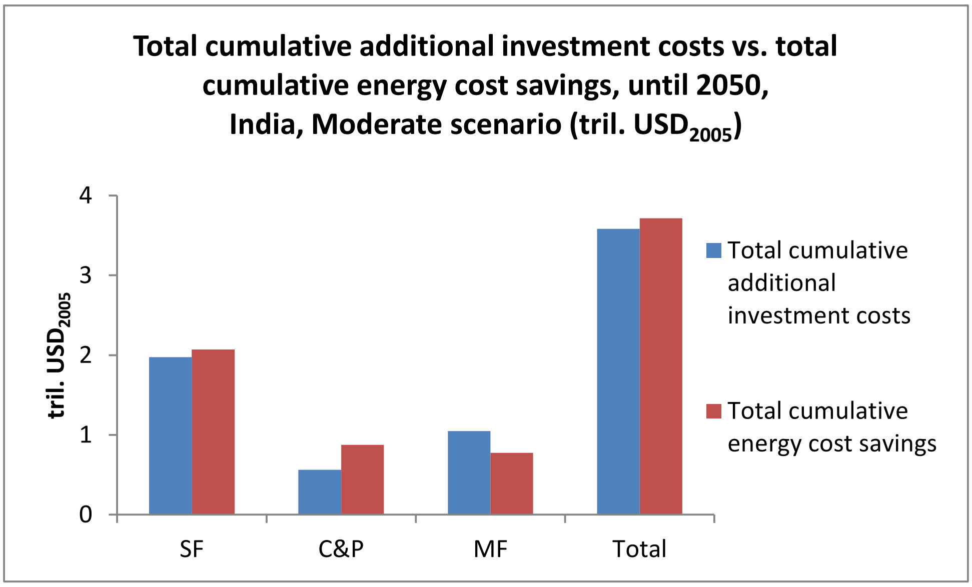
## 6.3 Results for India - Moderate efficiency scenario

Table 29 shows the total cumulative additional investment costs and total cumulative energy cost savings under the Moderate efficiency scenario.

Table 29 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in India under the Moderate efficiency scenario

| **Building type** | **Total cumulative additional investment costs until 2050** | **Total cumulative energy cost savings until 2050** |
|---|---|---|
| | **tril. USD$_{2005}$** | **tril. USD$_{2005}$** |
| **Single-family buildings (SF)** | 2.0 | 2.1 |
| **Commercial & public buildings (C&P)** | 0.6 | 0.9 |
| **Multi-family buildings (MF)** | 1.0 | 0.8 |
| **Total** | 3.6 | 3.7 |

Figure 24 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in India under the Moderate efficiency scenario



*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

Figure 24 shows that, in total, the Moderate scenario in India has almost neutral cost-effectiveness, as cumulative energy cost savings and cumulative investment costs are almost equal in 2050. Analysis of the results by building type shows that both SF and C&P buildings are cost-effective. This may be caused by relatively lower specific additional investment costs in developing countries for the conventional buildings as compared to the ones in developed regions.

The relatively low total cumulative energy cost savings in this scenario as compared to the Deep efficiency scenario can be explained by the fact that there are no advanced buildings assumed (new and retrofit) under the Moderate scenario in India, and thus, the energy savings (and consenquently, energy cost savings) are significantly lower than those under the Deep scenario.

In the Moderate efficiency scenario the cost-effectiveness is best in the case of C&P buildings due to their low additional specific investment costs for conventional new buildings, which is the dominating building vintage under this scenario (conventional new construction accounts for 53% of Indian 2050 total floor area, while conventional retrofit - for 47%).

Although C&P and MF are relatively comparable in terms of the level of the investment needs and the energy cost savings, however, unlike MF buildings, C&P building type can be cost-effective even under the Moderate scenario. This is due to the fact, that C&P buildings generate higher energy cost savings through higher specific energy savings per building than MF buildings.

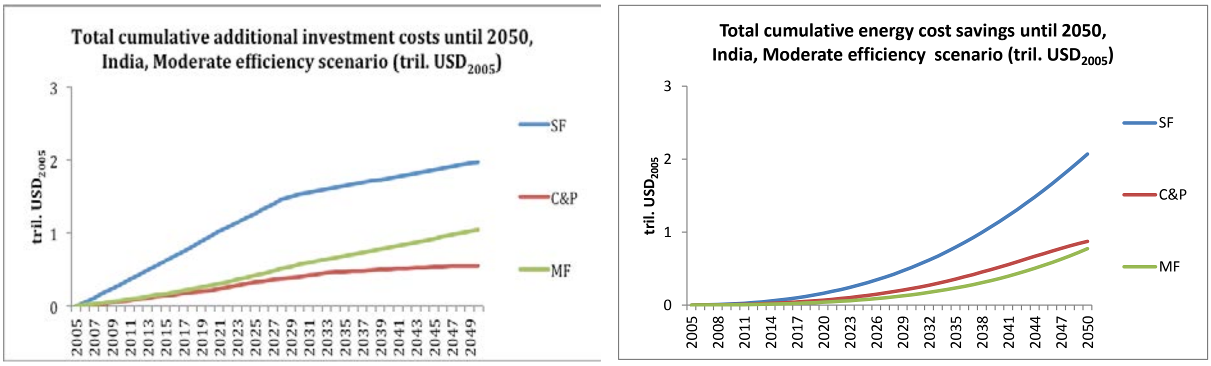
In order to analyse the non-cost effectiveness of the MF we may make a comparison to SF buildings, which are cost effective under the Moderate scenario. The specific energy savings per building of MF buildings are comparable to those of SF ones, however, MF building floor area for conventional new buildings is only half of that for SF ones, while MF building floor area for conventional retrofit buildings constitutes only one third of the respective SF floor area.

SF buildings show the second best cost effectiveness after C&P, and this happens even in spite of the fact that single-family buildings have the highest total cumulative additional investment costs among the building types caused by the dominance of the SF floor area in the Indian building stock. This implies that SF buildings have significant energy saving potential, which could allow for generating cost savings sufficient to compensate high investment needs.

Despite of SF and C&P being cost-effective, it seems unlikely for the Moderate efficiency scenario to achieve robust cost-effectiveness by 2050 for the total building stock, as the estimations of this study show. Therefore, it can be concluded that it is important for India, one of the developing countries, to follow the pathway of the Deep efficiency scenario.

Development of the total cumulative additional investment costs and total cumulative energy cost savings per building type over time is shown in Figure 25.

Figure 25 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in India under the Moderate efficiency scenario



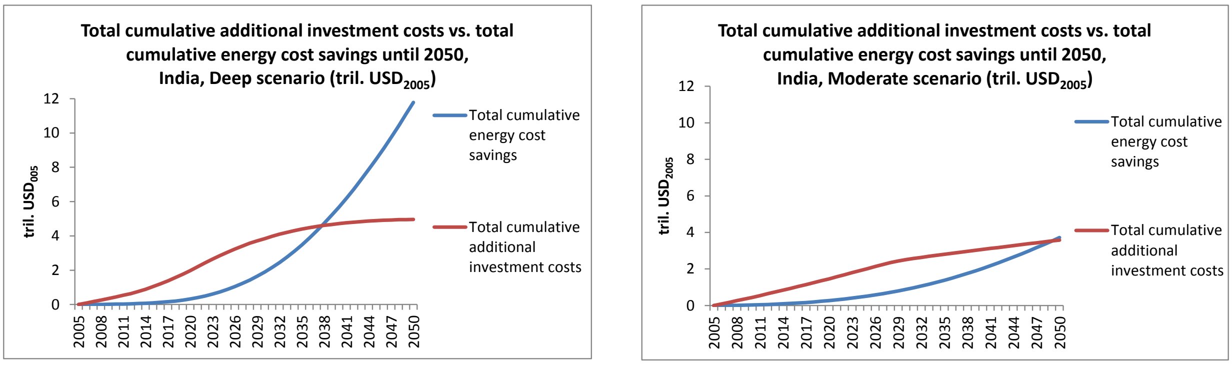
*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

## 6.4 Comparison – Deep and Moderate efficiency scenario

Under both Deep and Moderate scenarios the total cumulative additional investment costs are very low in India. Therefore, according to the estimates and under the assumptions described above, both Deep and Moderate scenarios for India are considered to be cost-effective for the total building stock and most building types (only MF buildings in Moderate scenario are not cost-effective).

The total cumulative additional investment costs under the Deep scenario are about one third higher than those under the Moderate scenario. This is mainly due to the fact that the specific investment cost of the advanced buildings (especially advanced new, which accounts for 64% of the 2050 India's total floor area) are higher than those of the conventional buildings under the Moderate scenario. On the other hand, the total cumulative energy cost savings are almost 3 times higher under the Deep scenario than those under Moderate scenario. This is mainly due to projected proliferation of the advanced buildings in the India's building stock under Deep scenario, which leads to higher energy savings.

Figure 26 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in India under the Deep and Moderate efficiency scenario



In both scenarios, the rate of increase of the total cumulative additional investment costs becomes slower around 2030 due to the process dynamics of the building stock and in case of Deep scenario also due to the learning effect.

# CHAPTER 7: ASSUMPTIONS AND FINDINGS: THE REST OF THE WORLD

This section describes the input data and assumptions for the cost analysis of all 11 world regions and shows the results first for the rest of the world regions (RoW, which is World except for EU, USA, China and India) and then for the whole World.

First, the process of identification of the major climate zones (CIDs) in the World is described. Second, the data collection and the main sources for cost data are presented. Third, the process and main assumptions of cost transfer are explained for those categories where relevant or reliable cost data is not available.

## 7.1 Cost database - Summary of the input data

This section explains the process of CID identification for the 11 world regions and provides information on the sources and assumptions for the cost data collection.

### 7.1.1 Identification of climate zones

The Section 2.5 Climate zone identification describes the general approach to the CID identification. Like in other regions, the case studies for the 11 world regions for the major climate zones were searched for. The 3CSEP HEB model provides shares of each climate zone in the total population of the 11 world regions. Table 30 shows the major climate zones per region. These major climate zones account together for 81% of the 2005 world's total population.

Table 30 The major climate zones in the 11 world regions in 2005

| Region | CID | Description of the climate zone (CZ) | Average share of the climate zone in the region's total population | Climate zone population in 2005 [million] | Share of the climate zone on the 2005 global population [%] |
|---|---|---|---|---|---|
| **AFR** | CID 12 | Only C (hd) | 33.0% | 239.5 | 3.7% |
| | CID 14 | C (vhd) and DH | 51.0% | 370.1 | 5.7% |
| **CPA** | CID 6 | H (hd) and C (ld) | 11.4% | 165.7 | 2.5% |
| | CID 15 | C (hd) and DH | 11.6% | 168.6 | 2.6% |
| | CID 17 | H + C + DH | 56.8% | 822.7 | 12.6% |
| **EEU** | CID 6 | H (hd) and C (ld) | 68.6% | 81.7 | 1.35% |
| | CID 8 | H (md) and C (ld) | 18.6% | 22.1 | 0.3% |
| **FSU** | CID 1 | Only H (vhd) | 32.0% | 91.1 | 1.4% |
| | CID 2 | Only H (hd) | 10.0% | 28.5 | 0.4% |
| | CID 6 | H (hd) and C (ld) | 39.0% | 111.1 | 1.7% |
| **LAC** | CID 12 | Only C (hd) | 21.0% | 116.0 | 1.8% |
| | CID 13 | Only C (ld + md) | 10.0% | 55.3 | 0.9% |
| | CID 14 | C (vhd) and DH | 33.0% | 182.3 | 2.8% |
| | CID 15 | C (hd) and DH | 23.0% | 127.1 | 1.9% |
| **MEA** | CID 9 | H (ld) and C (md) | 19.0% | 74.0 | 1.1% |
| | CID 11 | Only C (vhd) | 11.0% | 42.8 | 0.7% |
| | CID 12 | Only C (hd) | 24.0% | 93.4 | 1.4% |
| | CID 14 | C (vhd) and DH | 10.0% | 38.9 | 0.6% |
| | CID 15 | C (hd) and DH | 18.0% | 70.1 | 1.1% |
| **NAM** | CID 6 | H (hd) and C (ld) | 28.3% | 96.1 | 1.5% |
| | CID 17 | H + C + DH | 40.5% | 137.3 | 2.1% |
| **PAO** | CID 8 | H (md) and C (ld) | 30% | 45.6 | 0.7% |
| | CID 17 | H + C + DH | 42.0% | 63.8 | 1.0% |
| **PAS** | CID 14 | C (vhd) and DH | 81.0% | 428.7 | 6.6% |

| Region | CID | Description of the climate zone (CZ) | Average share of the climate zone in the region's total population | Climate zone population in 2005 [million] | Share of the climate zone on the 2005 global population [%] |
|---|---|---|---|---|---|
| **SAS** | CID 14 | C (vhd) and DH | 67.1% | 1,020.5 | 15.6% |
| | CID 15 | C (hd) and DH | 17.6% | 268.5 | 4.1% |
| **WEU** | CID 2 | Only H (hd) | 27.6% | 130.0 | 2.00% |
| | CID 6 | H (hd) and C (ld) | 20.4% | 96.4 | 1.5% |
| | CID 8 | H (md) and C (ld) | 27.7% | 130.8 | 2.0% |
| **Total** | | | 81.4% | 5,318.6 | |

### 7.1.2 Costs of advanced and conventional buildings

Table 31 summarizes the main sources used for the cost database of both advanced and conventional buildings in the 11 world regions. These include also the already mentioned sources used for data collection in the four major regions.

Table 31 Main sources for cost analysis in the World

| Data collected | Main sources/Notes | Reference |
|---|---|---|
| **Best-practices** | Austrian PH database | Courtesy of Gunter Lang (2009) |
| | Austrian PH web-based database | IG Passivhaus Österreich (2012) |
| | Energyinstitut Voralberg, Passive house retrofit kit (collection of case studies for several EU member states) | Energieinstitut (2012) |
| | German PH database | PHI (2012) |
| | Finish passive house projects | Energiaviisastalo (2012) |
| | Architecture 2030 database | Architecture 2030 (2011) |
| | NRDC database | NRDC (2012) |
| | The Research Triangle Park - database | RTP (2011) |
| | Engineering News-Record - database | ENR (2012) |
| | Energy Outreach Colorado case studies | Energy Outreach (2012) |
| | BASF, Energy Efficiency in Buildings | BASF (2012) |
| | UNEP Paris case studies | Hartkopf et al. (2009) |
| | WDBG Database | WBDG (2012) |
| | Using Financial and Market-based Mechanisms to Improve Building Energy Efficiency in China | REEP (2009) |
| | Green Rating for Integrated Habitat Assessment | GRIHA (2012) |
| | NBI Database | New Buildings Institute (2008) |
| | GBData | The Green Building Database (2012) |
| | GBCA | Green Building Council Australia (2012) |
| | Rockwool case studies | Rockwool (2012) |
| | Energy Efficiency in the Construction Sector in the Mediterrean | MED-ENEC (2012) |
| | Energy Efficiency and Renewable Energy (EERE) Building database | USDoE(2012) |
| | Net Zero Energy Buildings | Voss, Musall (2011) |
| | Individual studies and projects | Galvin (2010) |
| | | Voss (2000) |
| | | Josep Bunyesc (2012) |
| | | Kazinczy (2012) |

| Data collected | Main sources/Notes | Reference |
|---|---|---|
| | | Hermelink (2005-2007) |
| | | Haus der Zukunft (2012) |
| | | Harvey (2006) |
| | | Lain et al. (2001) |
| | | Edwards (2006) |
| | | Dascalaki et al. (2010) |
| | | Parker (2009) |
| | | Broad town building studies (2009) |
| | | Xuan (2011) |
| | | C40 (2011) |
| **Costs of conventional buildings*** | Hungarian Construction Cost Estimation Handbook | ETK (2009-2011) |
| | International Construction Cost Survey (For Different World Regions) | Gardiner & Theobald LLP (2009) |
| | International Construction Cost Survey | Turner & Townsend (2012) |
| | International construction cost survey(For different world regions) | Gardiner & Theobald LLP (2009) |
| | International construction cost survey(For different world regions) | Gardiner & Theobald LLP (2011) |
| | International construction cost survey (For major world regions) | Turner & Townsend (2012) |
| | Design Cost Data (US) | DCD (2011) |
| | Quarterly Construction Cost Report (US) | Rider Levett Bucknall (2012) |
| | Independent Real Estate Analysis On China | RET (2006) |

*Notes*: * Cost of conventional buildings include both “baseline costs”, which refer to the cost of the new and retrofitted buildings under the Frozen efficiency scenario ($N^{LOW}$, $R^{10}$), as well as costs of the conventional buildings ($N^{BC}$, $R^{30}$) under the Moderate/Deep efficiency scenario.

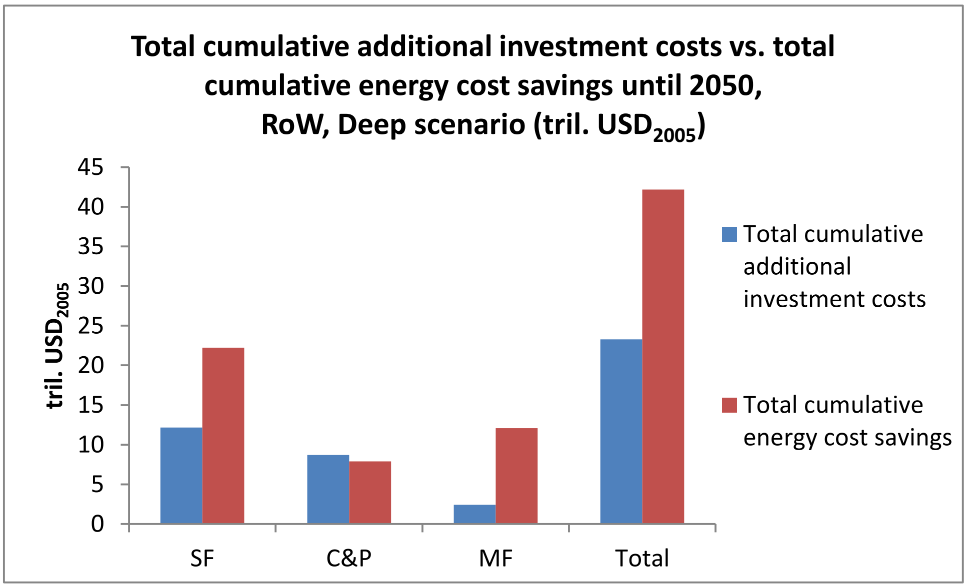
## 7.2 Results for the Rest of the World– Deep efficiency scenario

This section presents the results of cost analysis of the World except for the 4 regions examined above (EU-27, USA, China and India). This group of regions is called here “Rest of the World” (RoW). The specific construction costs ($USD_{2005}/m^2$) used as a basis for calculation of the total cumulative additional investment costs for the Deep and Moderate efficiency scenarios are shown in Annex 4: Specific investment costs per region and building type for all climate zones. Table 32 shows the total cumulative additional investment costs and total cumulative energy cost savings under the Deep efficiency scenario.

Table 32 Total cumulative additional investment costs and total cumulative energy cost savings in RoW until 2050 under the Deep efficiency scenario

| Building type | Total cumulative additional investment costs until 2050 | Total cumulative energy cost savings until 2050 |
|---|---|---|
| | **tril. $USD_{2005}$** | **tril. $USD_{2005}$** |
| **Single-family buildings (SF)** | 12.2 | 22.2 |
| **Commercial & public buildings (C&P)** | 8.7 | 7.9 |
| **Multi-family buildings (MF)** | 2.4 | 12.1 |
| **Total** | 23.3 | 42.2 |

Figure 27 Total cumulative additional investment costs and total cumulative energy cost savings in the RoW until 2050 under the Deep efficiency scenario per building type



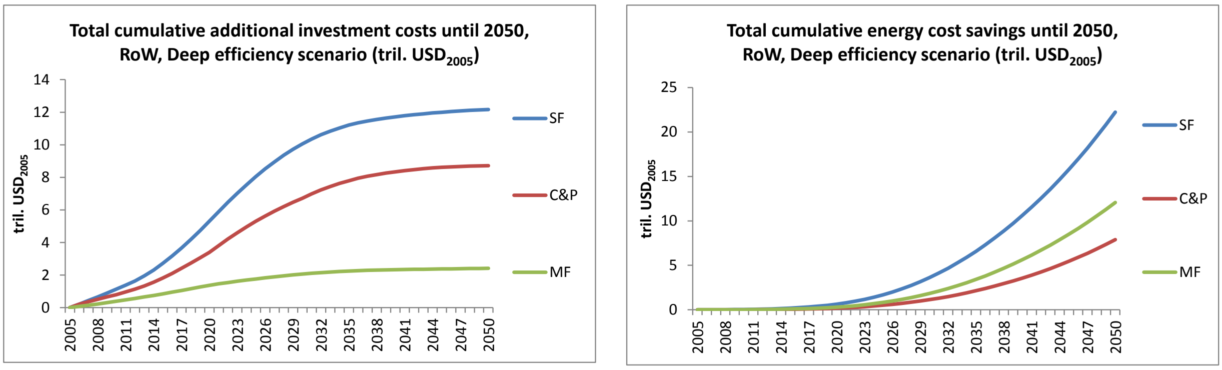
*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

Figure 27 shows that in total the Rest of the world region is cost-effective under the Deep efficiency scenario. SF and MF are both cost effective unlike C&P buildings, where total investment exceed the total cumulative energy cost savings. MF buildings seem to be the most cost-effective among the three buildings types (the total 2050 cumulative energy cost savings exceed the total cumulative investment needs by factor of 5), while SF buildings also show significant difference between the total cumulative additional investment needs and the total cumulative energy cost savinsg (a factor of two).

Both total cumulative additional investment costs and total cumulative energy cost savings are the highest for SF buildings. The former is due to SF buildings' dominance in the total floor area of the region (which is about 60% for both conventional and advanced buildings). The large floor area of SF buildings compensates relatively lower additional specific investment costs (especially those for advanced new, the dominant vintage under Deep scenario).

The SF buildings' primacy in the total cumulative energy cost savings can be explained by SF buildings' largest floor area of advanced buildings, both new and retrofit (see Figure 65 and Figure 66, Annex 6: Floor area for specified regions and building vintages). SF buildings account for approximately 60% of the 2050 total floor area of the RoW region. The floor area of the advanced new construction is more than twice as large as the floor area of advanced retrofit buildings in the RoW for all building types (advanced new accounts for 57% of the 2050 total region's floor area).

Figure 28 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in the RoW under Deep efficiency scenario



*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

## 7.3 Results for the Rest of the World – Moderate efficiency scenario

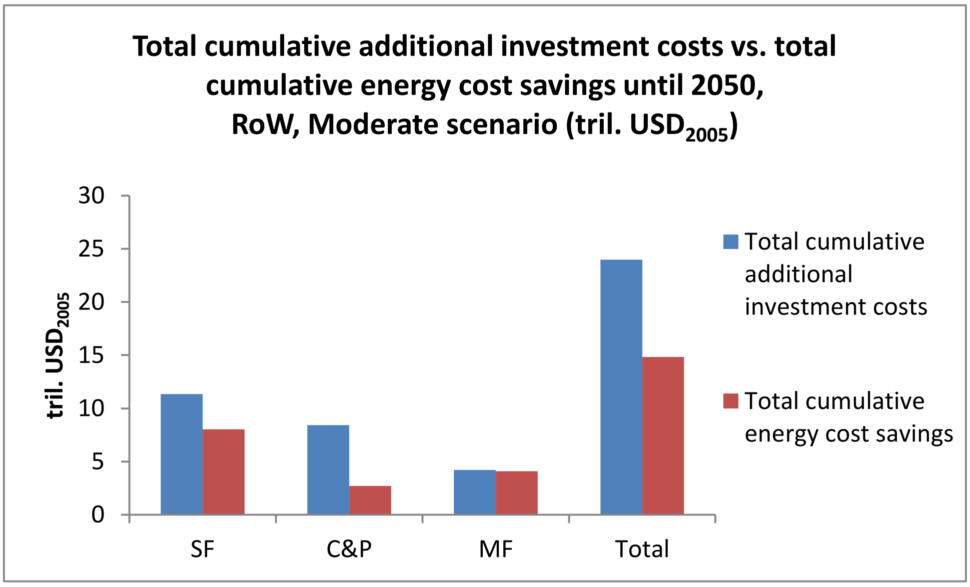
This section presents the results of cost analysis for the region of Rest of the World (RoW, World except for the four major regions; EU-27, USA, China, India) under the Moderate efficiency scenario. The specific construction costs ($USD_{2005}/m^2$) used as a basis for calculation of the total investment costs for the Deep and Moderate efficiency scenarios are shown in Annex 4: Specific investment costs per region and building type for all climate zones. Table 33 shows the total cumulative additional investment costs and total cumulative energy cost savings under the Moderate efficiency scenario.

Table 33 Total cumulative additional investment costs and total cumulative energy cost savings in RoW until 2050 under the Moderate efficiency scenario

| Building type | Total cumulative additional investment costs until 2050 | Total cumulative energy cost savings until 2050 |
|---|---|---|
| | tril. $USD_{2005}$ | tril. $USD_{2005}$ |
| **Single-family buildings (SF)** | 11.4 | 8.0 |
| **Commercial & public buildings (C&P)** | 8.4 | 2.7 |
| **Multi-family buildings (MF)** | 4.2 | 4.1 |
| **Total** | 24.0 | 14.8 |

In summary, when the total building stock is considered for the Rest of the world region the Moderate scenario is not likely to be cost-effective. When different building types are taken into account, MF is the only building type under this scenario to have a comparable magnitude of total cumulative energy cost savings to total cumulative investment costs (however, still not cost effective) (Table 33 and Figure 29). This implies that Deep scenario should be considered as a preferred pathway for the Rest of the world region, which is dominated by the developing and emerging economies.

Figure 29 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in the RoW under the Moderate efficiency scenario



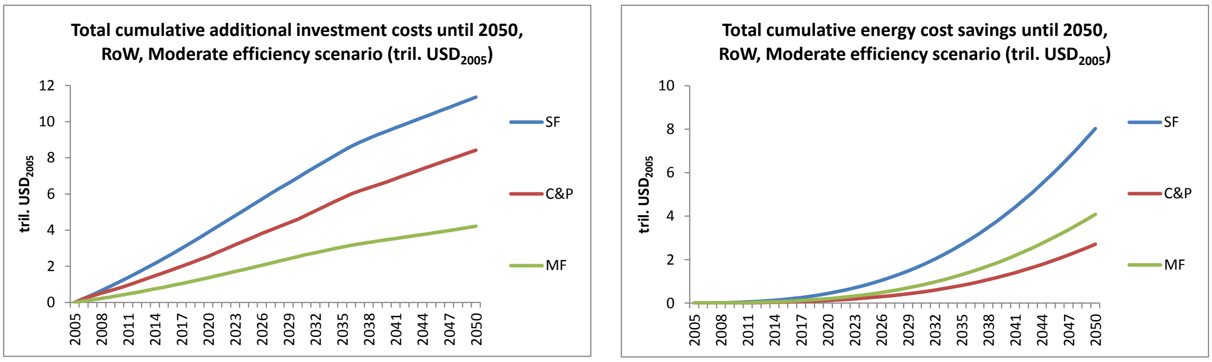
*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

SF buildings show both the highest total cumulative additional investment costs as well as total cumulative savings on energy cost among the three building types, because of its large share in the total regional floor area (see Figure 29). Under the Moderate scenario both new construction and retrofit are important building vintages (53% and 46% of the RoW's 2050 total floor area, respectively). SF building type accounts for majority of both vintages (58% and 63% of the RoW's new and retrofit floor area in 2050, respectively). In terms of total cumulative additional investment costs SF buildings are followed closely by

C&P. Despite the SF's outstanding primacy in the share on floor area the C&P's higher specific investment costs for the conventional buildings (relative to SF ones) contribute to C&P's high total cumulative investment costs.

Development of the total cumulative additional investment costs and total cumulative energy cost savings for each building type over time is shown in Figure 30.

Figure 30 Total cumulative additional investment costs until 2050 per building type in the rest of the world (RoW) under the Moderate efficiency scenario

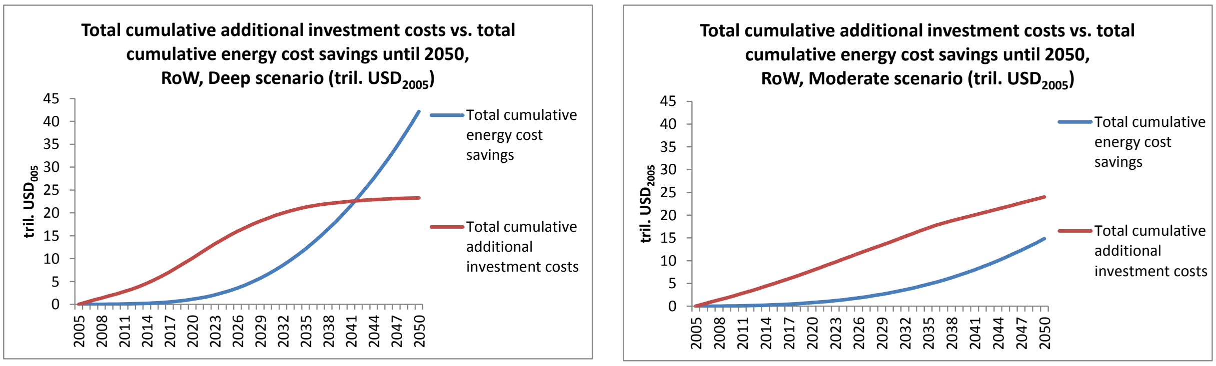


*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

## 7.4 Comparison – Deep and Moderate efficiency scenario

The results for the two scenarios show that, unlike in the case of the Moderate scenario, the RoW region is estimated to be cost-effective in general under the Deep efficiency scenario. This result is similar to the one presented for the four major regions and can be explained by relatively lower total cumulative additional investment costs and significantly higher total cumulative energy savings. Although the level of total cumulative additional investment costs are at the same level of magnitude for both scenarios, the Deep scenario generates almost three times more energy cost savings than the Moderate one, according to the estimates. This can be attributed mainly to the large proliferation of advanced buildings, assumed only for the Deep scenario. Under both scenarios the SF building type shows the largest energy cost savings, as well as the largest total investment needs.

Figure 31 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in the rest of the world (RoW) under Deep and Moderate efficiency scenario



# CHAPTER 8: RESULTS FOR THE WORLD

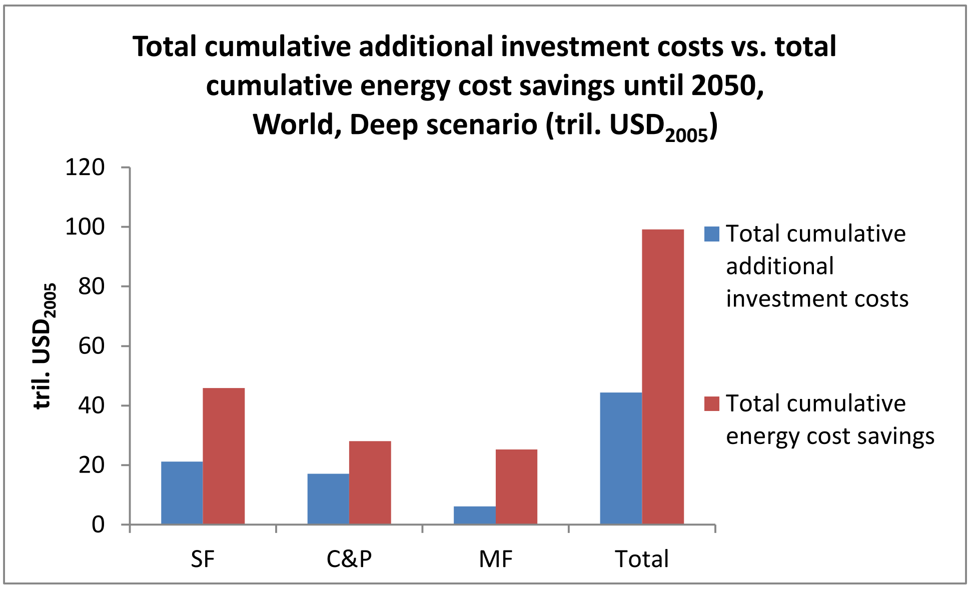
## 8.1 Results for the World – Deep efficiency scenario

In this section the total results of the cost analysis of all 11 world regions, which give the global coverage, are presented.[26] Table 34 and Figure 32 show the total cumulative additional investment costs and total cumulative energy cost savings under the Deep efficiency scenario.

Table 34 Total cumulative additional investment costs and total cumulative energy cost savings in the World until 2050 under the Deep efficiency scenario

| **Building type** | **Total cumulative additional investment costs until 2050** | **Total cumulative energy cost savings until 2050** |
|---|---|---|
| | **tril. USD$_{2005}$** | **tril. USD$_{2005}$** |
| **Single-family buildings (SF)** | 21.2 | 45.9 |
| **Commercial & public buildings (C&P)** | 17.1 | 28.1 |
| **Multi-family buildings (MF)** | 6.1 | 25.3 |
| **Total** | 44.3 | 99.2 |

Figure 32 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in the World under the Deep efficiency scenario



*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

Figure 32 shows that at the global level all building types can be cost-effective under the Deep efficiency scenario.

SF building type demonstrates the highest total cumulative additional investment costs and the highest total cumulative energy cost savings due to its relatively large share in the global floor area. This is followed by the C&P and MF buildings. MF buildings show the highest cost-effectiveness, which is due to their lowest average additional specific investment costs among the three building types.

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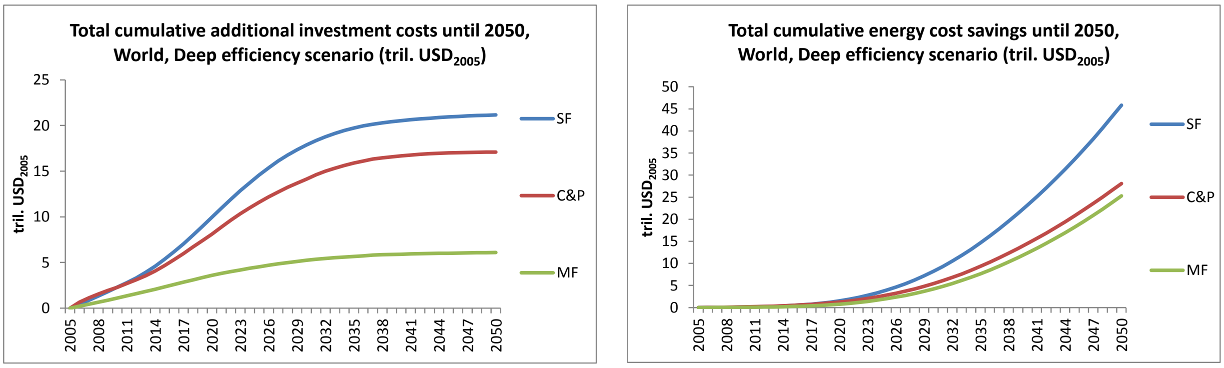
[26] World consists of the following 11 regions: AFR, CPA, EEU, FSU, LAC, MEA, NAM, PAO, PAS, SAS, WEU (see Annex for the complete list of the countries divided into the 11 world regions as based on Ürge-Vorsatz et al., 2011).

Development of the total cumulative additional investment costs and total cumulative energy cost savings per building type over time is shown in Figure 33.

Figure 33 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in the World under the Deep efficiency scenario



*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

## 8.2 Results for the World – Moderate efficiency scenario

Table 35 shows the total cumulative additional investment costs and total cumulative energy cost savings for the World under the Moderate efficiency scenario.

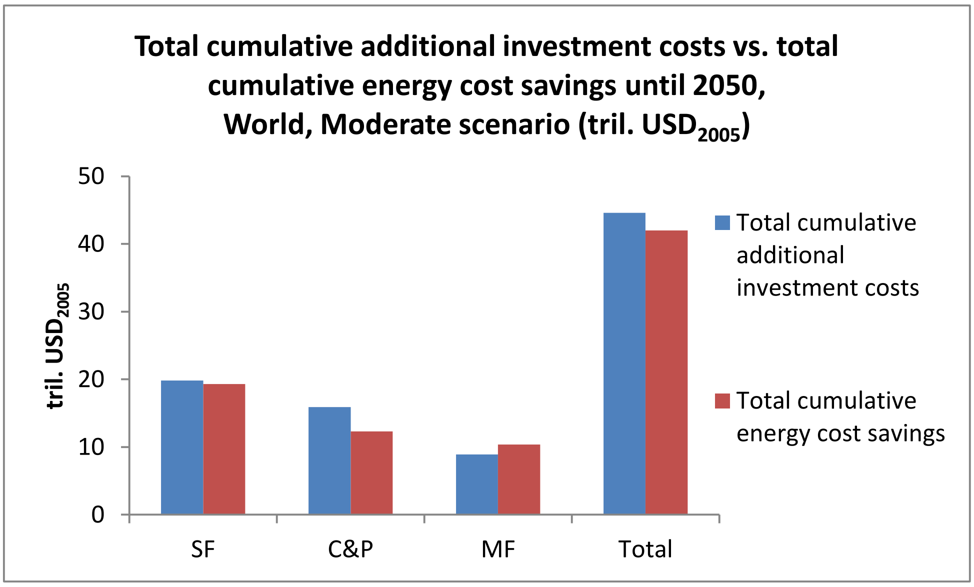
Table 35 Total cumulative additional investment costs and total cumulative energy cost savings in the World until 2050 under the Moderate efficiency scenario

| **Building type** | **Total cumulative additional investment costs until 2050** | **Total cumulative energy cost savings until 2050** |
|---|---|---|
| | **tril. USD2005** | **tril. USD2005** |
| **Single-family buildings (SF)** | 19.8 | 19.3 |
| **Commercial & public buildings (C&P)** | 15.9 | 12.3 |
| **Multi-family buildings (MF)** | 8.9 | 10.4 |
| **Total** | 44.6 | 42.0 |

The cost-effectiveness of the investment under the Moderate scenario is much lower than under the Deep efficiency scenario, however, the total cumulative investment needs are only slightly higher than the energy cost savings (

Figure 34). Moreover, one building type – MF buildings – is cost-effective, which is mainly due to its lowest additional specific investment costs among the three building types (especially for conventional retrofit).

Figure 34 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in the World under the Moderate efficiency scenario



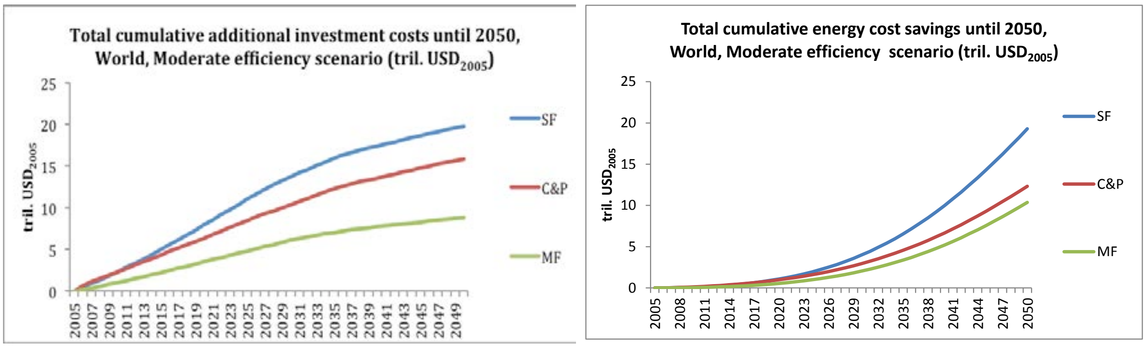
*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

SF buildings show both the highest total cumulative additional investment costs and the highest total cumulative energy cost savings (which is also mainly attributable to its largest total floor area, see Figure 73, Annex 6: Floor area for specified regions and building vintages). Although SF buildings account for the largest share of the global floor area, under the Moderate scenario not enough energy savings are produced to compensate the high total additional investment needs due to relatively low specific energy consumption reduction.

The results show that C&P buildings are unlikely to be cost-effectiveness under Moderate scenario, which can be explained by their highest additional specific investment costs, and the relatively low floor area of the retrofit building vintage (in combination with relatively low specific energy savings), which does not generate enough energy cost savings to compensate for the investment needs.

Development of the total cumulative additional investment costs and total cumulative energy cost savings per building type over time is shown in Figure 35.

Figure 35 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 per building type in the World under the Moderate efficiency scenario

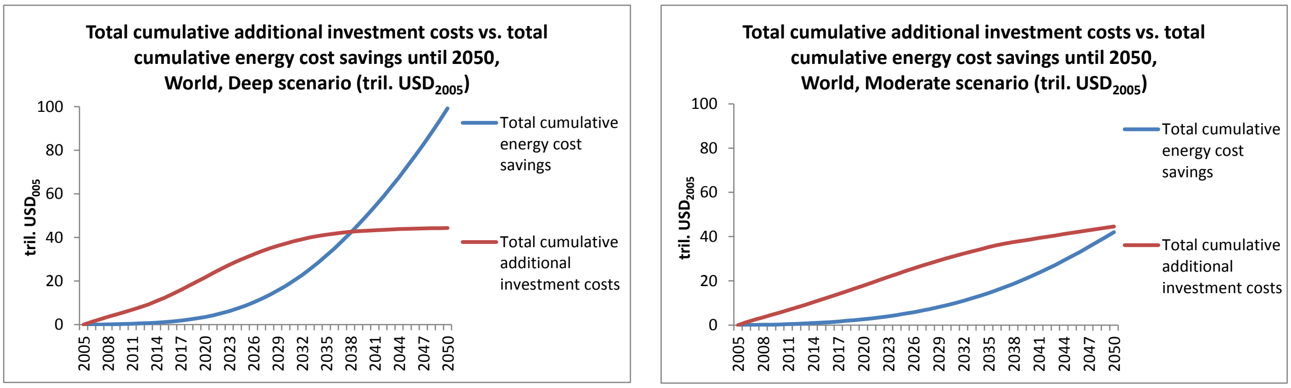


*Notes*: SF: single-family buildings, C&P: commercial and public buildings, MF: multi-family buildings

## 8.3 Comparison – Deep and Moderate efficiency scenario

While the total cumulative additional investments are at the same level of magnitude under both scenarios, the total cumulative energy cost savings under the Deep scenario are more than two times higher than those under the Moderate scenario. In both scenarios SF is the dominant building type in terms of the total cumulative additional investment costs as well as the total cumulative energy cost savings, due to its large floor area in most of the vintages (the dominant vintage in World under Deep scenario is advanced new – 47% of the 2050 World's total floor area; under Moderate it is conventional retrofit – 53% of the 2050 World's total floor area). These results clearly show the benefits of implementating the ambitious pathway of the Deep efficiency scenario.

Figure 36 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in the World under Deep and Moderate efficiency scenario



# CHAPTER 9: COMPARISON OF THE RESULTS WITH OTHER STUDIES

In this chapter the results of the current study are compared to the ones of several relevant studies, such as BPIE (2011), GEA (in Ürge-Vorsatz et al. 2011), McKinsey (2007, 2009a, 2009b) (see Table 36).

While the GEA (Global Energy Assessment) focuses on the global and regional building stocks, other comparable studies focus only on specific region(s). The GEA examines the development of final energy consumption for space heating and cooling until 2050 under two scenarios: state-of-the-art scenario and sub-optimal scenario. The cost analysis is conducted only for the state-of-the-art scenario.

BPIE (2011) focuses only on the European building stock (including EU-27, Switzerland and Norway), and several scenarios are developed until 2050. Two scenarios – Deep and Medium - are comparable to the two scenarios analysed under the current study. The BPIE study considers only limited array of specific investment costs: between 60 €/m$^2$ for minor building upgrade to 580 €/m$^2$ for renovation to the level of nearly zero energy building (BPIE 2011).

McKinsey has conducted several studies until 2030 including those focusing on USA, China and World. The studies analyze mitigation potential in different sectors of the economy including the building sector. As the studies focus only on the period until 2030, these results were extrapolated until 2050 so that they are comparable to the current study.

When the results of the current study are compared to the studies with a focus on cost analysis of the transitions towards high efficient buildings, the results of the current study in most cases present similar trends as the comparable studies, however, the absolute values of estimations differ from one study to other.

While the total cumulative additional costs are about 2-3 times higher in the current study than in GEA, the total cumulative energy cost savings of the current study are slightly lower than those of GEA (except for India) (see Table 36). The difference in the total cumulative additional costs is given by much lower specific investment costs (USD$_{2005}$/m$^2$) used in the comparable studies (especially GEA described in Ürge-Vorsatz et al. 2011, BPIE 2011) and higher learning factor (learning factor reaching approximately 60% of the 2005 marginal costs by 2030 is used in GEA). The difference in the total cumulative energy cost savings among the studies is much less significant and ranges from 30% lower results for EU-27 to 70% higher results for the World in the current study as compared to GEA.

Nevertheless, similarly to the comparable studies, the current study shows that the Deep scenario is cost-effective for all studied regions (Figure 37). As GEA did not perform cost analysis for the Sub-optimal scenario (which could be compared to the Moderate efficiency scenario in the current study) the comparison of the results for Moderate scenario can only be done for the EU-27 with those of the BPIE study.

When compared to the BPIE study for Europe, the results of the current study are several times higher under both scenarios (4-6 times higher under Deep scenario and almost 7 times higher under Moderate scenario). These differences can be explained by the relatively low specific investment costs and the resulting lower total cumulative additional investment costs used in the relevant studies (60 – 580 €/m$^2$ depending on depth of retrofit, see BPIE 2011) as compared to the current study. Nevertheless, it is important to note that like the current study BPIE study also shows that EU-27 is cost-effective under the Moderate scenario.

Moreover, other factors can contribute to the difference between the total cumulative additional investment costs in the compared studies, however it must be noted that the current study is based on a large, well-documented and highly detailed database consisting of over 600 case studies from all aver the world. In addition, reliable statistical sources, cost reports and cost databases are used for most of the baseline costs (ETK, 2009-2011; Gardiner & Theobald, 2009-2011; Turner & Townsend, 2012; RET, 2006; DCD, 2011). The rich cost database gives a justification for the specific investment costs applied in the current study and the resulting total cumulative additional investment costs.

Table 36 Overview of the studies relevant for the comparison of the model results

| Region | Deep efficiency scenario | | Moderate efficiency scenario | | Comments |
|---|---|---|---|---|---|
| | [trillion USD$_{2005}$] | | [trillion USD$_{2005}$] | | |
| | INV | ECS | INV | ECS | |
| **EU-27** | | | | | |
| 3 CSEP HEB | 5.1 | 9.8 | 5.0 | 7.4 | |
| BPIE (2011) | 1.24 | 1.75 | 0.73 | 1.13 | Original values assumed in Euro2010. |
| GEA (Ürge-Vorsatz, 2011) | 2.2 | 13.6 | - | - | The investment cost is additional to suboptimal scenario (not Frozen)<br>- Undiscounted<br>- Aggregation of WEU and EEU |
| **USA** | | | | | |
| 3 CSEP HEB | 4.3 | 8.3 | 5.6 | 2.8 | |
| GEA (Ürge-Vorsatz, 2011) | 2.0 | 9.6 | - | - | - The investment cost is additional to suboptimal scenario (not Frozen)<br>- Undiscounted<br>- NAM region used as a proxy for the USA |
| McKinsey (2007) | 0.16 by 2030,<br>0.31 by 2050 | | | | Building sector, measures of less than 50 USD$_{2005}$/t CO$_{2e}$ |
| **China** | | | | | |
| 3 CSEP HEB | 6.8 | 11.9 | 6.5 | 6.2 | |
| GEA (Ürge-Vorsatz, 2011) | 2.4 | 12.9 | - | - | - The investment cost is additional to suboptimal scenario (not Frozen)<br>- Undiscounted<br>- CPA region used as a proxy for China |
| McKinsey (2009b) | 1.0 by 2030, 2.0 by 2050 | na | na | na | Cumulative additional investment by 2030 for buildings including appliances (assuming 50 bil. USD$_{2005}$/year). Extrapolation to 2050. |
| **India** | | | | | |
| 3 CSEP HEB | 5.00 | 11.8 | 3.6 | 3.7 | |
| GEA (Ürge-Vorsatz, 2011) | 2.3 | 3.3 | - | - | - The investment cost is additional to suboptimal scenario (not Frozen)<br>- Undiscounted<br>- SAS region used as a proxy for India. |
| **World** | | | | | |
| 3 CSEP HEB | 44.3 | 99.2 | 44.6 | 42.0 | |
| GEA (Ürge-Vorsatz, 2011) | 14.2 | 57.9 | - | - | - The investment cost is additional to suboptimal scenario (not Frozen)<br>- Undiscounted |
| McKinsey (2009a) | 9.5 | na | na | na | Only measures of less than 60 €/tCO$_{2e}$ included. Building sector. |

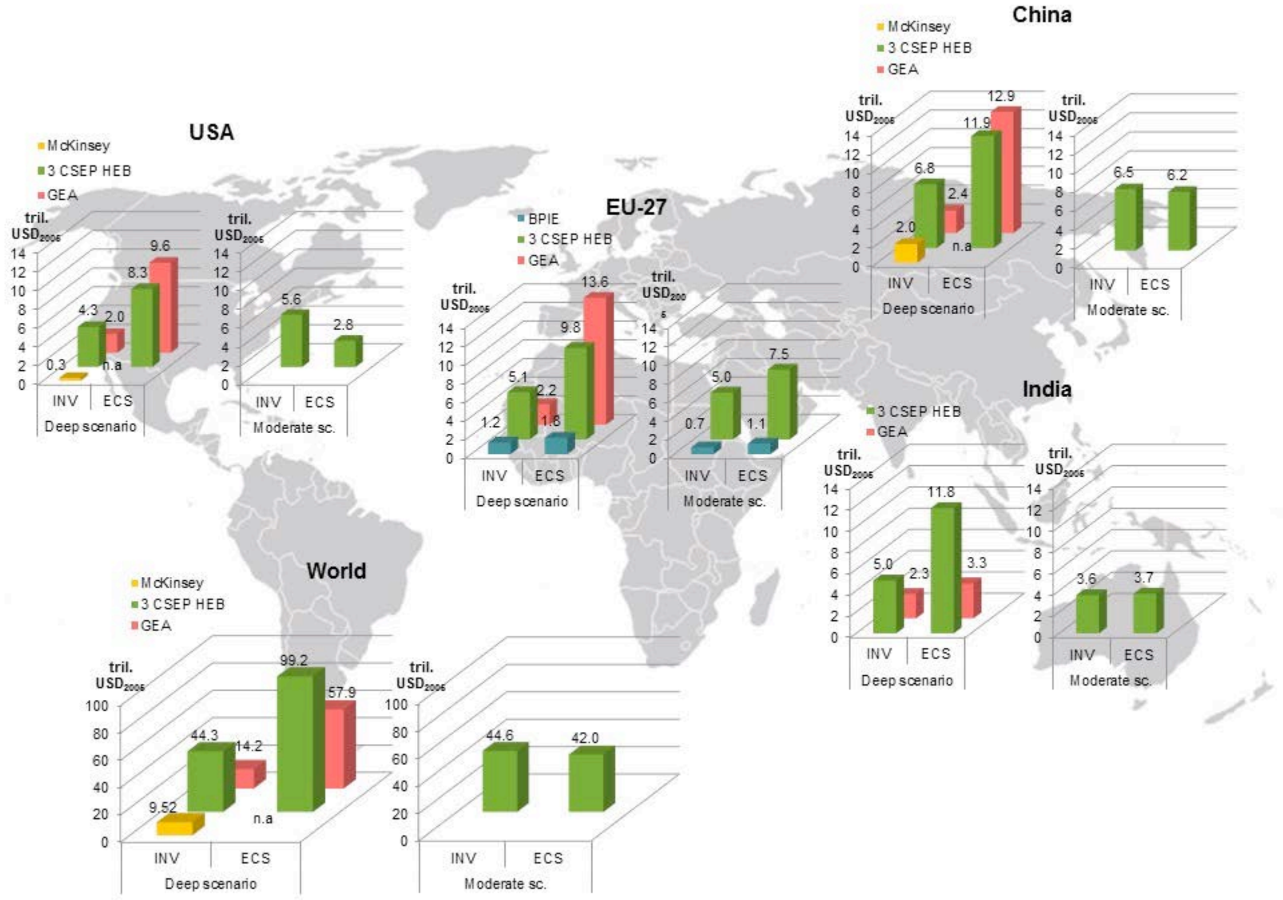
*Note*: INV - total cumulative additional investment costs until 2050, ECS - total cumulative energy cost savings until 2050

India is a special case in the comparison with GEA. Although the levels of total cumulative additional investment costs are more or less comparable in both studies, and the differences are in line with the differences for other regions, the results for total cumulative energy cost savings differ significantly (total cumulative energy cost savings in the current study are more than 3 times higher than those under GEA). Nevertheless, the total cumulative energy cost savings for India are similar to those of China in the current study, a country comparable in total floor area as well as roughly comparable in terms of the energy intensity of the building stock.

Another difference between the two studies is, for instance, in the level of cost-effectiveness for India in GEA, where the total cumulative energy cost savings are only slightly higher than the total cumulative additional investment costs. On the other hand, in the current study, India is the most cost-effective regions in the Deep efficiency scenario. These large differences can be explained by the lack of accurate data and imply that more data collection and verification is needed in this region.

In summary, the number of the studies, for which the results of the current study can be compared to, is limited. The large differences, especially in terms of the total cumulative additional investment costs, can be explained by significantly lower specific investment costs assumed in the other comparable studies (as it is in the case of BPIE, 2011) as well as lack of comprehensive cost data collection for some regions in other studies.

Figure 37 Comparison of the results of 3CSEP HEB with other relevant studies for the major regions and for the World



# CHAPTER 10: SENSITIVITY ANALYSIS

The aim of the sensitivity analysis is to show how different variables influence the overall results of the cost analysis, and which variables have a significant impact on the cost-effectiveness under the two scenarios. In order to examine the sensitivity of the Cost module to the key parameters, the sensitivity analysis has been performed for the following variables: specific investment costs, learning factor, energy prices and specific energy consumption. The factors of variation are presented in Table 37.

Table 37 Main variables for sensitivity analysis and their factors of change

| Variable | Scenario | Factor of change | Comment |
|---|---|---|---|
| **Specific investment costs ($USD_{2005}/m^2$)** | Default: | As set in the input cost tables | Collected under the current study |
| | Low 1 | -25% | The factor refers to change of the specific investment cost in 2005 (for all vintages). |
| | Low 2 | -50% | |
| | High 1 | +25% | |
| | High 2 | +50% | |
| **Learning factor (%)** | Default | -50% | The factors refer to a gradual decrease in specific investment cost ($USD_{2005}/m^2$) by given % by 2050 as compared to 2005 level. Factors are applied to advanced buildings (anew and aret) only. |
| | Low 1 | -30% | |
| | Low 2 | -15% | |
| | High | -60% | |
| **Specific energy consumption per unit of floor area ($kWh/m^2/a$)** | Default | Output of the Module 1: Scenario analysis | |
| | Low | -10% | Factors of change are based on Ürge-Vorsatz et. al (2012b) and refer to specific energy consumption for space heating and cooling. Factors are applied to advanced buildings only (advanced new & advanced retrofit). |
| | High 1 | +10% | |
| | High 2 | +25% | |
| | High 3 | +50% | |
| | High 4 | +100% | |
| **Energy prices ($USD_{2005}/kWh$)** | Default | Energy prices of GEA | Default energy prices based on Ürge-Vorsatz et al. (2011) and updated for selected fuels and regions. |
| | Low 1 | -30% | |
| | Low 2 | -70% | |
| | High 1 | +30% | |
| | High 2 | +70% | |

The variables represent parameters that are expected to have significant influence on the results of the Module 2: Cost analysis. Specific investment costs and learning factor influence the amount of the total cumulative additional investment costs. The main difference in the effects of the two variables is the following: while the changes in specific investment costs ($USD_{2005}/m^2$) apply to all building vintages (standard, new, retrofit, advanced new, advanced retrofit), changes in the learning factor apply only to the cost of the advanced new and advanced retrofit buildings. Thus, the latter influences the total cumulative additional investment costs only partially. The factor of change in the specific investment costs means a percentual increase/decrease of the current specific investment costs ($USD_{2005}/m^2$) in the year 2005. The learning factor refers to the technological learning of the advanced technologies and the factor represents a % decrease of the specific investment cost ($USD_{2005}/m^2$) by 2050 as compared to 2005. The default learning factor used in the Module 2: Cost analysis is 50% learning rate, in other words, it is assumed that the specific investment costs gradually decrease by 50% by 2050 as compared to their 2005 value.

The specific energy consumption per unit of floor area (kWh/m$^2$/a) and change in energy prices influence the total cumulative energy cost savings.

In order to examine the sensitivity of the applied specific energy consumption in the case of advanced buildings, several factors of change are applied to specific energy consumption per unit of floor area (kWh/m$^2$/a), which is applied only to the advanced buildings (advanced new and advanced retrofit). Specific energy consumption per unit of floor area is an output of the Module 1: Scenario analysis, but has an impact on the results of the Module 2: Cost analysis. The factors of change are based on the rates used for this variable in the sensitivity analysis in Module 1: Scenario analysis in Ürge-Vorsatz et al. (2012b).

Since the projections of energy prices are a matter of the considered assumptions, sensitivity analysis is performed for several factors of change in energy prices. The factor of change in energy prices means a % change (increase/decrease) in energy prices as compared to the default energy prices, which are based on GEA projections (Ürge-Vorsatz et al. 2011).

## 10.1 Specific investment costs

Specific investment costs have been among the most difficult data to collect and their accuracy, although representing the best-possible level given the available information, is limited. Therefore, it is very important to see how robust the findings are in case of variations in these data and underlying assumptions. The examined factors of change are an increase by 25% and 50% and an decrease by 25% and 50% of the specific investment costs in 2005.

The results for Deep efficiency scenario show that the major finding of the study is robust against even significant changes in specific investment cost data inputs: all major regions are still cost-effective in total even if the specific investment costs are increased by half (Figure 38). Similarly, for the World, the total cumulative energy cost savings by far exceed the total cumulative additional investment costs including all variations of the examined variable (Figure 40).

Under the Moderate efficiency scenario, in 2 major regions (USA, China) the total cumulative energy cost savings do not reach the default total cumulative additional investment costs (Figure 39). The Moderate scenario is cost-effective for all variations in the EU-27, even when the specific investment costs are increased by half. Moderate scenario is cost-effective also for India provided specific investment costs do not increase above the default level.

On the other hand, Moderate scenario can become cost-effective in China and the World region only when the specific investment costs are significantly decreased (by -25% or even less for China, and by more than -50% for the USA) as compared to their 2005 value (other variations are not examined in the sensitivity analysis) (Figure 39, Figure 40). The USA is the only region where the Moderate scenario is not cost-effective even when the specific investment costs decrease by 50% as compared their to their 2005 value (the cost-effectiveness can be reached just slightly beyond this point, the exact point was not examined).

Figure 38 Total cumulative additional investment cost for varying specific investment costs as compared to total cumulative energy cost savings for 4 regions, Deep sc.

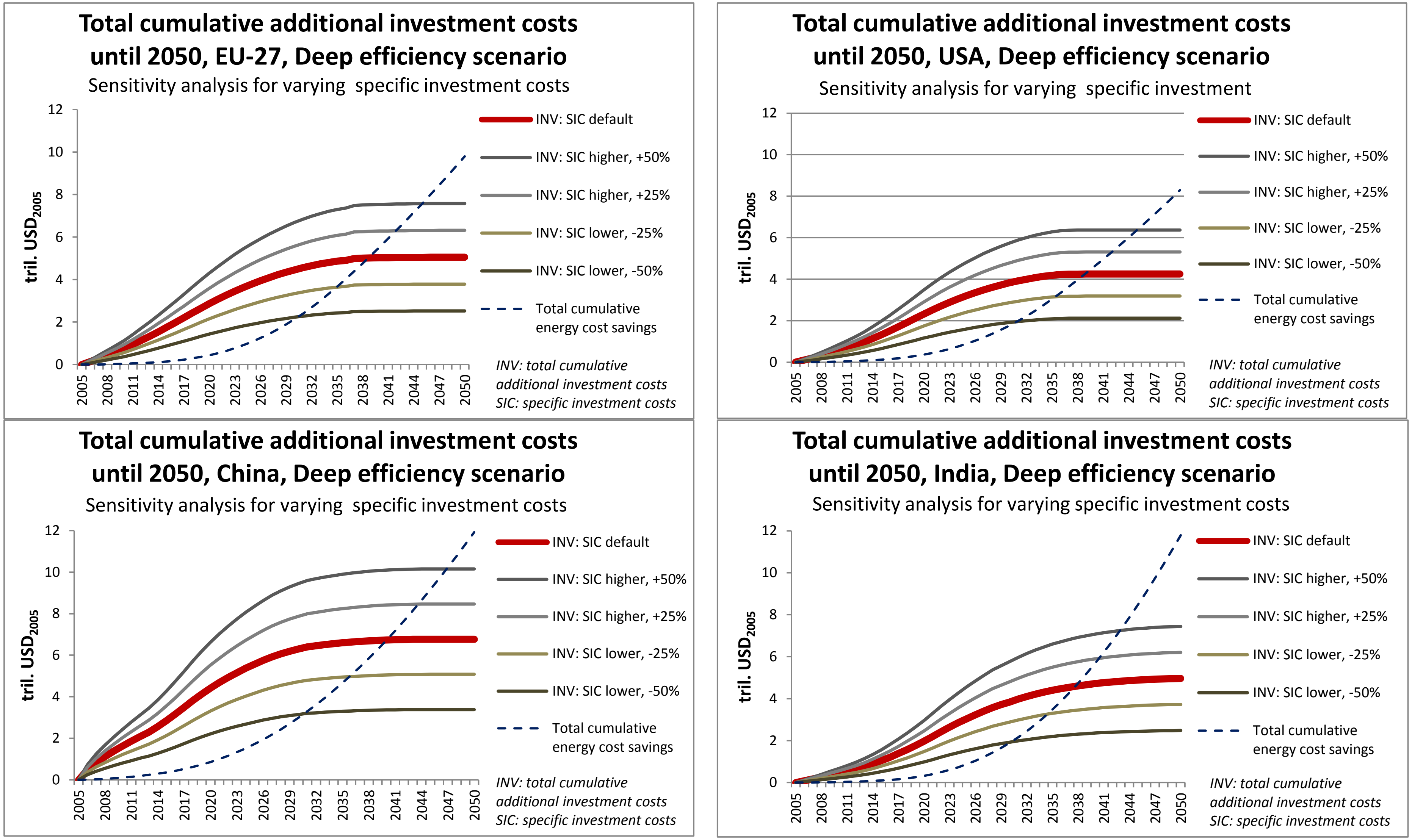


Figure 39 Total cumulative additional investment cost for varying specific investment costs as compared to total cumulative energy cost savings, 4 regions, Moderate

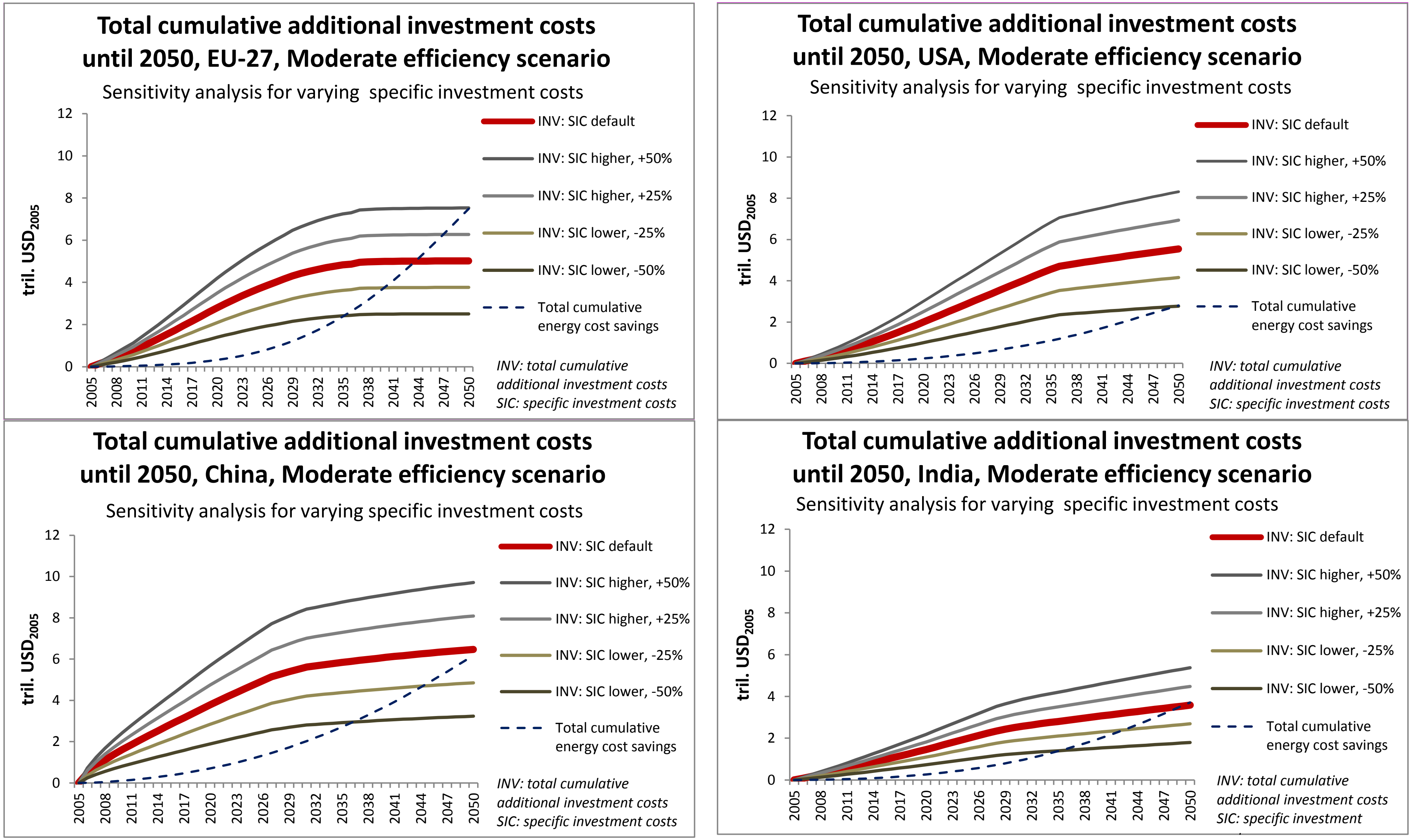
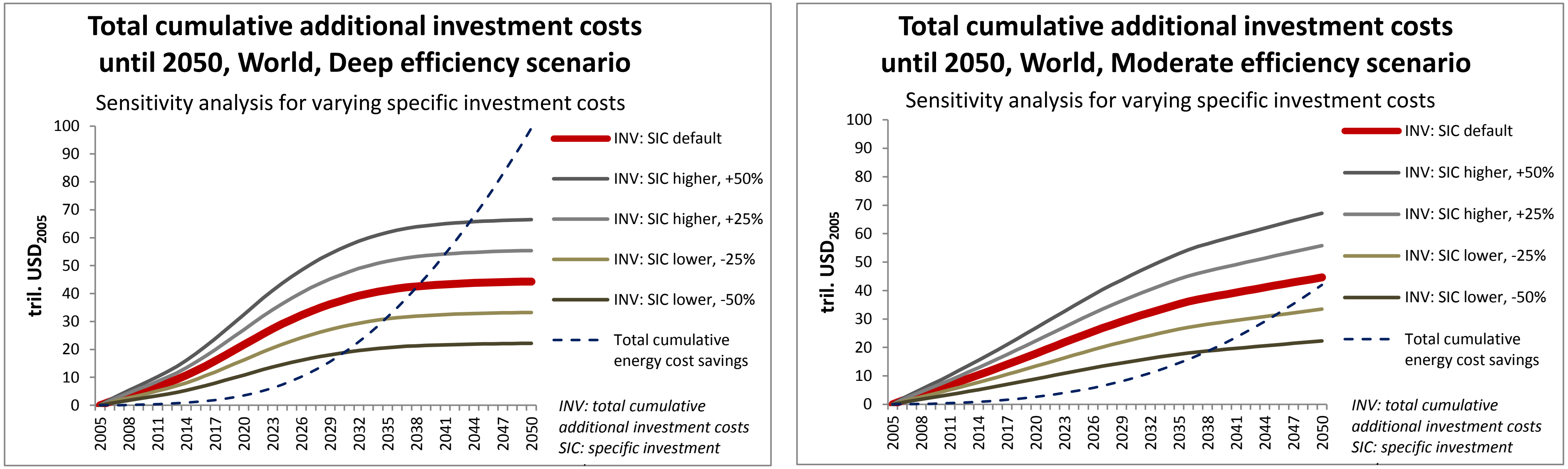


Figure 40 Total cumulative additional investment cost for varying specific investment costs as compared to total cumulative energy cost savings, World, Deep and Moderate efficiency scenario



## 10.2 Learning factor

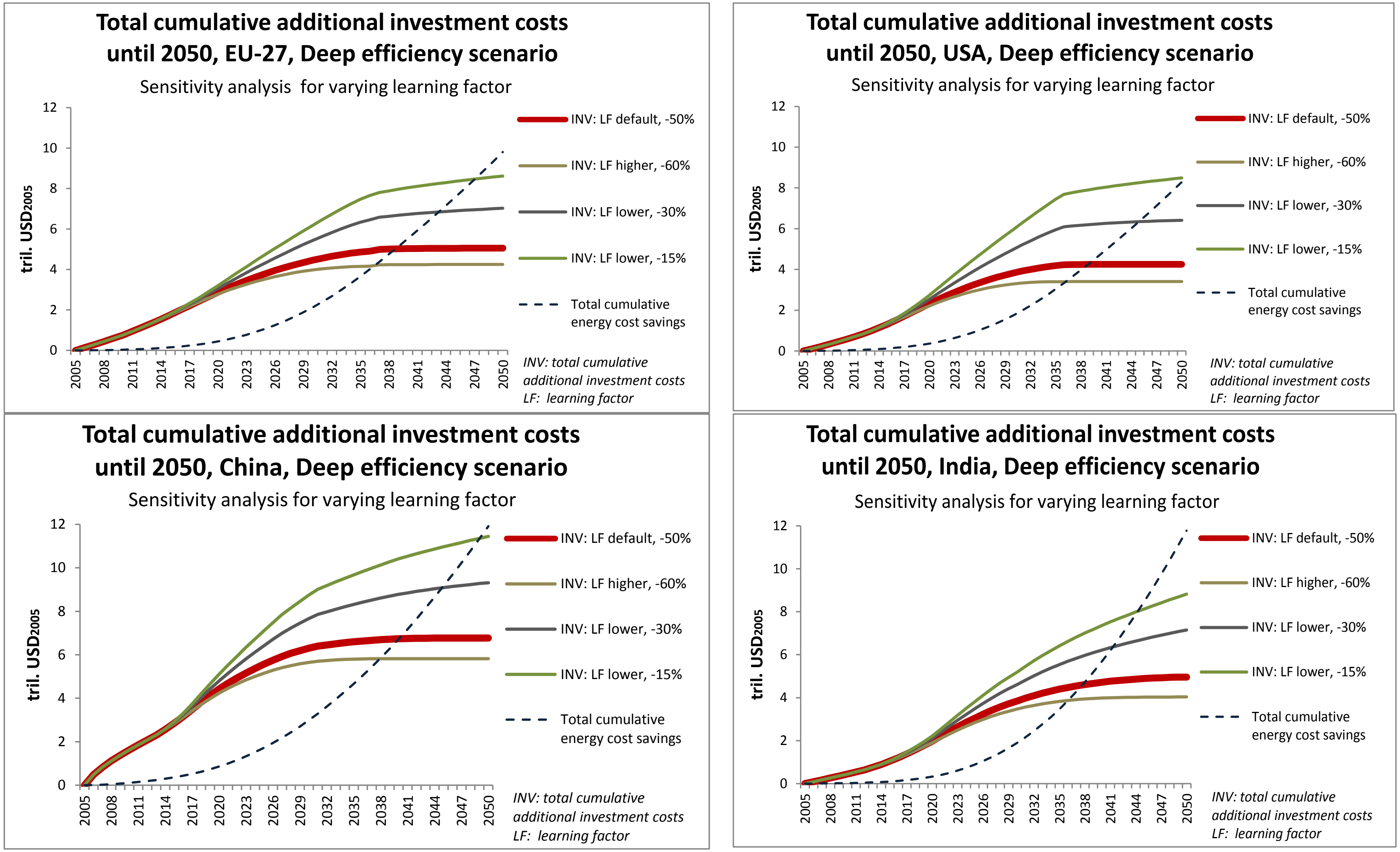
Contrary to the change in specific investment costs, which is applied to all vintages, the learning factor is applied only to the advanced buildings because cost learning is only assumed for these best-practices that are at the early phases of their market introduction and deployment, as opposed to conventional buildings with mature markets. The default learning rate in the model is 50%, i.e. the specific investment costs are assumed to decrease by 50% by 2050 as compared to their 2005 value. The applied factors of change represent both smaller decrease of the specific investment costs (-15%, -30%) as compared to default, as well as larger decrease (-60%) in order to examine the sensitivity of the results in both directions.

The results in the Deep scenario show that the learning factor is an important variable in the calculation of the total cumulative additional investment costs, however, its influence is limited to certain extent as compared to the impact of the change in the specific investment costs. This is logical, as learning factor influences only the specific investment cost of advanced new and advanced retrofit buildings and not the costs of the other vintages.

That is also the reason why learning factor influences the results mainly in the Deep efficiency scenario. Three out of four major regions (EU-27, China and India) and the World are estimated to be cost-effective under the Deep scenario even if the learning factor is only 15% (Figure 41). The only exception is the USA, which is no longer cost-effective with the learning factor of 15% under the Deep scenario. Note that although the variation in the learning factor does not cause radical changes in the total cost-effectiveness of the total building stock of the region, it can have a deeper impact on the cost-effectiveness of different building types. In general, rather than the cost-effectiveness, the learning factor influences more the time when the scenario reaches cost-effectiveness in a given region. The higher the learning factor, the sooner the cost-effective level can be reached (while other variables are kept constant). Overall, Deep scenario is cost-effective at the global scale for all investigated ranges of the learning factor.

In the Moderate efficiency scenario the learning factor influences the level of total cumulative additional investment costs only in the EU-27, as this is the only region with advanced buildings (both advanced new and advanced retrofit) under the Moderate efficiency scenario. The EU-27 is also the only region, where Moderate scenario reaches cost-effectiveness for most of ranges of learning factor in the Moderate scenario (Figure 42). The EU-27 is cost effective under the Moderate scenario provided that the learning factor is at least 30%. The total cumulative additional investment costs in other regions under different variations of learning factor are the same as the default situation – the learning factor of 50% - as there are no advanced new and advanced retrofit buildings under this scenario. The difference among the outcomes of the varying learning factor for World is insignificant (around 1% as compared to default). The difference is caused by the influence of the learning factor in the EU-27, which accounts only for about 6% of the global total cumulative additional investment costs under this scenario (Figure 43).

Figure 41 Total cumulative additional investment cost for varying learning factor as compared to total cumulative energy cost savings, 4 regions, Deep scenario



Total cumulative additional investment costs until 2050, EU-27, Deep efficiency scenario

Sensitivity analysis for varying learning factor

Total cumulative additional investment costs until 2050, USA, Deep efficiency scenario

Sensitivity analysis for varying learning factor

Total cumulative additional investment costs until 2050, China, Deep efficiency scenario

Sensitivity analysis for varying learning factor

Total cumulative additional investment costs until 2050, India, Deep efficiency scenario

Sensitivity analysis for varying learning factor

Figure 42 Total cumulative additional investment cost for varying learning factor as compared to total cumulative energy cost savings, 4 regions, Moderate scenario

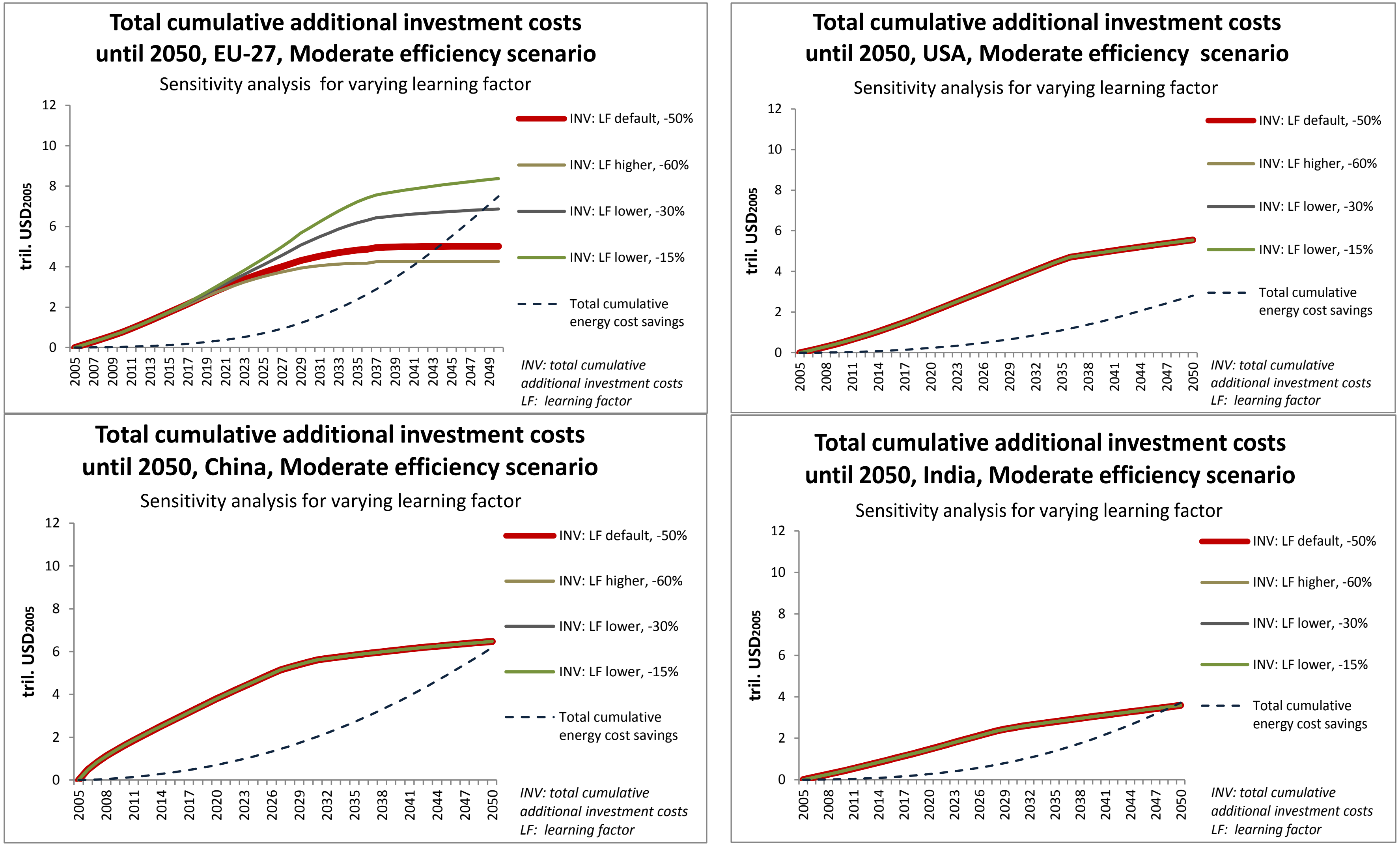
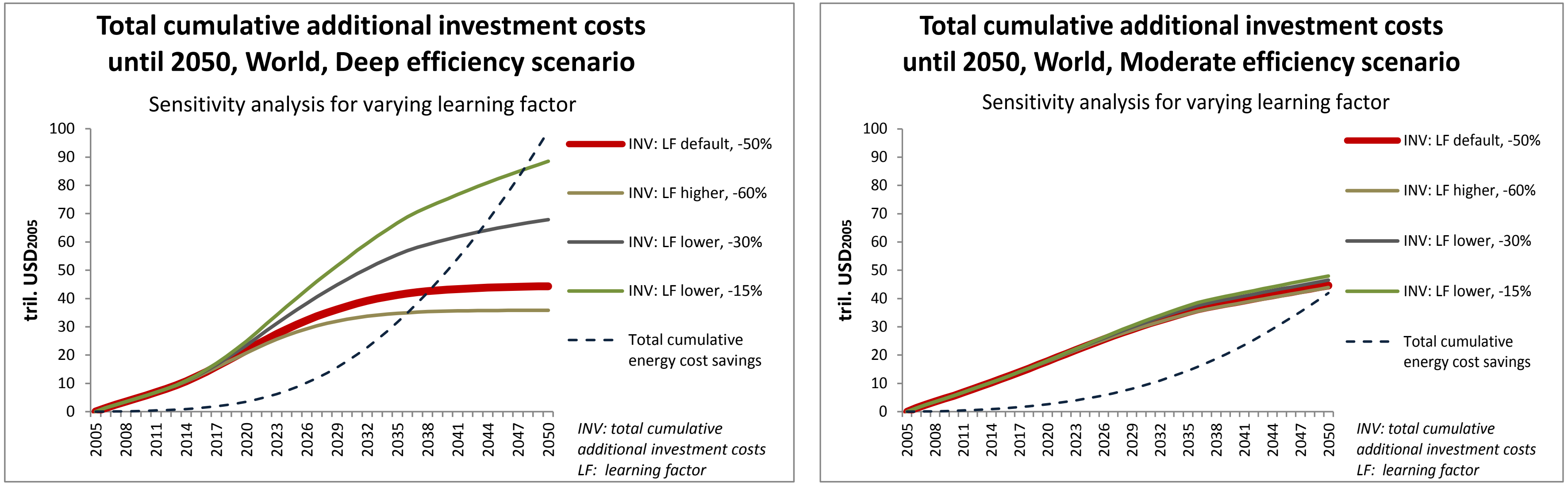


Figure 43 Total cumulative additional investment cost for varying learning factor as compared to total cumulative energy cost savings, World, Deep and Moderate



## 10.3 Specific energy consumption

The change in the input variable "specific energy consumption (kWh/m$^2$/a)" means a change in specific energy consumption of the advanced buildings only (advanced new and advanced retrofit). Thus, change in this variable influences the total cumulative energy cost savings in those scenarios and regions where the advanced buildings are assumed (all regions under Deep efficiency scenario, only EU-27 under Moderate efficiency scenario). Thus, when the specific energy consumption decreases (e.g. by 10%) for advanced buildings only, larger energy savings can be reached under that scenario in the given timeframe. And therefore, the total cumulative energy cost savings increase as well. On the other hand, the higher the specific energy consumption for advanced buildings (by 10%, 25%, 50% and 100%), the lower the energy savings and the lower the total cumulative energy cost savings. With the decreasing total cumulative energy cost savings the cost-effectiveness is also decreasing, or rather is reached later than under default situation.

As the Deep scenario is cost-effective for all regions, increasing specific energy consumption of advanced buildings only delays reaching the cost-effectiveness. However, the results show that even if the specific energy consumption of the advanced buildings is doubled, Deep scenario remains cost-effective for the four major regions (Figure 44), as well as the World (Figure 46). This means that the results are valid for a wide array of energy performances of the advanced buildings (and thus, their definitions).

The EU-27 is the only region, where the Moderate efficiency scenario is cost-effective for all variations of the variable, and remains cost-effective even if the specific energy consumption of advanced buildings is doubled (Figure 45). All other major regions do not show any change (as compared to default) due to the fact that there are no advanced buildings under the Moderate scenario in these regions. The World’s total cumulative energy cost savings do change due to the changes in Europe, however, the change is not significant.

The changes in specific energy consumption of the advanced buildings do influence the total cumulative energy cost savings, however, these changes do not have a significant impact on the overall cost-effectiveness of either of the four major regions or the World. The influence is most significant in China and India, where large deployment of advanced buildings is expected under the Deep efficiency scenario within the analysed timeframe.

Figure 44 Total cumulative energy cost savings for varying specific energy consumption (kWh/m²/a) as compared to total cumulative additional investment costs, 4 regions, Deep efficiency scenario

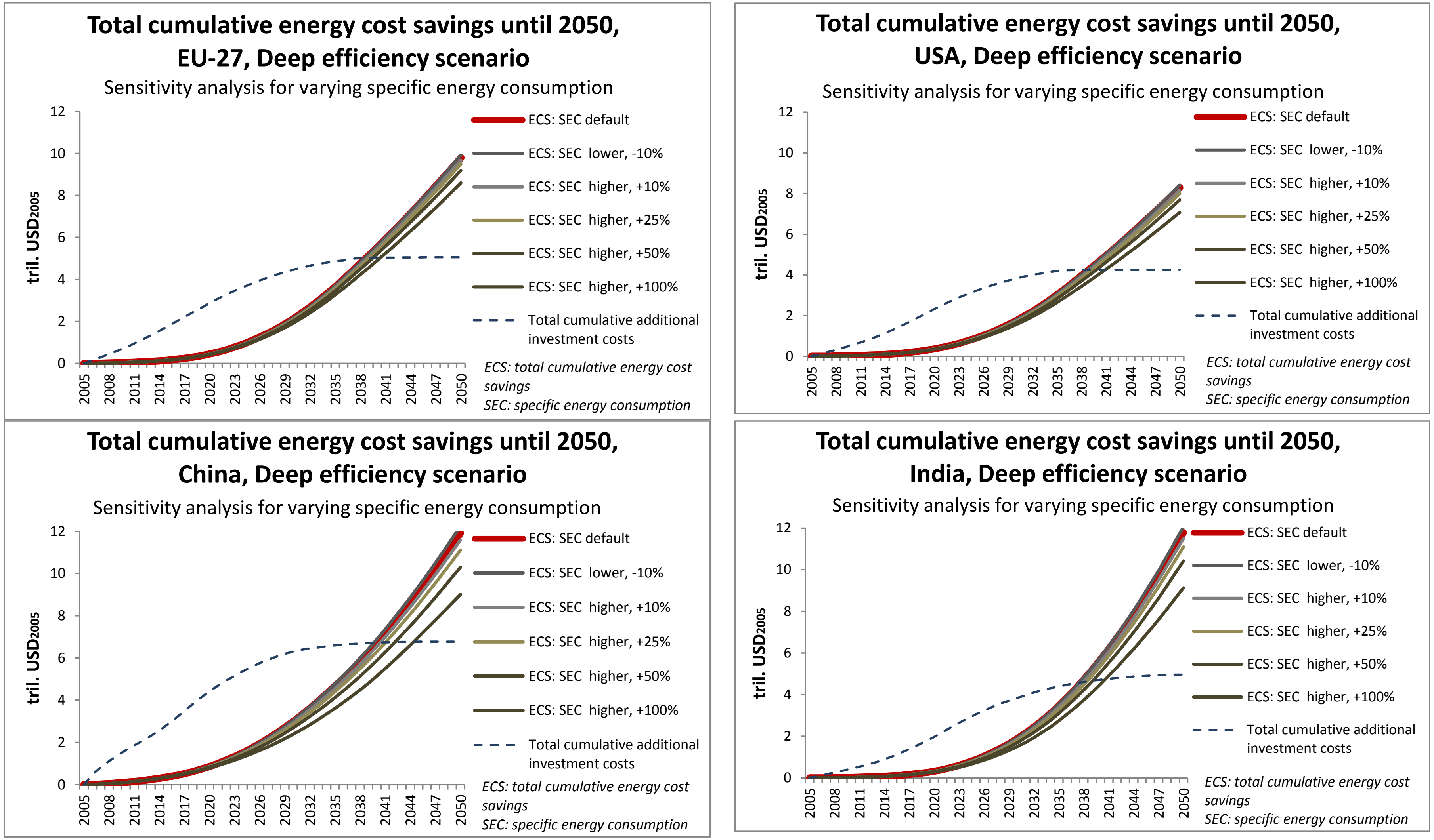


Figure 45 Total cumulative energy cost savings for varying specific energy consumption (kWh/m$^2$/a) as compared to total cumulative additional investment costs, 4 regions, Moderate efficiency scenario

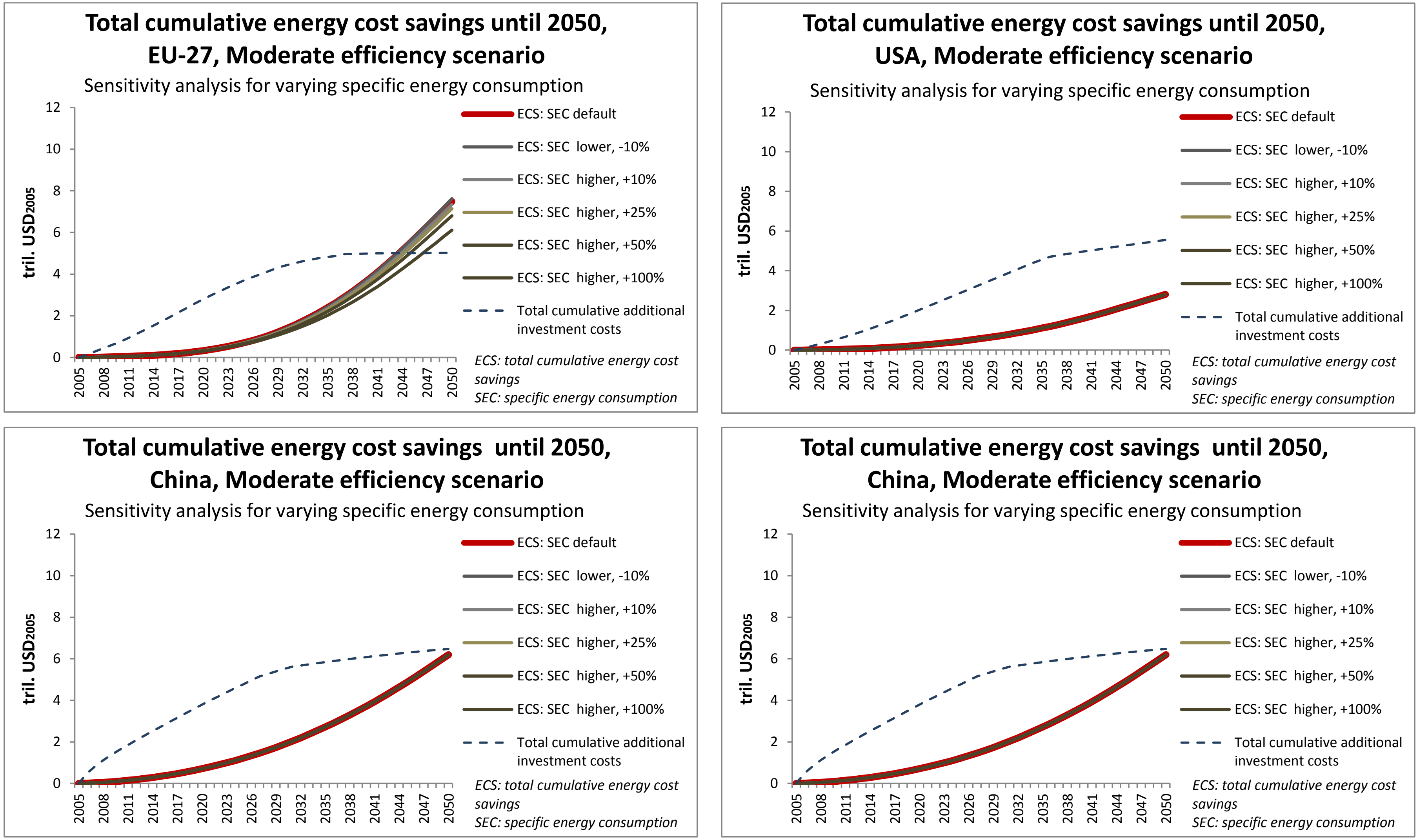
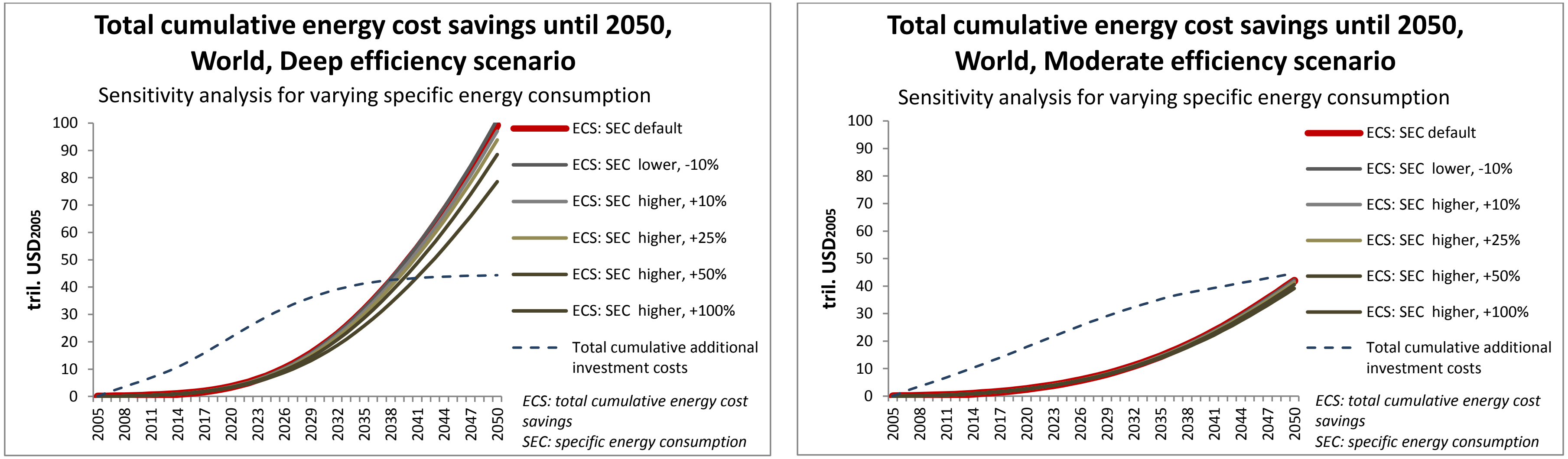


Figure 46 Total cumulative energy cost savings for varying specific energy consumption (kWh/m²/a) as compared to total cumulative additional investment costs, World, Deep and Moderate efficiency scenarios



## 10.4 Energy prices

Energy prices are the second variable chosen for sensitivity analysis of the total cumulative energy cost savings. While the energy prices increase to a larger extent, the cost-effectiveness of the scenario should improves. As this variable influences the total cumulative energy cost savings in a direct way, the % change in energy prices directly translates into the change of the total cumulative energy cost savings of the same extent. The sensitivity analysis includes an increase of currently used energy price level by 30% and 70% as well as a decrease of -30% and -70% as compared to the currently used energy price level.

Under the Deep efficiency scenario none of the four major regions, nor the World remain cost-effective for all variations of energy prices (Figure 47, Figure 49). All major regions, as well as the World, are cost-effective for all factors of change in energy price level except for the decrease of 70% in energy prices. That means that investments into energy efficiency improvements in buildings are economically feasible provided that the energy price levels do not fall significantly (by 70% as compared to the default price level).

Under the Moderate efficiency scenario most of the regions are or become cost-effective with the increase in energy prices. The USA is the only region, where the Moderate scenario is not cost-effective even if the energy prices increase by 70% as compared to the default energy price level (Figure 48). On the other hand, for the EU-27 and India Moderate scenario is cost-effective already in default, so with the increase in energy price level the scenario becomes cost-effective sooner than under default conditions. However, for EU-27 Deep scenario may become non cost-effective if the energy prices decrease by 70% as compared to their default level. For India the conditions of the default must be maintained in order to remain cost-effective. China as well as the World (Figure 49), which are not cost-effective by default, become cost-effective only when the energy prices are increased by 30% of the current projected values.

Figure 47 Total cumulative energy cost savings for varying energy prices as compared to total cumulative additional investment costs, 4 regions, Deep efficiency scenario

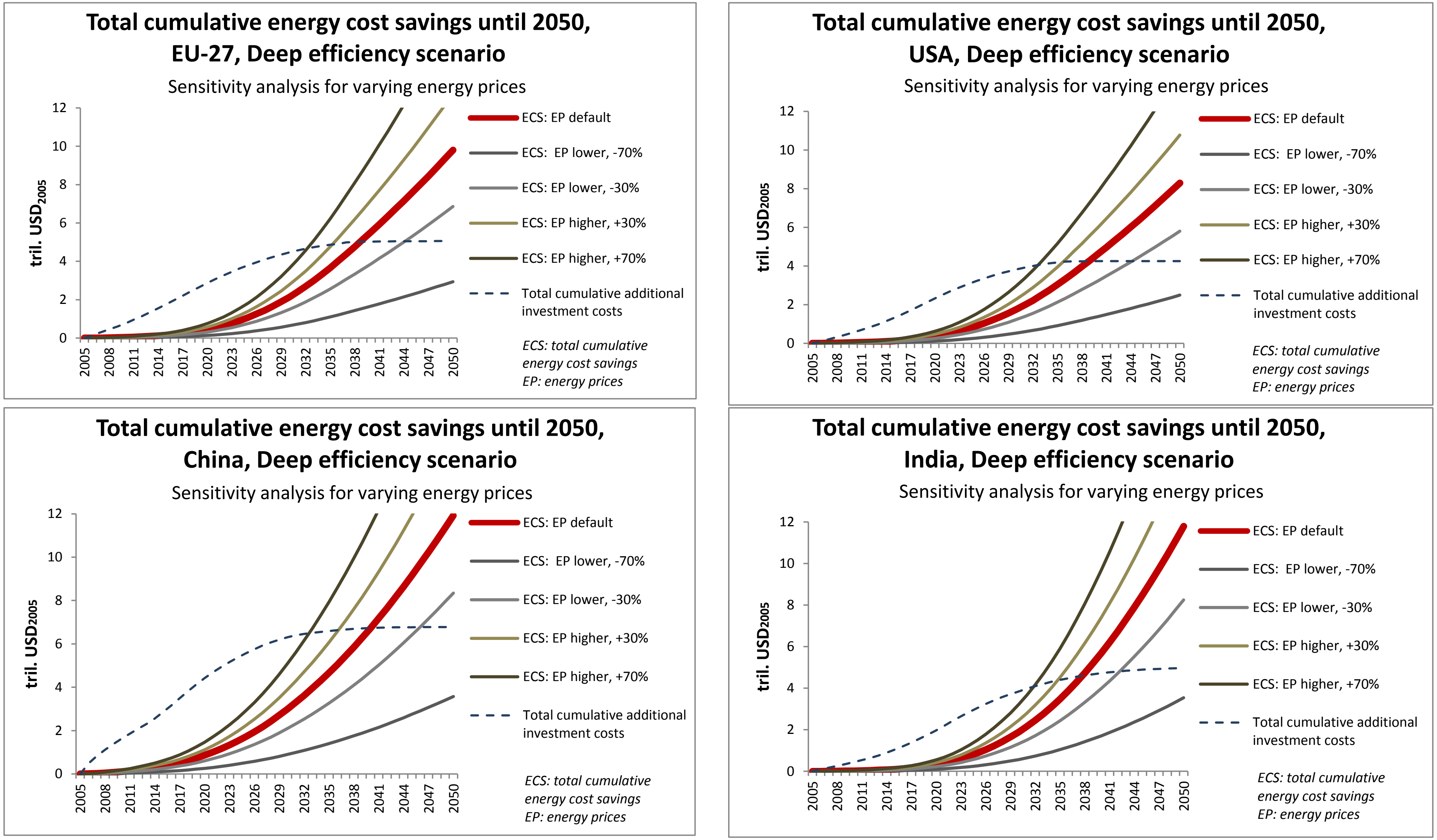
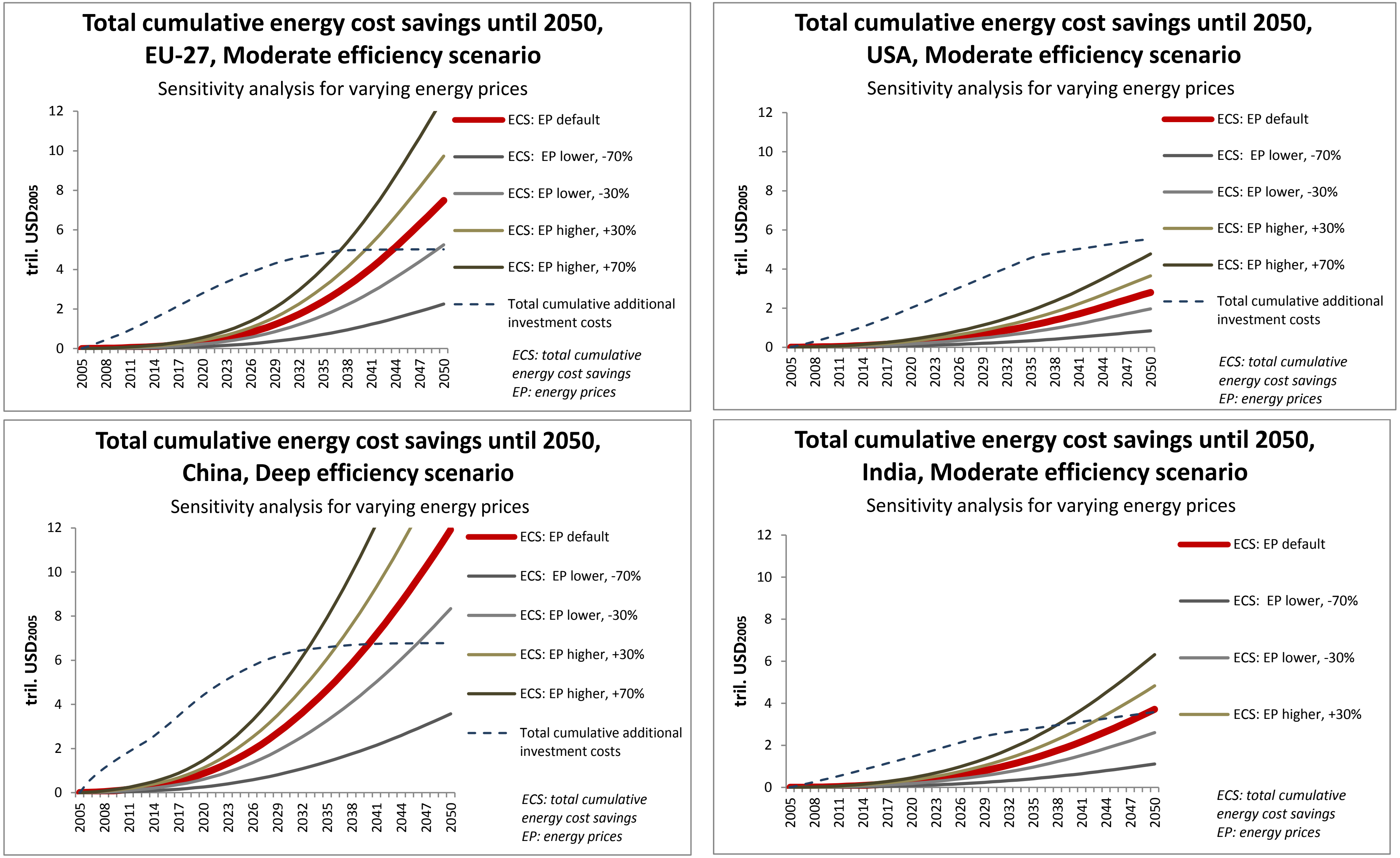


Figure 48 Total cumulative energy cost savings for varying energy prices as compared to total cumulative additional investment costs, 4 regions, Moderate scenario



Total cumulative energy cost savings until 2050, EU-27, Moderate efficiency scenario

Sensitivity analysis for varying energy prices

Total cumulative energy cost savings until 2050, USA, Moderate efficiency scenario

Sensitivity analysis for varying energy prices

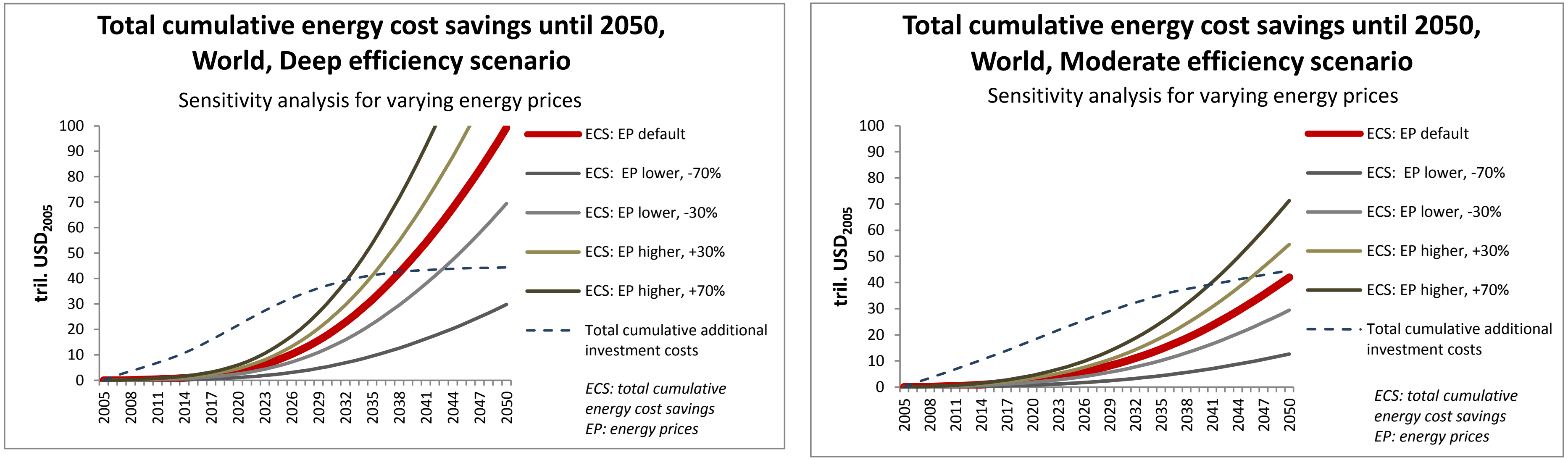
Total cumulative energy cost savings until 2050, China, Deep efficiency scenario

Sensitivity analysis for varying energy prices

Total cumulative energy cost savings until 2050, India, Moderate efficiency scenario

Sensitivity analysis for varying energy prices

Figure 49 Total cumulative energy cost savings for varying energy price as compared to total cumulative additional investment costs, World, Deep and Moderate scenario



# CHAPTER 11: CONCLUSIONS AND RECOMMENDATIONS

The aim of the presented study was to analyze the costs and benefits of selected building energy consumption scenarios developed by previous research on behalf of GBPN (Ürge-Vorsatz et al. 2012b). To fulfill this aim, two objectives were set: 1. to calculate the total cumulative additional investments needed by 2050 for the Moderate and Deep efficiency scenarios, and 2. to calculate the total cumulative energy cost savings by 2050 for the Moderate and Deep efficiency scenarios.

The aim of the study was achieved through developing a Cost analysis module (Module 2) of the 3CSEP HEB Model (Center for Climate Change and Sustainable Energy Policy High Efficiency Buildings Model), which uses data based on a thorough data collection for the four major world regions, and their major climate zones for the different analyzed building types and vintages. Similarly to that of the Scenario analysis module (Module 1) of the 3CSEP HEB model, the pillar of modeling logic, are best-practices. The model assumes that those protypes that represent best-practice will (be) proliferate(d)- not only in terms of energy performance, but also from the cost perspective. The data collection extended to the construction costs of advanced buildings (best-practices), as well as to those of conventional ones. As another important input into the calculation, the floor area, stems from the first module of the 3CSEP HEB model. The results of the calculation are also influenced by an assumption of technology learning, which is crucial when advanced and newly-introduced technologies are concerned. The second objective was fulfilled through applying region-specific energy prices to energy savings, which are based on the energy consumption of the building stock under different scenarios, an output of the first module of the 3CSEP HEB model.

The results of the cost analysis show that for all four major regions (EU-27, USA, China and India), as well as for the World as a whole, the total cumulative energy cost savings under the Deep efficiency scenario exceed the total cumulative additional investment costs (see Table 38 and Figure 51).

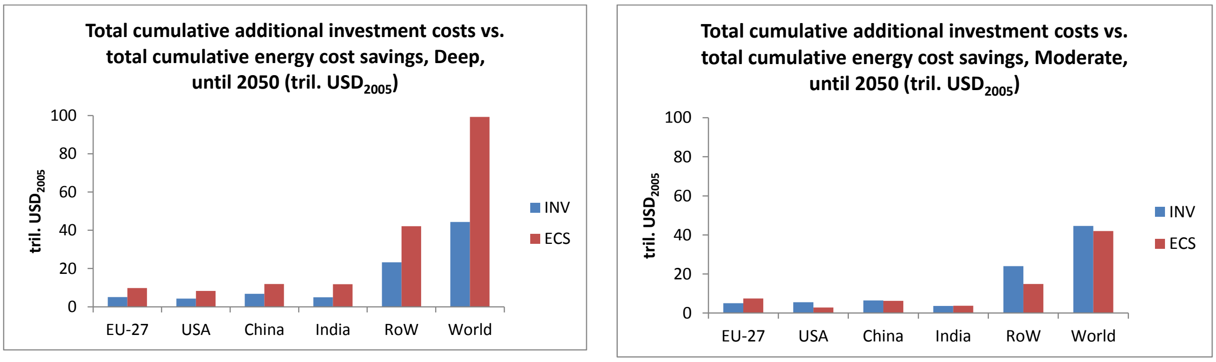
Table 38 Total cumulative additional investment costs vs. total cumulative energy cost savings until 2050

| | **Deep efficiency scenario** | | **Moderate efficiency scenario** | |
|---|---|---|---|---|
| | Total cumulative additional investment costs | Total cumulative energy cost savings | Total cumulative additional investment costs | Total cumulative energy cost savings |
| **Region** | tril. $USD_{2005}$ | tril. $USD_{2005}$ | tril. $USD_{2005}$ | tril. $USD_{2005}$ |
| **EU-27** | 5.1 | 9.8 | 5.0 | 7.5 |
| **USA** | 4.3 | 8.3 | 5. 6 | 2.8 |
| **China** | 6.8 | 11.9 | 6.5 | 6.2 |
| **India** | 5.0 | 11.8 | 3.6 | 3.7 |
| **RoW** | 23.3 | 42.2 | 24.00 | 14.8 |
| **World** | 44.3 | 99.2 | 44.6 | 42.0 |

*Note:* * The region World is not a simple sum of the four major regions and RoW region, but rather a sum of the 11 world regions. Therefore there are differences in World and sum of the four major regions.

On the other hand, under the Moderate efficiency scenario, in most of the regions (except for EU-27) the total cumulative additional investment costs exceed the total cumulative energy cost savings achieved through such investment. The moderate efficiency scenario shows cost-effectiveness for all building types only in the EU-27, which is the only major region where advanced buildings are expected in this scenario. In India, two out of three building types are cost-effective under the Moderate scenario.

Figure 50 Total cumulative additional investment costs vs. total cumulative energy cost savings until 2050 under the Deep and Moderate efficiency scenario



*Note*: INV – total cumulative additional investment costs; ECS - total cumulative energy cost savings

In the rest of the world region (World except for EU-27, USA, China and India) Deep efficiency scenario is cost-effective, as contrary to the Moderate efficiency scenario (which is not cost-effective for any of the building types in RoW). Similarly, the Deep efficiency scenario is cost-effective for the global total building stock, while the Moderate efficiency scenario is not (however, it is cost-effective for MF).

In summary, the results show that in the long term, unlike the Moderate efficiency scenario, the Deep efficiency scenario is cost-effective for the four major world regions, as well as for the whole World. The results also show that the Deep efficiency scenario is more cost-effective than the Moderate efficiency scenario in those cases where the Moderate efficiency scenario is also cost-effective.

When these results are compared to those of similar studies assessing the costs of a low-energy transformation in the building sector, the findings of the cost analysis of the 3CSEP HEB Model in most cases present trends similar to other studies, with certain differences in the absolute values. While the results of the current study for total cumulative energy cost savings are at the same level of magnitude as those of the other relevant studies, the total cumulative additional investment costs calculated in the current study are several times higher than the results of other relevant studies (especially GEA described in Ürge-Vorsatz et al. 2011 and BPIE 2011). This difference in total investment needs can be explained by much lower additional specific investment costs used in other relevant studies (e.g. in BPIE 2011) as compared to the current study and higher learning factor (a learning factor of approx. 60% of the 2005 marginal costs is used in GEA). The authors of this report consider the findings of this report rather robust, as their estimations are based on a thorough data collection for different climate zones, regions, building types and vintages, carefully elaborated cost transfer methodology and profound multiple-expert reviews. These efforts constitute the major value added of this study in the research area as compared to previous work.

Nevertheless, a large deviation can be seen between the results of the GEA and those of the current study for India, especially for the level of energy cost savings, which implies that further data collection and verification is still necessary especially in this region. Moreover, further data collection would be beneficial for those regions that depend heavily on cost transfer rather than primary data collection (China and partially also for some building vintages in the USA).

Sensitivity analysis in this research is especially important due to the major input data challenges, especially with regard to construction and retrofit costs. The aim of the sensitivity analysis was to show how variations in different input variables influenced the overall results of the cost analysis, and which variables have a significant impact on the cost-effectiveness of the two scenarios. The sensitivity analysis underpinned that the key findings of this report are robust: the Deep scenario is cost-effective for all world regions even when larger variations from presently-used input data and assumptions are considered, and remain more cost-effective than the Moderate scenario. More concretely, the results show that changes in the examined key input variables in general do not significantly influence the status of cost-effectiveness of the two scenarios for the World as a whole. However, after larger changes in certain variables in some regions, the Deep scenario may no longer be cost-effective. This occurs when energy prices fall significantly (hypothetically, if energy prices decrease by 70% lower than in the default values assumed, a deep building energy transition is no longer cost-effective in the EU-27, China, USA and the World), or when specific investment costs do not decrease enough due to an insufficiently low learning factor (when specific investment costs of the advanced buildings decrease only by 15% by 2050 as compared to their 2005 value, i.e. if the learning factor was only 15% as opposed to the default of 50%, the Deep scenario is no longer cost-effective in the USA).

The cost-effectiveness in the Deep scenario does not change for any region even if the specific investment costs (both costs of advanced buildings and costs of conventional buildings) increase by 50%. An increase in specific energy consumption does not have a significant influence on cost-effectiveness, as the change in this variable is only applied to advanced buildings. Although advanced buildings do constitute a large share of the future building stock by 2050, the change of the already rather low specific energy consumption of advanced buildings is not significant enough to change the cost-effectiveness of the scenario in a given region. This implies that the results are robust for a wide range of values for specific energy consumption of advanced buildings. A change in specific energy consumption triggers the most significant impact in China and India, where a large number of advanced buildings is expected by 2050.

On the other hand, the results show that cost-effectiveness can be reached under certain circumstances even under the Moderate efficiency scenario in some regions - for example this scenario can become cost-effective in China, India and the World provided energy prices increase by at least 30% of their currently projected level- by 2050. Similarly, this scenario may become cost-effective in China, and the World if specific investment costs decrease by at least 25%, and in the USA with the decrease of at least 50% of the specific investment costs.

Based on the sensitivity analysis, we can summarize that overall the key findings are very robust; the key messages do not change even in the case of significant variations in the key input parameters. The variables with the most significant impact on the results and overall cost-effectiveness are energy prices and the learning factor. Thus, these are important variables that need to be taken into account when interpreting the results of the current study.

These sensitivity analysis results may also have important policy implications. For instance if a long-term deep building energy transformation strategy is to be implemented, eliminating distorting energy price subsidies and reforming of social energy payments are important parts of such a strategy; jointly with a concerted effort at catalyzing technology learning, i.e. a deployment/market transformation strategy that ensures a continuous improvement of the materials, technologies and know-how underpinning deep retrofits and very low-energy construction. This is because the cost-effectiveness of the pathway is very sensitive to the energy price, i.e. distortions such as subsidies and social payments will jeopardise the cost-effectiveness, i.e. the feasibility of such pathways. Equally, as the cost-effectiveness depends very strongly on the rate of technology learning, policies to encourage this learning process strongly catalise the cost-effectiveness of the patyway; while changes in other parameters as compared to our assumed values, such as the achievable performance levels, affect the overall outcomes and main messages to a smaller degree if at all.

## 11.1 Recommendations

The results of the study show that from a long-term perspective it is societally much more cost-effective to invest into the higher proliferation of advanced construction and retrofits rather than a pathway focusing on accelerated investment into retrofit and/or new construction without ambitious energy efficiency requirements. This is valid for both developed countries, where the main focus should be made on retrofit, as well as for emerging economies and developing countries, where significant volumes of new buildings are added every year. Therefore, among other actions, implementation of building codes with very ambitious energy performance mandates for new construction and their strong enforcement are necessary in the developing and emerging regions. As in China both new and retrofit are expected to be important vintages in terms of their share in the Chinese 2050 building stock, in the long term well designed building codes need to be developed also for retrofit buildings. Such building codes with the strong requirements for the building energy performance after renovation will be very important especially for the developed world, where the share of retrofit buildings is significant in the total building area, and should be complemented by the introduction of the necessary financing structures and other incentivizing measures.

The analysis highlights the importance of a long-term perspective, despite all uncertainties that such foresight may mean, in order to have a comprehensive overview of the financial costs and benefits of alternative pathways in the building sector. The reason is that buildings are structures with long lifetimes, and the full benefit of the advanced measures can only be seen after several decades of a building's operation. The Deep scenario crosses the payback threshold between 2030-2040 in most of the examined regions , i.e. beyond the 2030 framework, which is often used for analysis of energy savings potential in buildings.

The results of the study show that the Deep efficiency scenario creates much higher benefits, and can even have lower investment costs than the Moderate scenario due to the technology learning of advanced buildings. Thus, in order to avoid the risk of the "lock-in effect", the governments are recommended to first develop a strategy to increase the ambition of the minimum requirements for new construction and retrofit towards advanced energy performance levels. Only then it is advisable to introduce financial mechanisms or policies to accelerate retrofit rates (where applicable) supporting the deployment of advanced retrofits on a large scale. This is important as it is usually the financial mechanisms with low energy savings requirements that lead to the acceleration of "shallow" retrofits (i.e. retrofits with low or no energy savings, such as under the Moderate efficiency scenario). These mechanisms, without a long-term framework strategy and progressive improvement of energy performance requirements as a condition for provision of the support, will inevitably lead to a significant "lock-in effect", when a significant portion of the building's energy consumption, and thus, related emissions, are locked-in for several decades until the next round of renovation becomes timely.[27]

Another important factor crucial to realize the full energy efficiency potential that a long-term strategy and ambitious minimum requirements may bring is education and training. The extent and rate of deployment of advanced buildings depends both on the availability of high efficiency building elements and the preparedness of the construction industry. Therefore, it is recommended that governments ensure that all professionals involved in the construction process of advanced buildings (such as architects, planners, engineers, equipment installers, craftsmen, building inspectors, energy auditors, and site managers) have access to the necessary information, education and (re)training so that advanced buildings can be deployed at a large scale.

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[27] The renovation cycle lasts usually between 30-40 years in the OECD countries according to Laustsen (2008), but can be longer in countries with long period of building stock depreciation (Csoknyai 2009 in Korytarova 2010).

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GBPN
Global Buildings Performance Network

9 rue du Quatre Septembre
75002 Paris
France

+33 (0)1 70 98 31 30
info@gbpn.org

**www.gbpn.org**
**@GBPNetwork**

**About GBPN** The Global Buildings Performance Network (GBPN) is a globally organised and regionally focused network whose mission is to advance best-practice policies that can significantly reduce energy consumption and associated $CO_2$ emissions from buildings.