How much can sustainable buildings help the climate?

A global building thermal energy model

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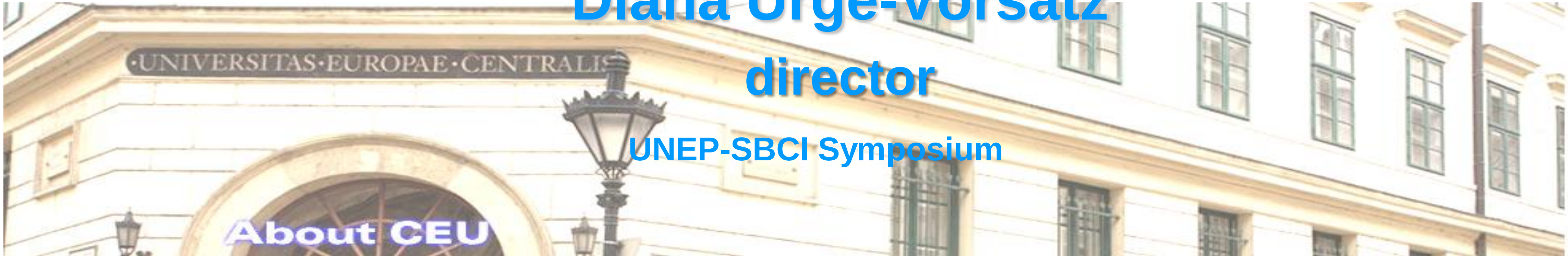
Diana Ürge-Vorsatz
director

UNEP-SBCI Symposium



Overview

- Background: the Global Energy Assessment and its scenarios
- The fundamentals of the GEA-SBCI-3CSEP building energy use scenarios
- Results:
  - how far *can* buildings take us?
  - And how far will they take us if we compromise? i.e. how far will they not allow us to go further? => the lock-in effect
- Conclusions

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www.GlobalEnergyAssessment.org

Background: the Global Energy Assessment and its scenarios

IIASA

International Institute for Applied Systems Analysis

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www.GlobalEnergyAssessment.org
Towards a more Sustainable Future

- Energy problems are broader than just climate change: access, development, poverty, security, environment, health – all key problems
- CC is well assessed but without in isolation from related issues
- GEA Initiated in 2006 and involves >300 CLAs and LAs and >200 Anonymous Reviewers
- Final report (Cambridge Univ. Press) in June 2011;(pre-)release at the Vienna Energy Forum with 64 Energy Ministers confirmed

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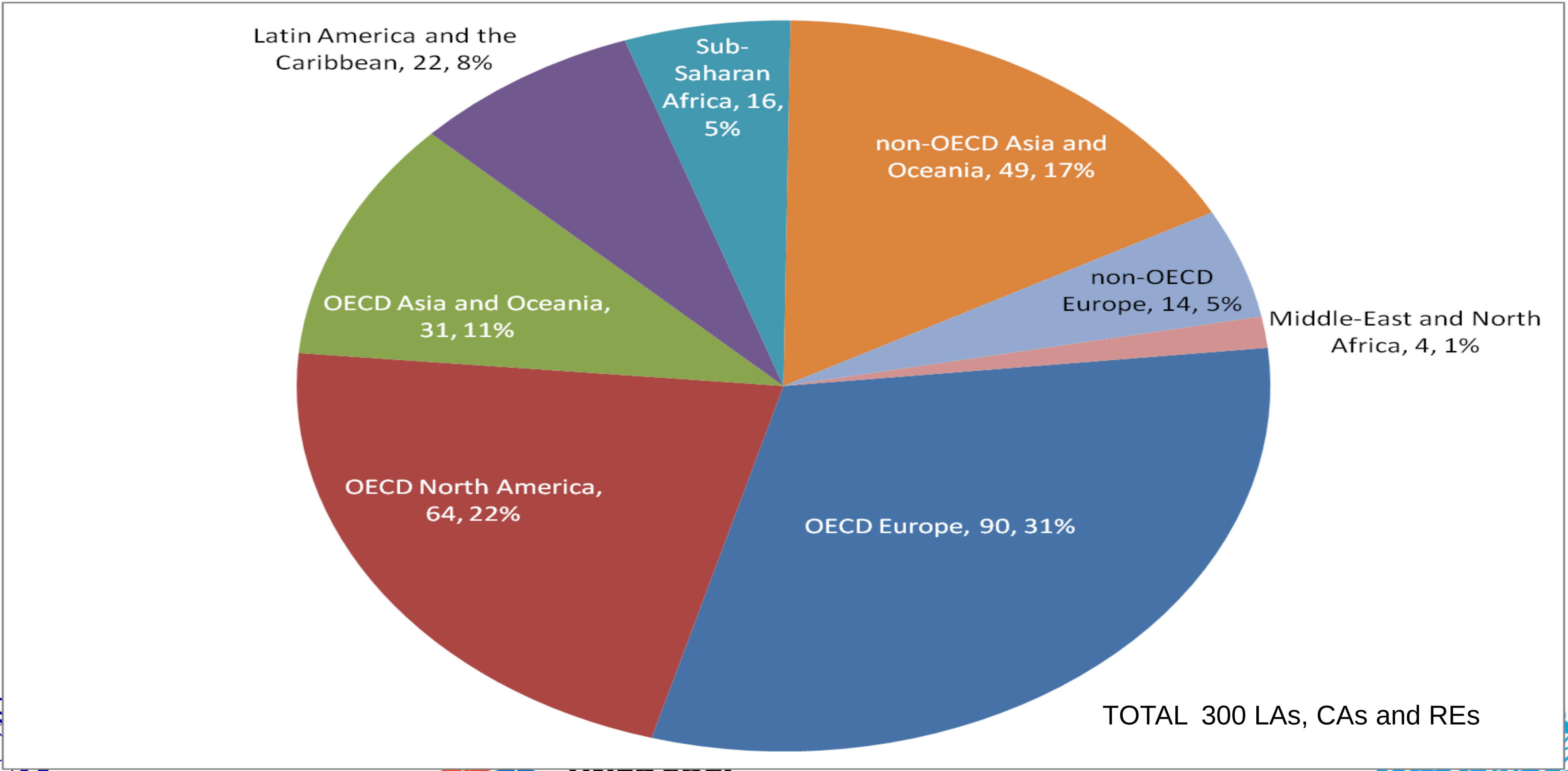
All Analysts and Executive Committee



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The GEA pathways

- All meet the GEA objectives
  - On access, security, environment, climate change, health and development
- Demonstrate the feasibility of the multiple pathways towards the transformative change that is needed
- The novel philosophy is of transformative change vs. incrementalism (e.g. no baseline)
- Integrates end-use sector models closely
- building model created by 3CSEP (CEU), in collaboration with UNEP SBCI

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GEA – SBCI – 3CSEP Model design

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Approach, methodology, assumptions and data

A novel approach to global building energy modeling

- Considers buildings as complete systems rather than sums of components
- Recognizes that
  - state-of-the-art building energy performance can be achieved through a broad variety of designs and component combinations
  - Systemic gains are important when buildings are optimised to very high energy performance, not typically captured by modeling buildings by components
- Assumes that existing best practices become the standard (both in new construction AND renovation) after a certain transition time
- Costs also follow best practice philosophy rather than averages

Energy Use Calculation

$$\text{Final Energy} = \sum_{i=1}^{11}\sum_{j=1}^{3}\sum_{k=1}^{4}\sum_{l=1}^{5} \text{Floor Area}_{i,j,k} \times \text{Energy Intensity}_{i,j,k} \; (m^2 \times \frac{kWh}{m^2 \cdot year})$$

- Energy Calculation:
  - *i = 1 to 11 Regions*
  - *j = 1 to 3 Building Types*
  - *k = 1 to 4 Climate Zones*
  - *l = 1 to 5 Different Building Thermodynamic Classes*
- *The five Thermodynamic Classes of buildings are:*
  - *Existing*
  - *New (Built to code)*
  - *Retrofit (Built to code or 30% less than existing)*
  - *Advanced New (Best Practice for region and climate zone)*
  - *Advanced Retrofit (Best Practice for region and climate zone)*

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Scenarios Considered
Key Scenario Assumptions (1/3)

- Global 1.4% Retrofit rate
- Switch to 3.0% Retrofit rate in 2020
- All floor area is fully conditioned and 100% access to commercial energy is achieved by 2050
  - i.e. fuel poverty eliminated
- Developing countries see large increase in floor area per capita, synonymous with full development

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Detailed findings

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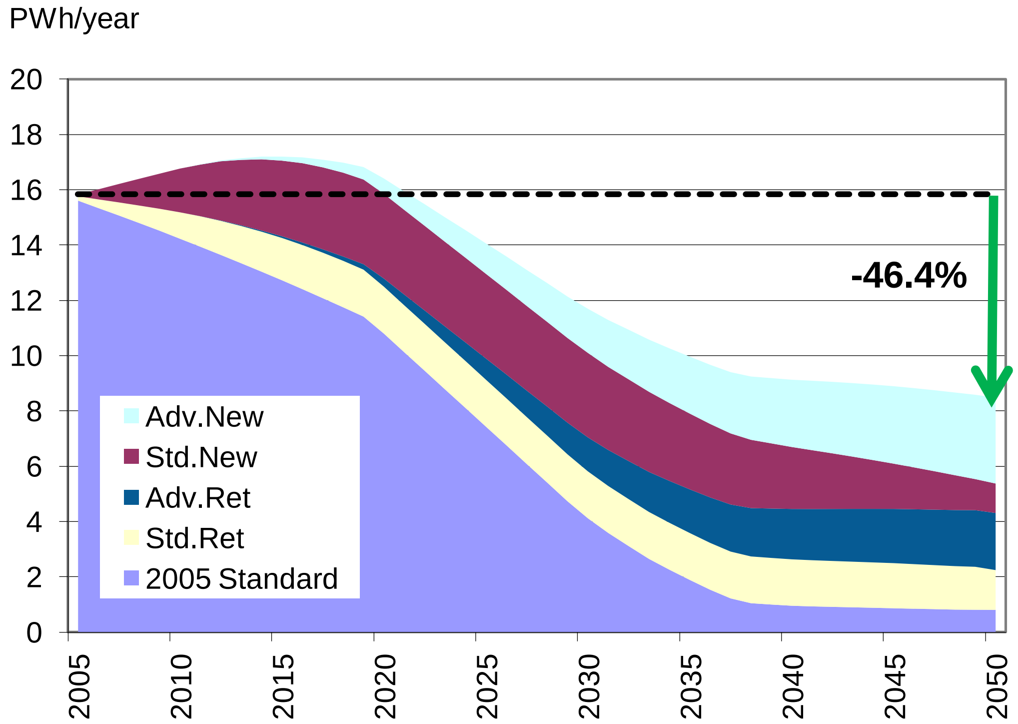
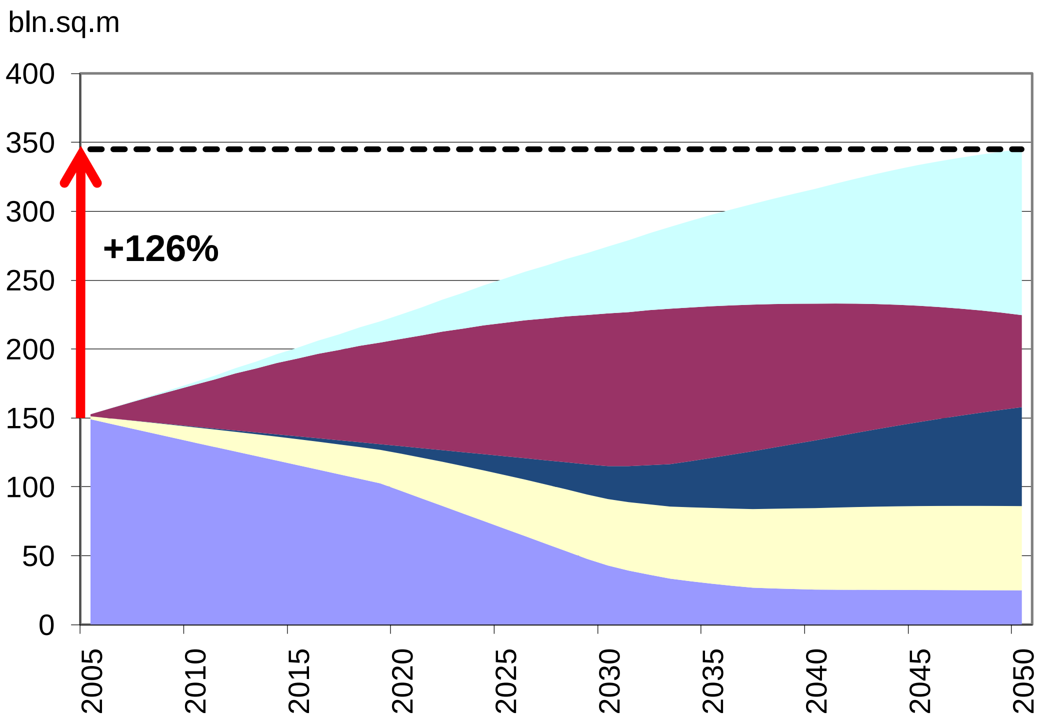
Findings of the buildings scenario exercise

State of the Art scenario: global heating&cooling energy consumption if today's best practices proliferate

Thermal Energy



Floor Area



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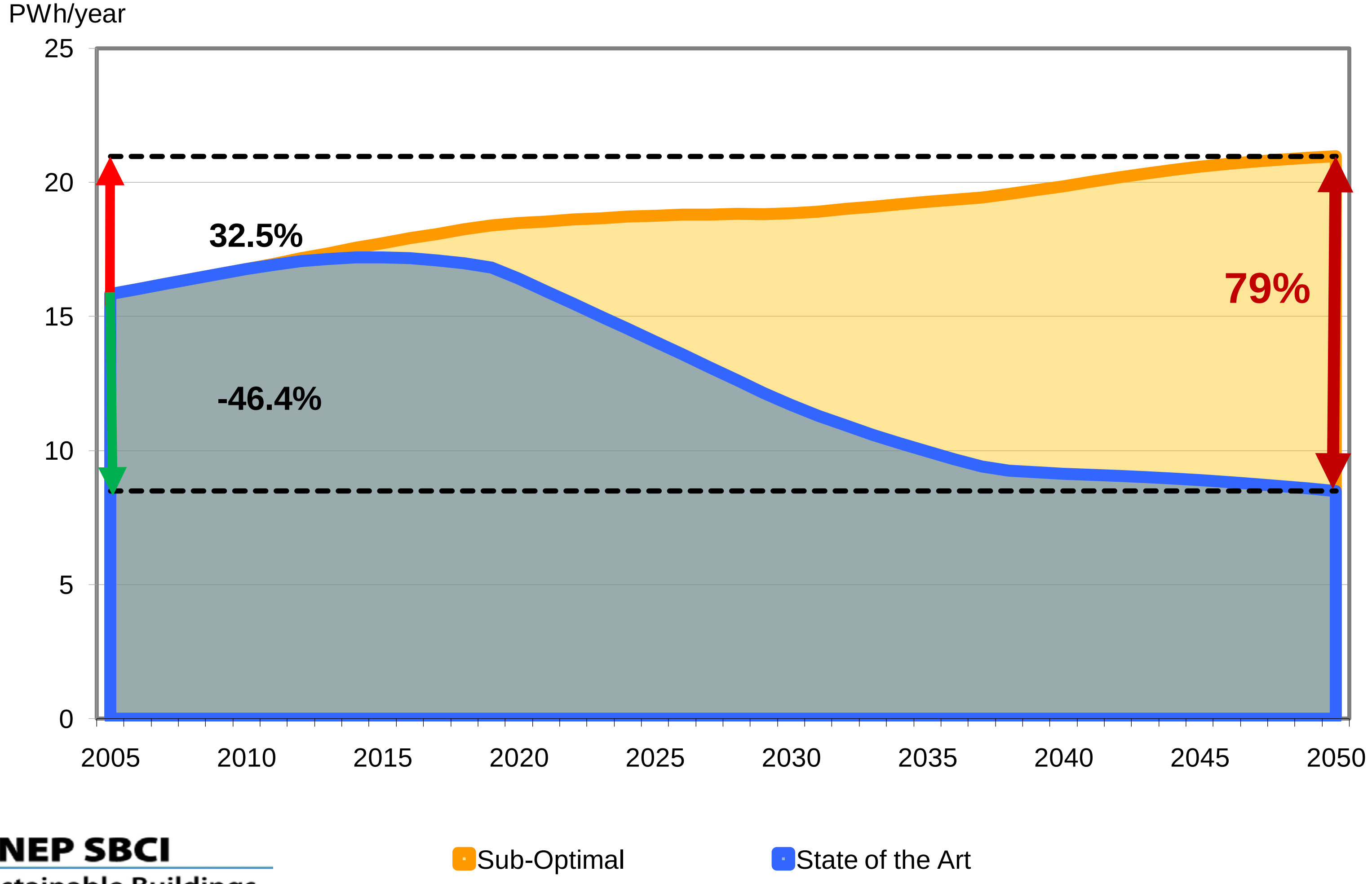
Lock-in Effect
World



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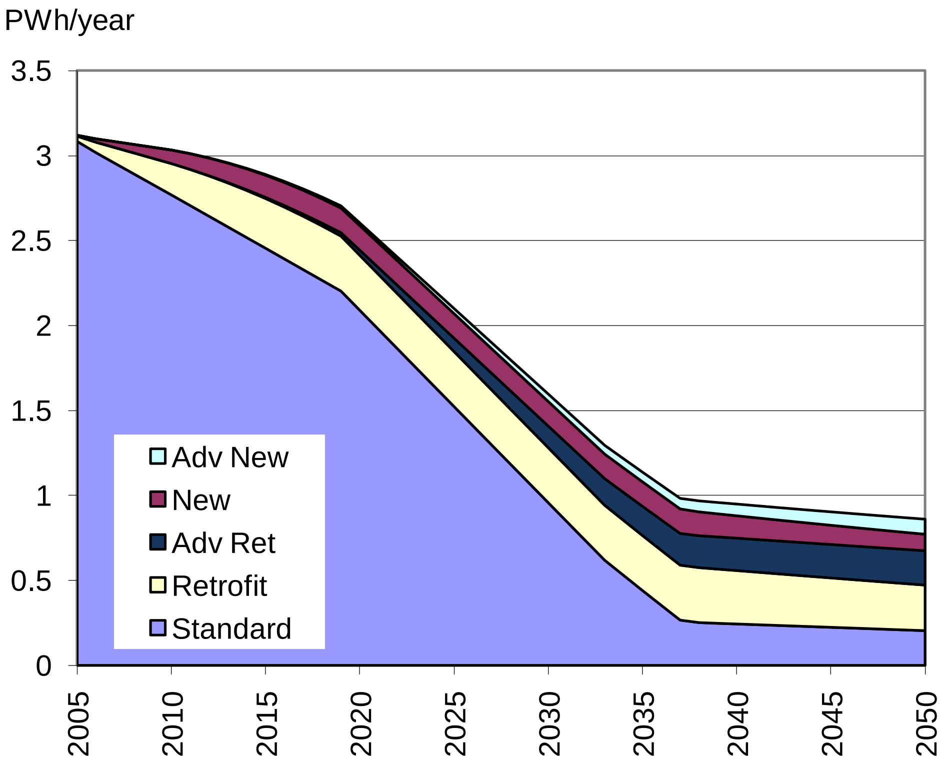
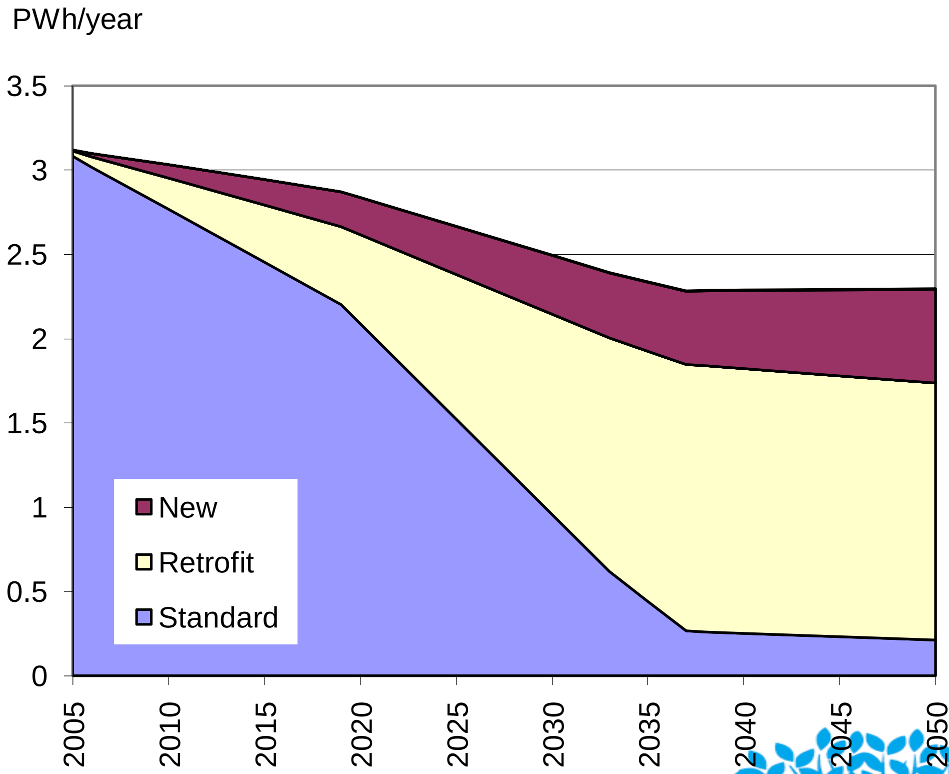
Scenario Results
Western Europe – Energy Use

State-of-the-Art Scenario



Sub-Optimal Scenario



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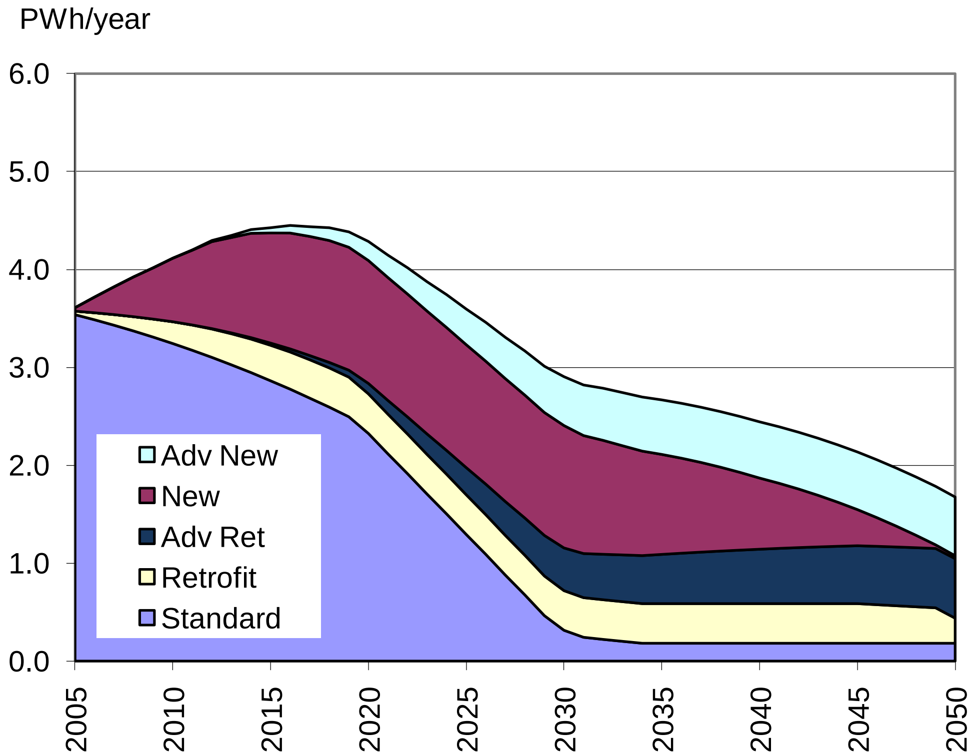
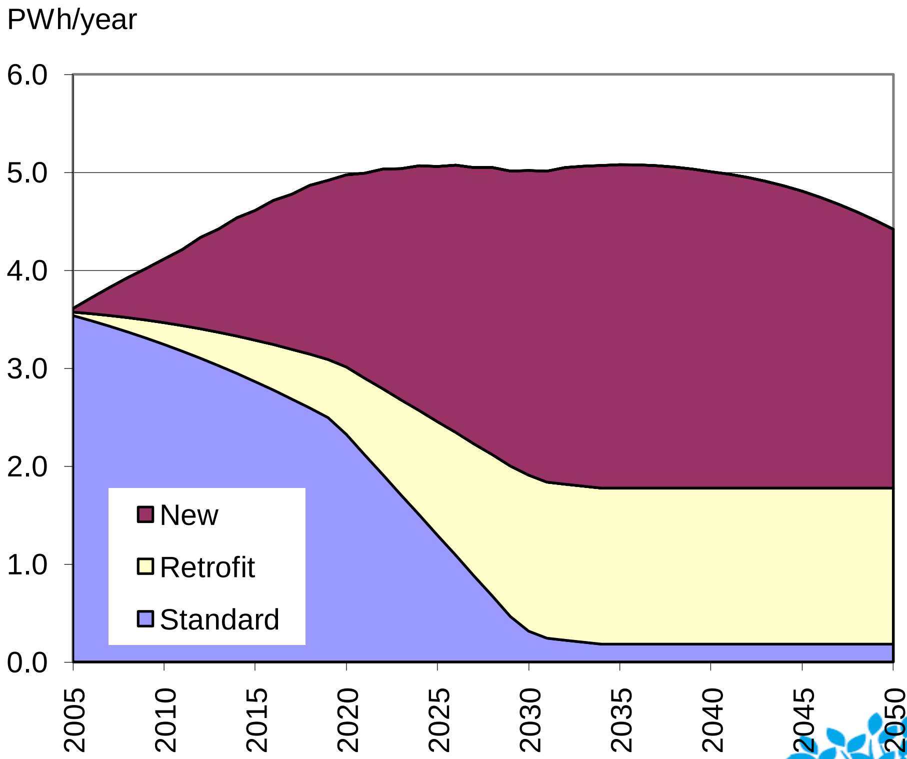
Scenario Results
Centrally Planned Asia – Energy Use

State-of-the-Art Scenario



Sub-Optimal Scenario



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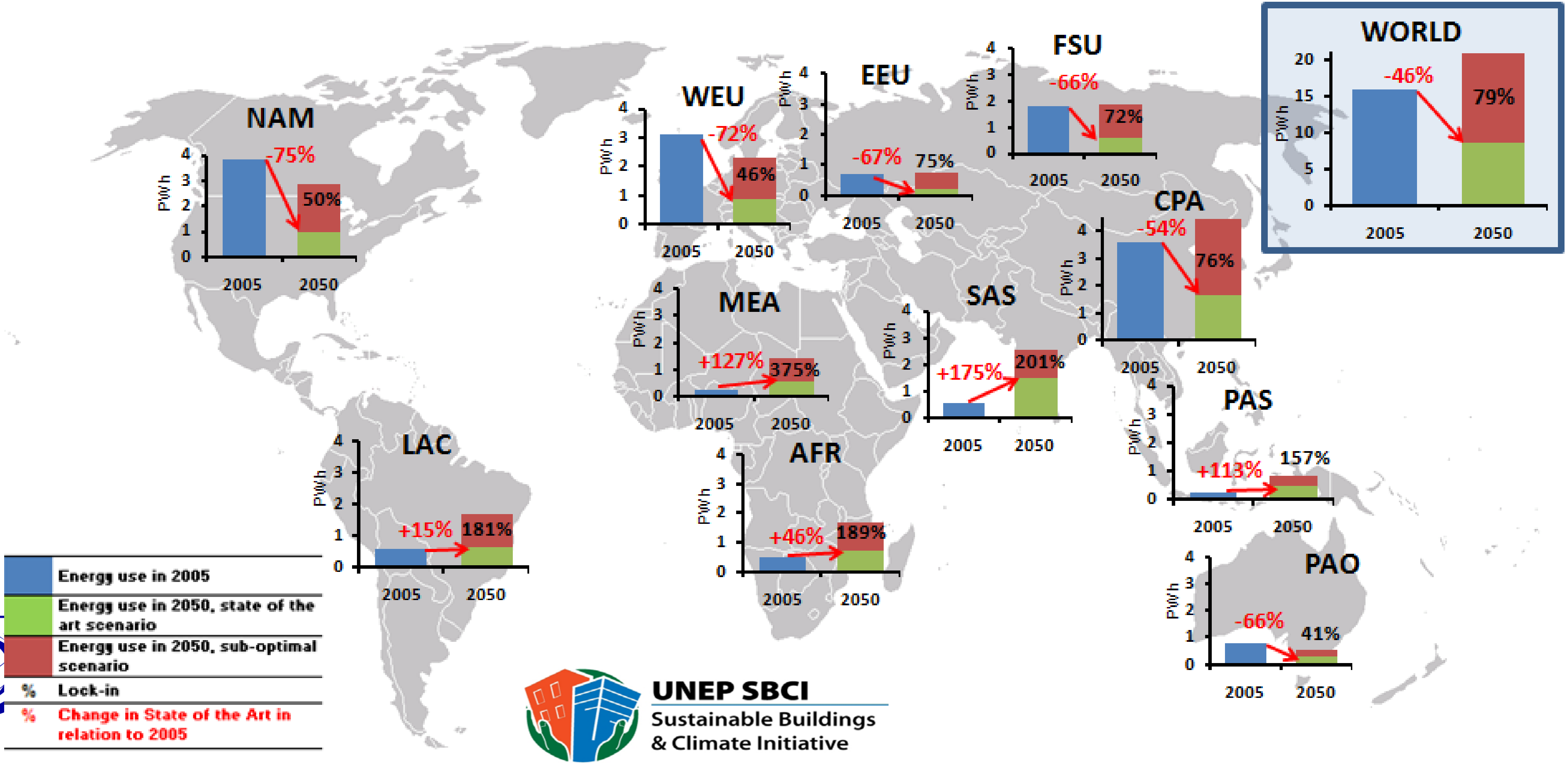
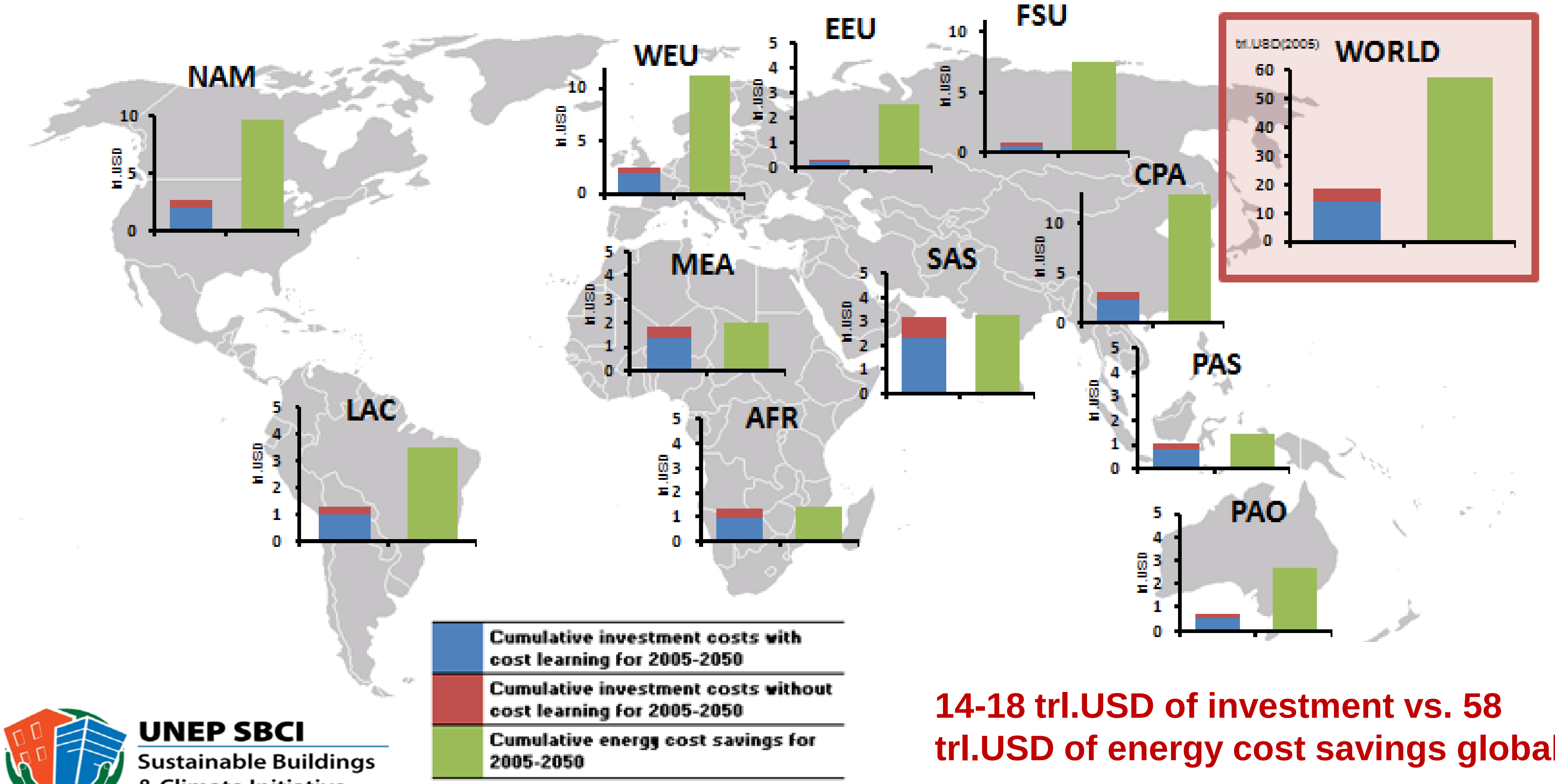
Lock-in effect and potential energy savings for different regions



Investment costs and energy cost savings for different regions



14-18 trl.USD of investment vs. 58 trl.USD of energy cost savings globally

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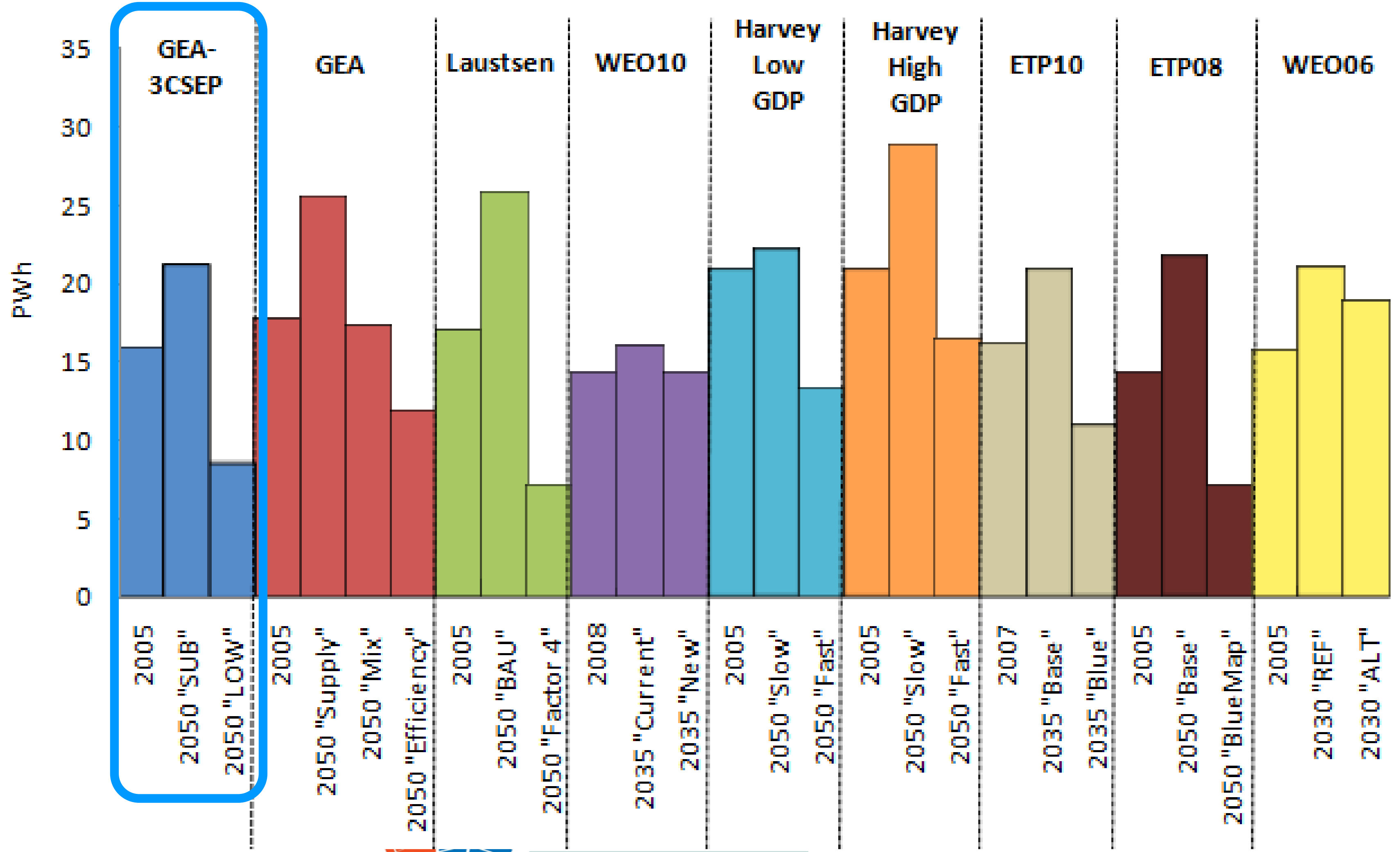
Comparison of the results to other global scenarios



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Conclusions

- If existing holistic best practices for space conditioning are implemented, it will almost halve today's final thermal energy use in buildings worldwide by 2050, which roughly corresponds to a 16-26% reduction of *total* global emissions.
- Such an energy use reduction can be achieved despite the considerable increase in floor area (app. 126%) and thermal comfort.
- Significant investments are needed: app. USD 17 trillion cumulative inv. Needs; vs. Close to 60 bln energy cost savings.
- However, there is a huge risk of locking in unnecessarily high energy consumption and thus emissions if suboptimal, piecemeal solutions are promoted
- Almost 80% of energy savings may be lost by 2050 or postponed and, consequently, climate mitigation targets are unlikely to be met.
- In dynamically developing regions what happens in the next 5 – 10 years fundamentally determines energy use in 2050 – action NOW is vital
- Thus, actions are to be taken without any further delay: the building energy revolution needs to start today

“the stone age did not end for the lack of stones….”

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Thank you for your attention

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Trust me – they just keep promising this global warming; they just keep promising; but they won't keep this promise of theirs either…

Diana Ürge-Vorsatz

Center for Climate Change and Sustainable Energy Policy (3CSEP), CEU

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Supplementary slides

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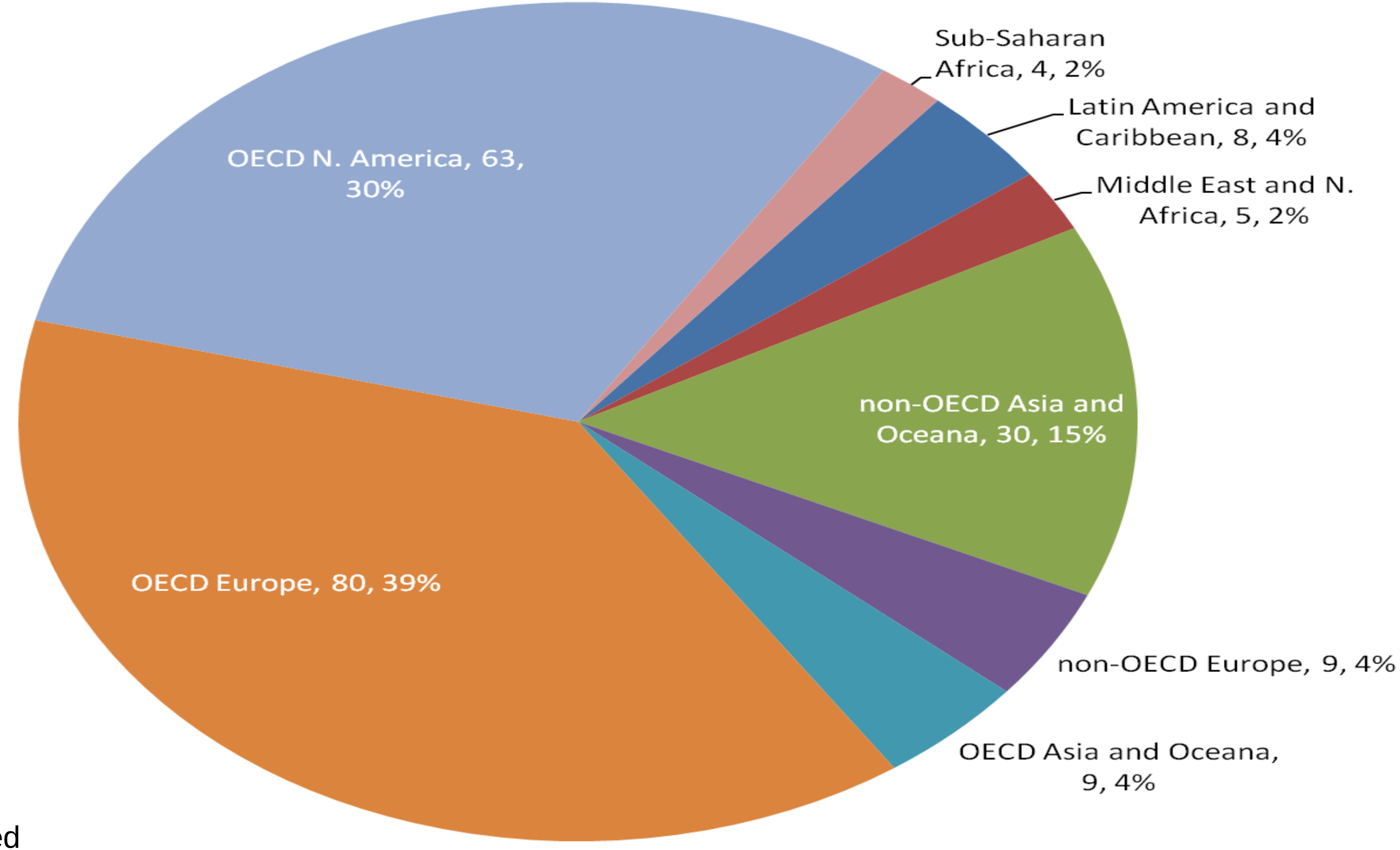
Confirmed Reviewers



TOTAL 200 confirmed

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Integration of Knowledge Clusters

- **Cluster I** characterizes nature and **magnitude** of challenges, and express them in selected indicators
- **Cluster II** reviews existing and future resource and technology **options**
- **Cluster III integrates** cluster II elements into systems, and links these to indicators from Cluster I
  - This will include energising of rural areas, land use, water, urbanisation, life-styles, etc.
  - Scenarios, using numerical models and storylines, will be used for the **integration**, in an **iterative** fashion
- **Cluster IV** assesses policy options, and specifically identifies **policy packages** that are linked to scenarios meeting the needs, again in an **iterative** fashion.

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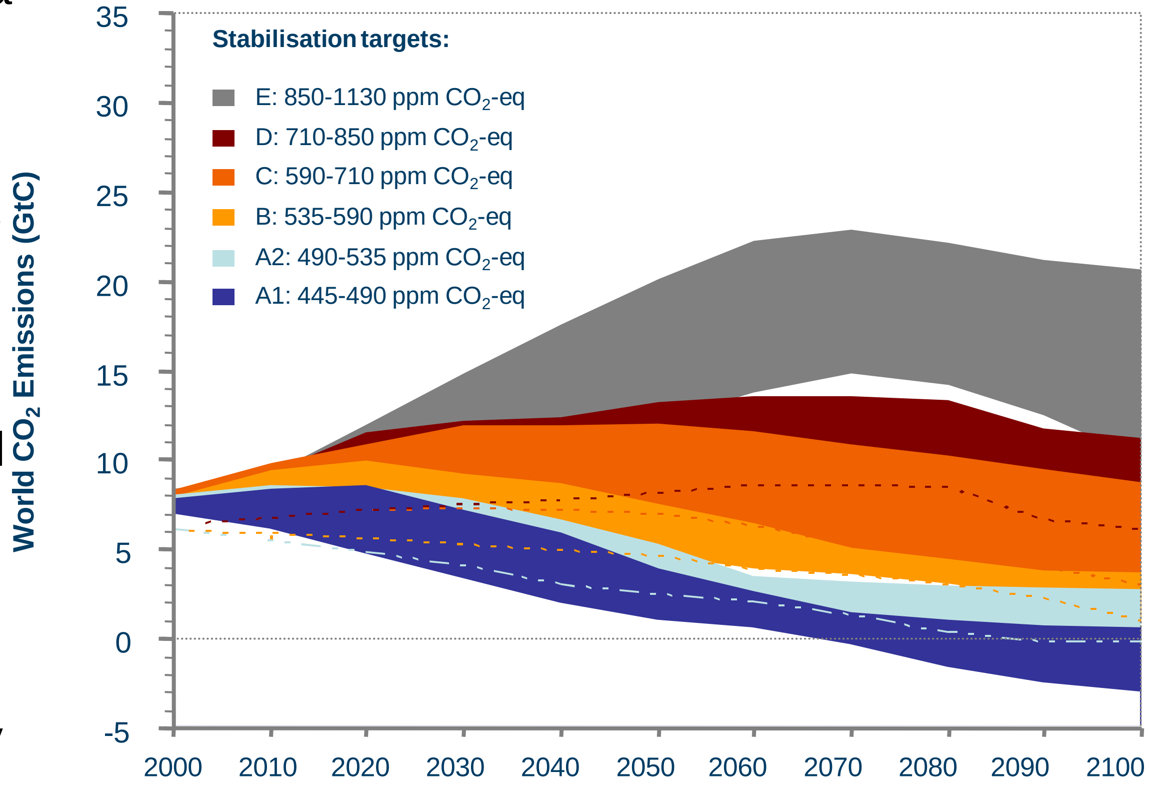
The climate change challenge

In order to limit the impacts of CC, GHG emissions have to be reduced significantly

- Stabilizing global mean temperature requires a stabilization of GHG concentrations in the atmosphere -> GHG emissions would need to peak and decline thereafter (SPM 18 WG III)
- The lower the target stabilisation level limit, the earlier global emissions have to peak.
- Limiting increase to 3.2 – 4 C requires emissions to peak by 2020-2060.
- Limiting increase to 2.8 – 3.2 C requires global emissions to peak by 2000-2020.
- Limiting global mean temperature increases to 2 – 2.4 C above pre-industrial levels requires global emissions to peak by **2000-2015** and then fall to about **-50 to -85%** of 2000 levels by 2050.

Based on SPM 7, WG III. Emission pathways to mitigation scenarios



Multigas and CO_2 only studies combined

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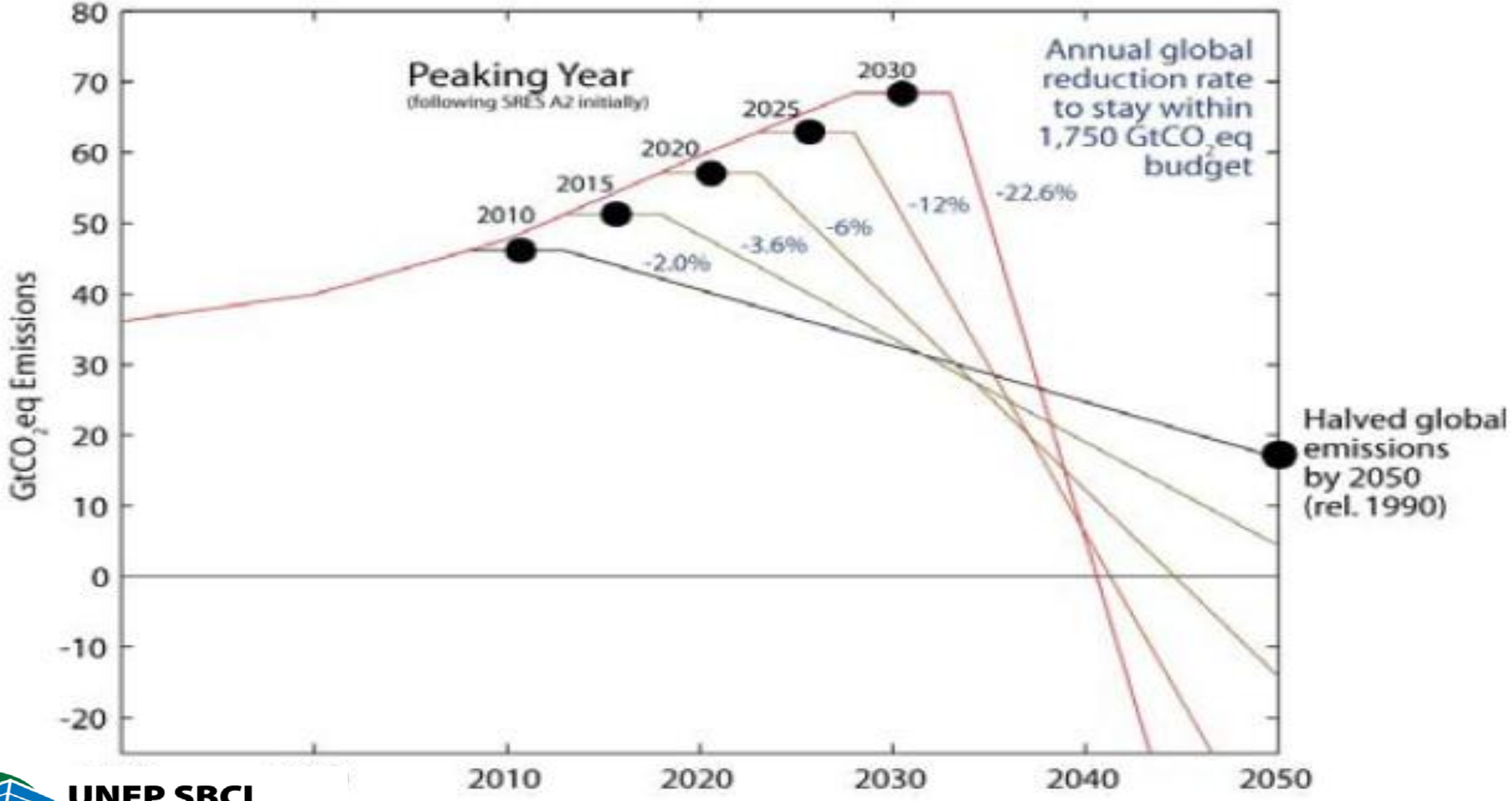
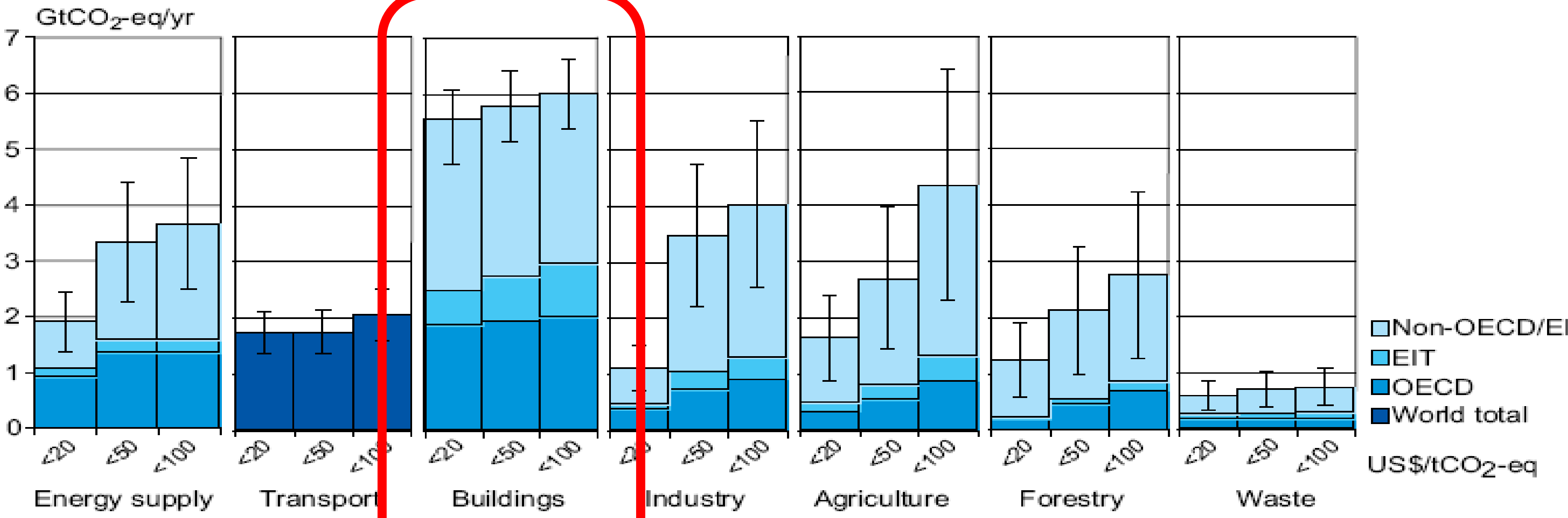
The later emissions peak, the more ambitious reductions needed



Source: Meinshausen et al 2009

Buildings offer large mitigation potentials (at low costs)



(potential at <US$100/ tCO_2-eq: 2.4 - 4.7 Gt CO_2-eq/yr)	*(potential at <US$100/ tCO_2-eq: 1.6 - 2.5 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 5.3 -6.7 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 2.5 - 5.5 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 2.3 -6.4 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 1.3 - 4.2 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 0.4 - 1 Gt CO_2-eq/yr)*

Figure SPM.6: *Estimated sectoral economic potential for global mitigation for different regions as a function of carbon price in 2030 from bottom-up studies, compared to the respective baselines assumed in the sector assessments. A full explanation of the derivation of this figure is found in Section 11.3.*

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Few sectors can deliver the magnitude of emission reduction needed for climate stabilisation

- know-how has recently developed that we can build and retrofit buildings to achieve 50 – 90% savings as compared to standard practice in all climate zones (providing similar or increased service levels)

However, most of the buildings around the world are still highly energy-consuming

Photos from Günter Lang

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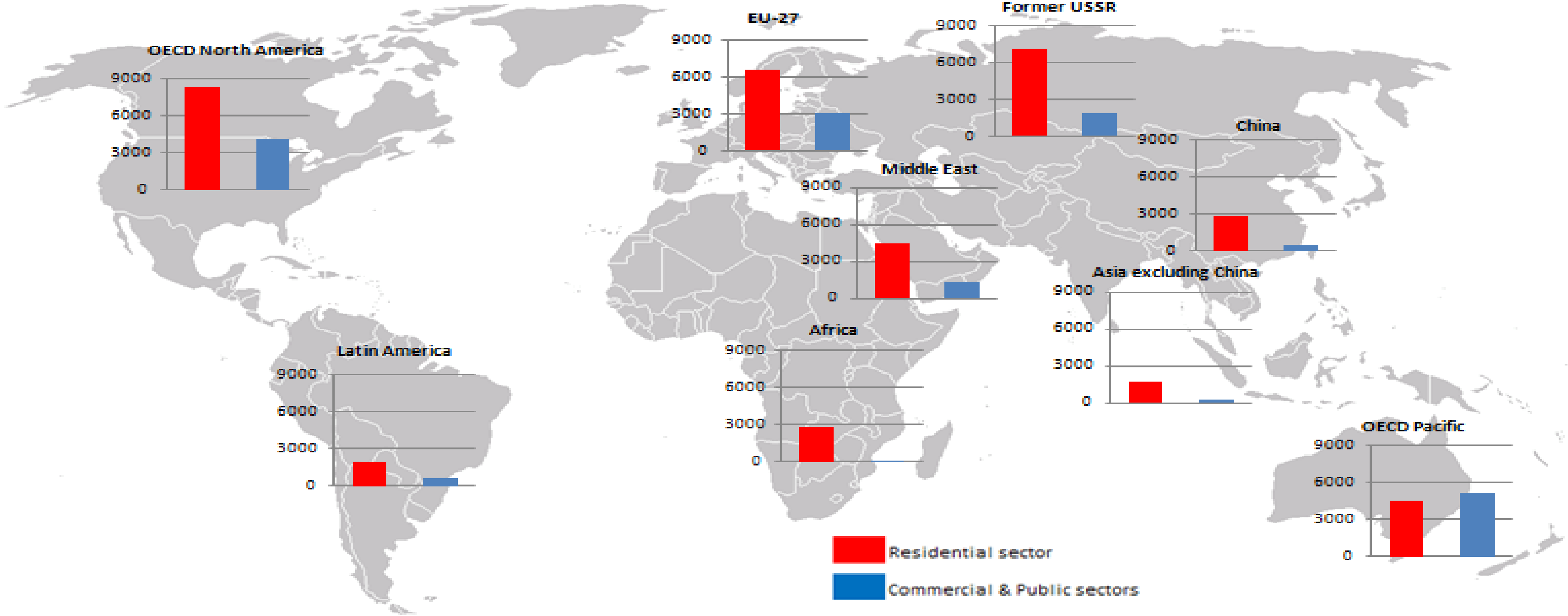
Total final building energy consumption per capita by region and building type in 2007 (kWh/capita/yr)



Data Source: IEA online statistics (2007)

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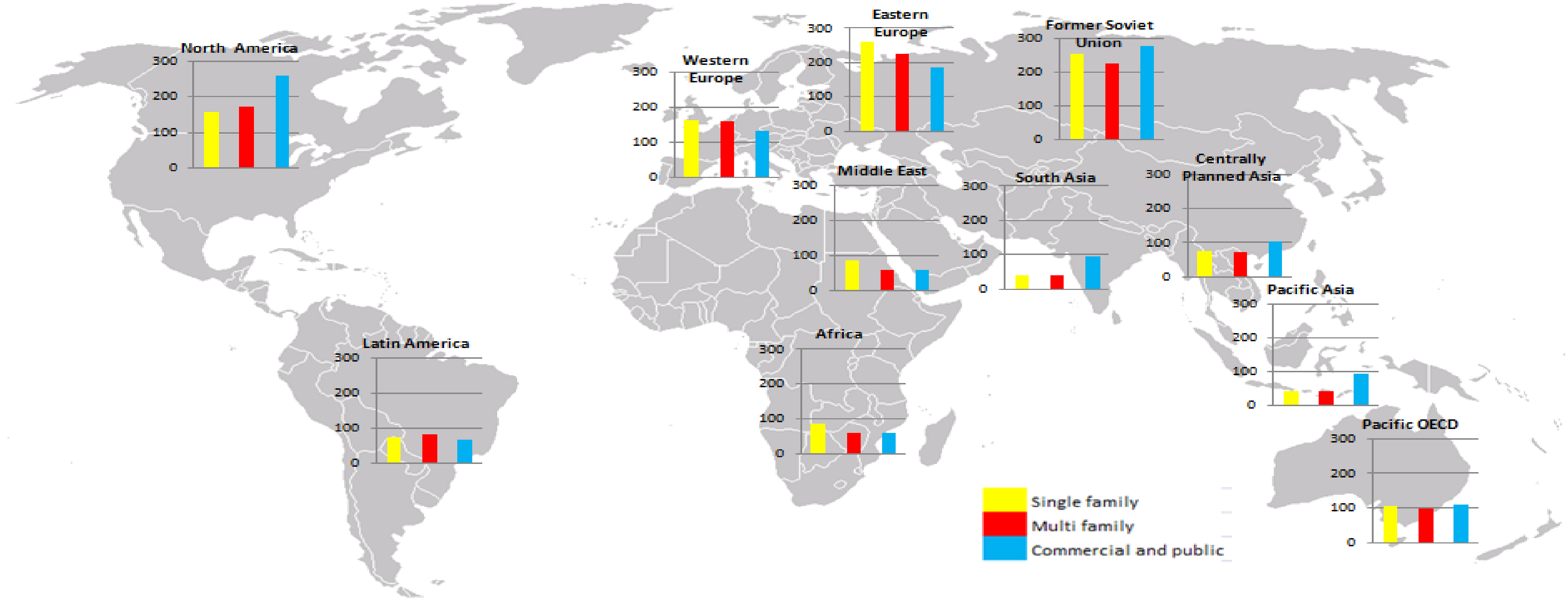
Final heating and cooling specific energy consumption by region and building type in 2005 (kWh/m2/yr)



This energy use can be significantly reduced…

Data Source: Model estimations

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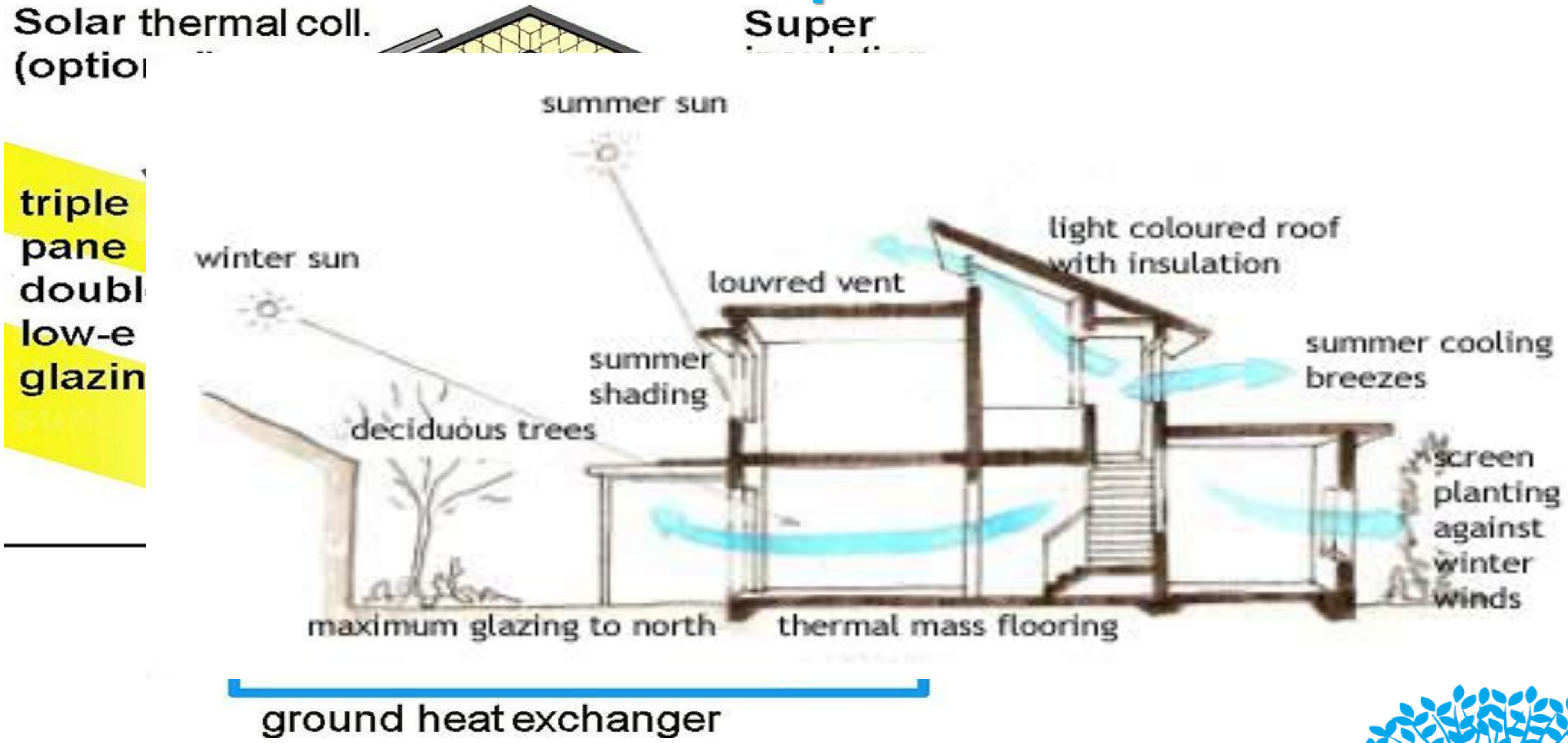
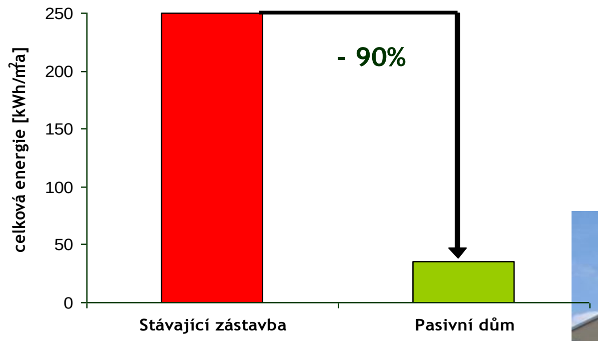
…as long as optimal technologies are applied instead of sub-optimal ones



Buildings utilising passive solar construction ("PassivHaus")



Source: Jan Barta, Center for Passive Buildings, www.pasivnidomy.cz

Example of savings by reconstruction

Before reconstruction

Reconstruction according to the passive house principle

over 150 kWh/(m²a)

-90%

15 kWh/(m²a)

Source: Jan Barta, Center for Passive Buildings, www.pasivnidomy.cz, EEBW2006

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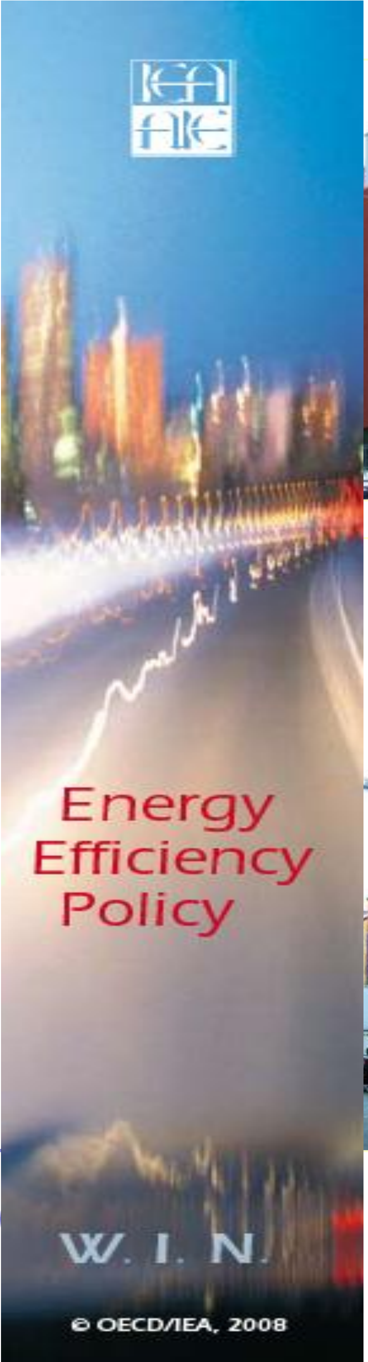

Frankfurt/M Germany Sophienhof
FAAG/ABG Frankfurt Architect Fuessler

Blocks of Flats

160 dwellings
14 767 m²
Passive House Technology
15 kWh / m² per year

Extra costs
= 3-5% of the total costs

Payback = 9 – 10 years

Can we afford this ?

Source: Jens Lausten, IEA

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Base Year Floor Area and Projections Residential

- Floor Area per building type per capita main indicator
- GEA Population Projection Database
- Assumed that developing regions will increase their floor area per cap to that of the OECD by 2050 or some fraction of OECD levels (South Asia 50% of 2005 OECD Levels)
- Previous demolition trends continue throughout modeling period
- A fraction of existing building stock for both Residential and C&P is considered “Historical” and cannot be retrofitted to Advanced Status

$$\text{Floor Area} = \sum_{i=1}^{11} \sum_{j=1}^{2} Population_i \times \left(\frac{m^2}{Capita} \right)_{i,j}$$

Base Year Floor Area and Projections Commercial

- Floor area for first year from BUENAS model and regional reports (McKinsey, LBNL, etc.)
- GEA GDP 2005USD projections
- C&P Floor Area projection based on Floor Area per unit GDP (USD2005) in 2005
- Developing regions are assumed to reach OECD levels of this “floor area elasticity” by 2050
- Tempers otherwise exponential floor area increase if C&P floor area tied directly to GDP

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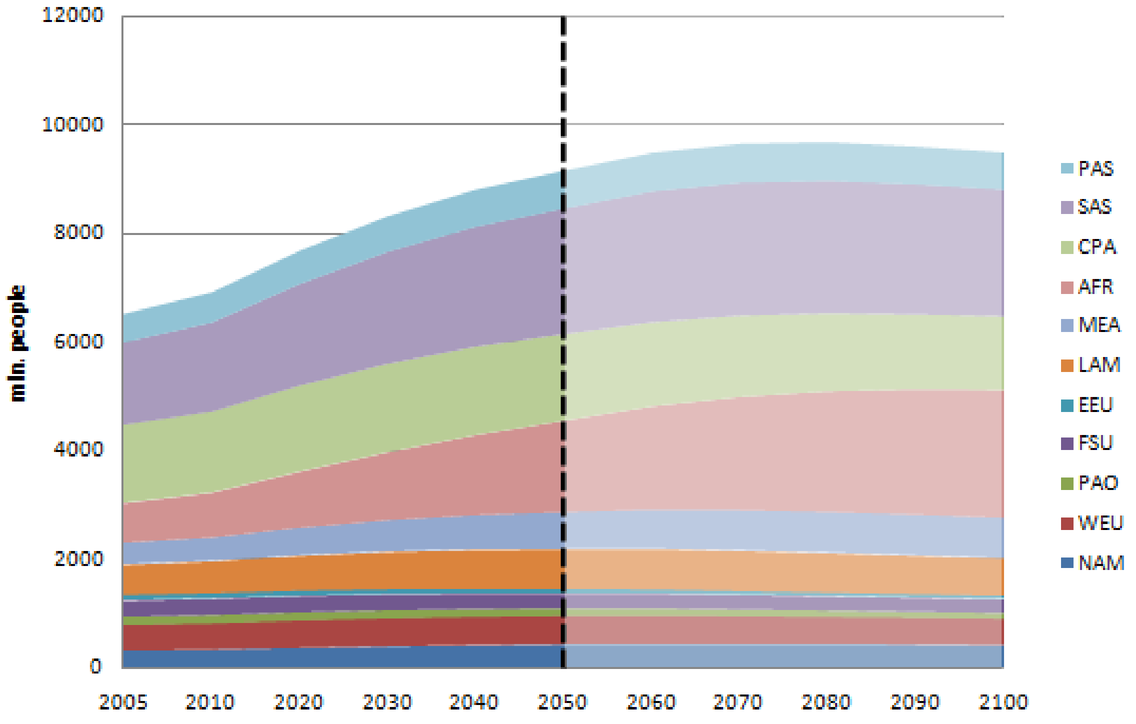
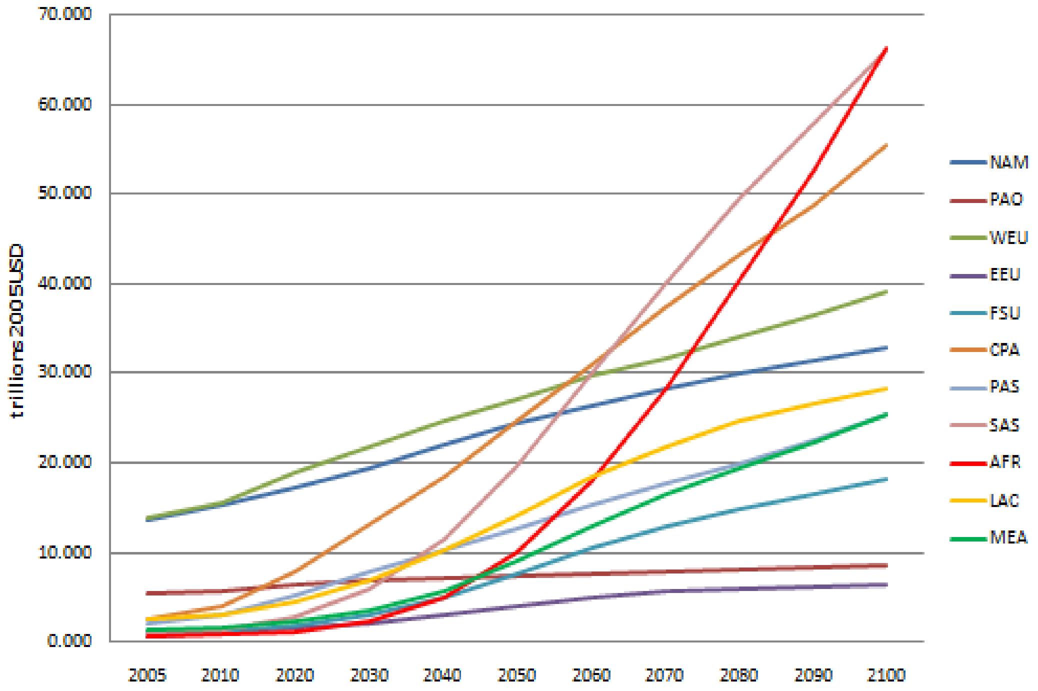
Population and GDP data used in the model





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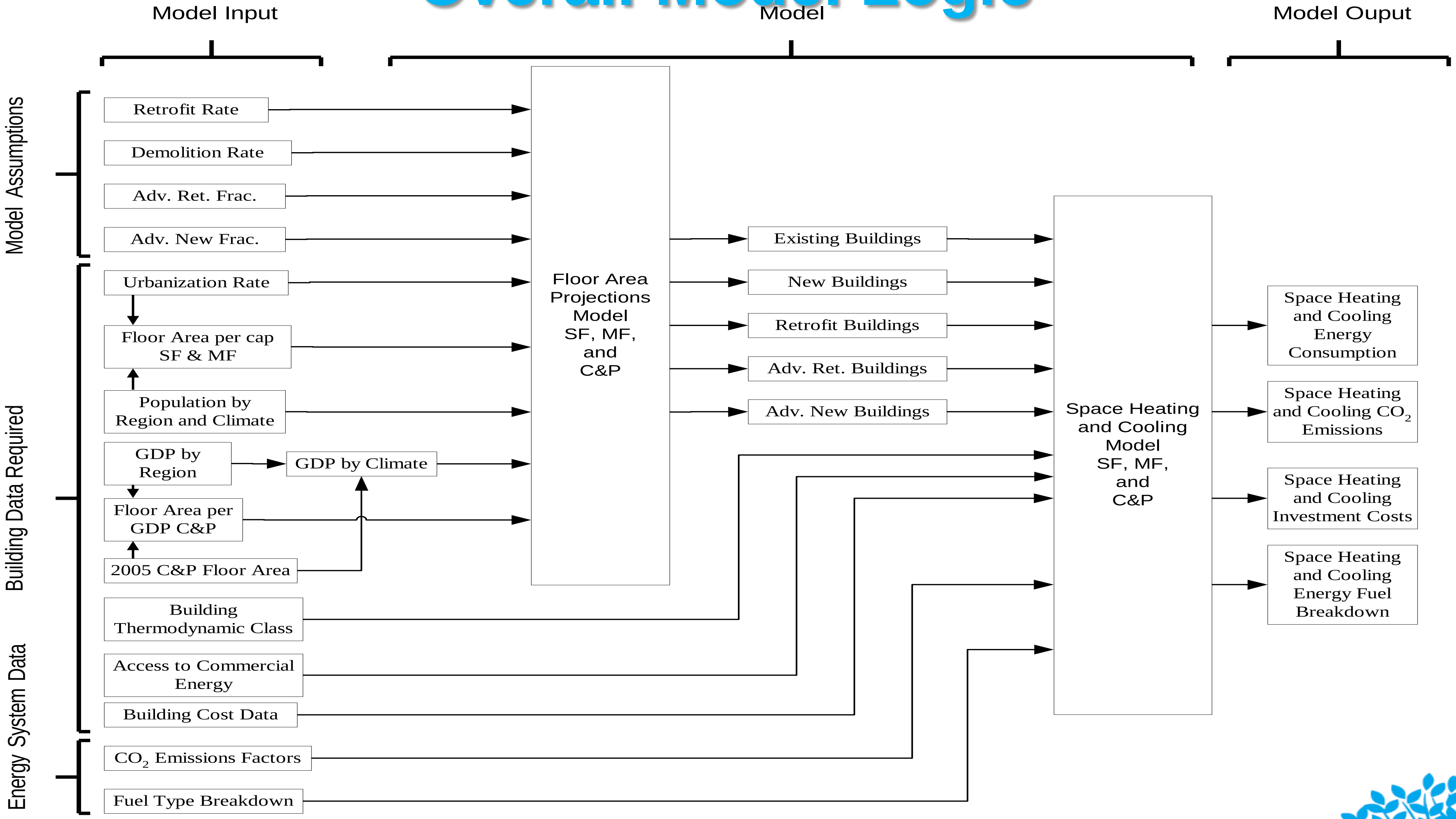
Overall Model Logic



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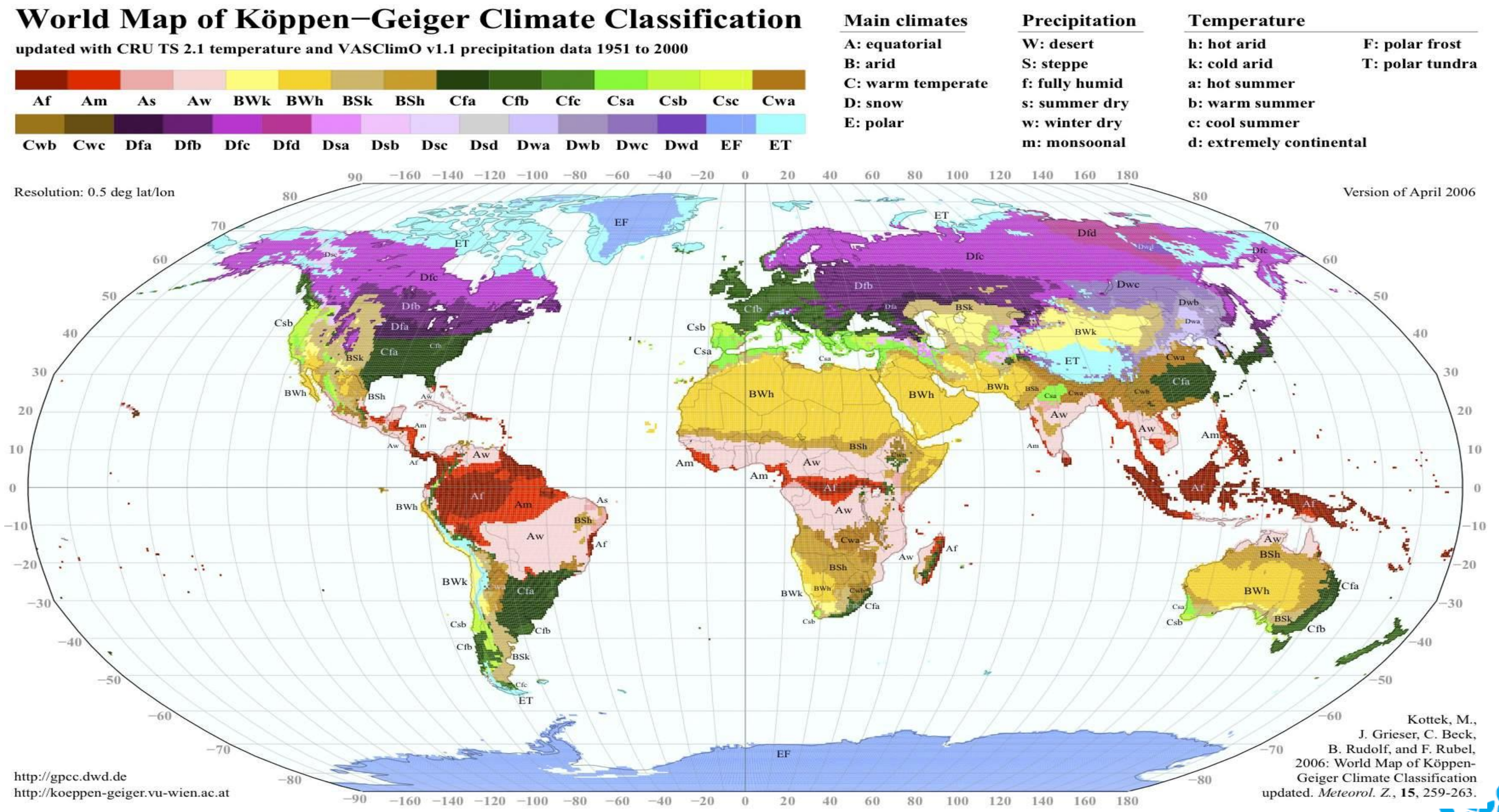
Köppen-Geiger Climate Map



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Climate types

- Climate Zones
  - Warm Moderate
  - Cold Moderate
  - Tropical
  - Arid
- Köppen Climate Equivalents

Köppen Climate Zone	Characteristics	Model Climate Zone	Regional examples
Group A - Tropical	High temperatures all 12 months of the year. >18 C	Tropical	
Af	Rainforest Climate		Hilo, Hawaii, USA
Am	Monsoonal Climate		Miami, Florida, USA
Aw	Wet and Dry/Savannna Climate		Mumbai, Maharashta, India
Group B - Dry	Precipitation is lower than potential evapotranspiration	Arid	
BS	Steppe Climate		Cobar, NSW Austrailia (BSh)
BW	Desert Climate		Almeria, Spain (BWh)
BS/BW-k	Coldest Month Avg. Below 0C		Denver, CO USA (BSk)
BS/BW-h	Coldest Month Avg Above 0C		Dubai, UAE (BWh)
Group C - Temperate	Avg. temperature above 10C in warmest months, Avg. temperature between -3 C and 18 C in coldest months	Warm Moderate	
Csa	Meditereanean Climates		Madrid, Spain
Csb			San Francisco, CA, USA
Cfa	Humid Subtropical - Interiors of large land masses		Buenos Aires, Argentina
Cwa			Hong Kong, PRC
Cfb	Oceanic Climates		Bergen, Norway
Cwb			Mexico City, Mexico
Cfc			Reykjavík, Iceland
Group D - Continental	Avg. temperature above 10C in warmest months, Avg. temperature below -3C in coldest months	Cold Moderate	
Dfa	Hot Summer continental climates		Chicago, Illinois, USA
Dwa			Seoul, South Korea
Dsa			Tabriz, Iran
Dfb	Warm Summer Continental - Hemiboreal Climates		Minsk, Belarus
Dwb			Harbin, China
Dfc	Continental Sub Arctic - Boreal		Anchorage, Alaska, USA
Dwc			Irkutsk, Russia
Group E - Polar		Not Considered in the model	

Sources:
1) koeppen-geiger.vu-wien.ac.at/
2) City Information from Wikipedia

Key Assumptions on Building Types

- Buildings are split into three primary types
  - Single Family (SF): either attached or detached single family homes.
  - Multi Family (MF): multi apartment complexes from high-rise structures to low rise and terrace structures
  - Commercial and Public Buildings (C&P): everything else.
- The urbanization rate
  - % of population living in an urban environment
  - Used as a proxy for the relative proportion of SF and MF

$$\text{Urbanization Rate (\%)} = \frac{\text{Urban Population}}{\text{Total Population}} = \frac{MF_{\text{Floor Area}}}{(MF_{\text{Floor Area}} + SF_{\text{Floor Area}})}$$

Energy Consumption Data

- For new and renovation, case Studies (standard and best practice) were collected for each region and climate type, if available
  - Final Energy performance (kWh/m2)
    - By Climate type
    - Building Type including status: Existing, New; Renovation; standard vs best practice
  - If no data found for a building and climate type, Best Practice assumed to be Passiv Haus Standard, approximately15 kWh/m^2/year
  - Values of specific energy consumption of advanced retrofit buildings are higher than the ones of advanced new buildings as it is easier to achieve very low level of energy consumption through new construction rather than renovation of existing buildings. Therefore, in advanced retrofit buildings these values are usually a bit higher.
  - Specific energy consumption values for advanced multi-family buildings are lower or the same that the ones of single-family buildings in the same region and climate zone.

- Major Challenge is Existing Building Stock energy intensity for Space Heating and Cooling (since that needs to rely on averages and provide totals)

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Summary of Building Stock Projections

11 Regions	Residential, billions of m2			C&P, billions of m2		
	2005	2050	Change, %	2005	2050	Change, %
NAM	11	14	27%	8	12	51%
WEU	15	14	-3%	6	13	119%
PAO	5	4	-16%	2	4	70%
EEU	3	3	18%	0.3	2	483%
FSU	7	9	33%	1	4	442%
CPA	43	54	25%	13	29	130%
SAS	11	68	508%	3	14	471%
PAS	4	18	415%	1	6	329%
LAC	6	23	315%	2	7	323%
MEA	3	18	481%	1	4	549%
AFR	9	27	201%	1	5	307%
World	116	253	118%	37	99	169%

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Thermal final energy intensities assumed in the scenarios for different building types and regional climate zones

Region	Climate Type	Single Family					Multi-Family					Commercial and Public				
		Existing	New	Adv New	Retrofit	Adv Retrofit	Existing	New	Adv New	Retrofit	Adv Retrofit	Existing	New	Adv New	Retrofit	Adv Retrofit
NAM	Warm Mod.	150	65	15	105	20	170	65	10	119	15	220	65	15	154	17
	Cold Mod.	191	65	20	134	30	200	65	15	140	20	340	65	15	238	20
	Tropical	75	65	17	53	25	75	65	17	53	25	131	65	25	92	30
	Arid	87	65	12	61	20	87	65	12	61	20	114	65	20	80	25
WEU	Warm Mod.	160	50	12	112	15	155	50	10	109	15	130	50	10	91	17
	Cold Mod.	261	50	14	183	20	225	50	14	158	20	209	50	14	146	20
PAO	Warm Mod.	100	55	15	70	20	95	60	10	67	15	90	66	15	63	17
	Cold Mod.	150	65	20	105	30	130	80	15	91	20	90	66	15	63	20
	Tropical	65	55	17	46	25	63	55	17	44	25	131	65	25	92	30
	Arid	155	65	12	109	20	155	60	12	109	20	114	65	20	80	25
EEU	Warm Mod.	240	145	14	168	15	205	120	10	144	15	180	120	10	126	17
	Cold Mod.	280	123	20	196	20	245	150	15	172	20	280	111	14	196	20
FSU	Warm Mod.	240	150	15	168	25	205	130	15	144	20	180	120	10	126	17
	Cold Mod.	280	180	20	196	20	246	150	20	172	25	353	150	14	247	20
	Arid	210	100	12	147	20	210	100	15	147	20	210	65	18	147	25
CPA	Warm Mod.	65	42	15	46	20	65	42	10	46	15	96	62	15	67	17
	Cold Mod.	140	91	20	98	30	120	78	15	84	20	150	98	15	105	20
	Tropical	60	39	17	42	25	55	36	17	39	25	96	62	25	67	30
	Arid	70	46	12	49	20	55	36	12	39	20	96	62	20	67	25
SAS	Warm Mod.	65	42	15	46	20	65	42	10	46	15	96	55	15	75	17
	Tropical	35	23	17	25	25	35	23	17	25	25	96	65	25	75	30
	Arid	35	23	12	25	20	35	23	12	25	20	96	65	18	75	18
PAS	Warm Mod.	65	42	15	46	20	65	42	10	46	15	96	55	15	75	17
	Tropical	35	23	17	25	25	35	23	17	25	25	96	65	25	75	30
MEA	Arid	87	50	12	50	20	62	60	12	60	20	62	65	20	75	25
LAC	Warm Mod.	81	50	15	50	20	81	60	10	60	15	91	55	15	55	17
	Cold Mod.	196	50	20	50	30	170	60	15	60	20	209	65	15	65	20
	Tropical	63	50	17	50	25	63	55	17	55	25	131	65	25	65	30
	Arid	87	50	12	50	20	155	60	12	60	20	114	65	20	65	25
AFR	Warm Mod.	120	50	15	50	20	100	60	10	60	15	100	55	15	55	17
	Tropical	63	50	17	50	25	63	55	17	55	25	65	65	25	65	30
	Arid	87	50	12	50	20	62	60	12	60	20	62	65	20	65	25

Sources of data are very broad, range from national statistics through literature to personal interviews and expert judgments for regions without documented data.

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Scenarios Considered
Key Scenario Assumptions (1/3)

- Global 1.4% Retrofit rate
- Switch to 3.0% Retrofit rate in 2020
- Access to commercial energy assumption
  - Fraction of buildings within a region have no access to commercial energy and consume 1/3 less energy than a similar building in the region
- All floor area is fully conditioned and 100% access to commercial energy is achieved by 2050
- Developing countries see large increase in floor area per capita, synonymous with full development

Scenarios Considered
Key Scenario Assumptions (2/3)
Sub-Optimal Scenario

- Best Practices are adopted to little extent
  - Only the WEU region will have 5% of New Buildings achieve "Advanced" Energy standard
- All other regions continue current (to code or equivalent) retrofit and new build energy requirements.
  - Regions without code are assumed to retrofit to 30% lower energy consumption than an existing building
- New buildings are built to current code

Scenarios Considered
Key Scenario Assumptions (3/3)
State-of-the-Art Scenario

- Steady phase in of Best Practices for each region
  - Fraction of Retrofits are "Advanced" Status starting in 2010 and ramping up to 100% in 2020
  - Most retrofits to go state-of-the-art, with 3 – 10% (historic and other non-retrofitable buildings) to less ambitious levels
  - Fraction of New Buildings are "Advanced" Status starting in 2010 and ramping up to 100% in 2020
- New buildings are built to current code
- Retrofits are built to code or 30% lower than existing buildings

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Summary of key messages I. Scenario findings

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- Our scenarios demonstrate that more than **46%** global final **heating and cooling energy reduction** is possible **by 2050** as compared to 2005 by proliferating today's best practices in design, construction and building operation technologies and know-how. This is reachable while increasing amenity and comfort; without interceding in economic and population growth trends and the applicable thermal comfort and living space demand increases. These reductions go hand-in-hand with **eradicating fuel (energy) poverty** and 126% increase in global floor are.
- Most regions are able to decrease final thermal energy use in buildings, with the largest drop in OECD countries (73%), followed by reforming economies (66%). Even ASIA final energy decreases, after an initial increase, ending 16.5% lower than in 2005.
- Reaching these state-of-the-art energy efficiency levels in buildings requires approximately US$14.2 trillion in undiscounted cumulative investments until 2050. However, these investments return substantially higher benefits: app. US$58trillion in undiscounted energy cost savings alone during the same period.

Summary of key messages II.
The lock-in risk

- Lock-in risk: If building codes are introduced universally and energy retrofits accelerate, but policies do not mandate state-of-the-art efficiency levels, substantial energy consumption, and corresponding GHG emissions, can be "locked in" for many decades. Such a scenario results in an app. 32.5% increase in global energy use by 2050 from 2005, as opposed to a 46% decrease – i.e. an app. **79% lock-in effect** if expressed in 2005 global building heating and cooling energy use.
- This points to the importance of building-shell related policies being very ambitious about the efficiency levels they mandate (or encourage), and to the major lock-in risk present policies, typically under the banner of climate change mitigation, energy security and other public goals, are taking us to.

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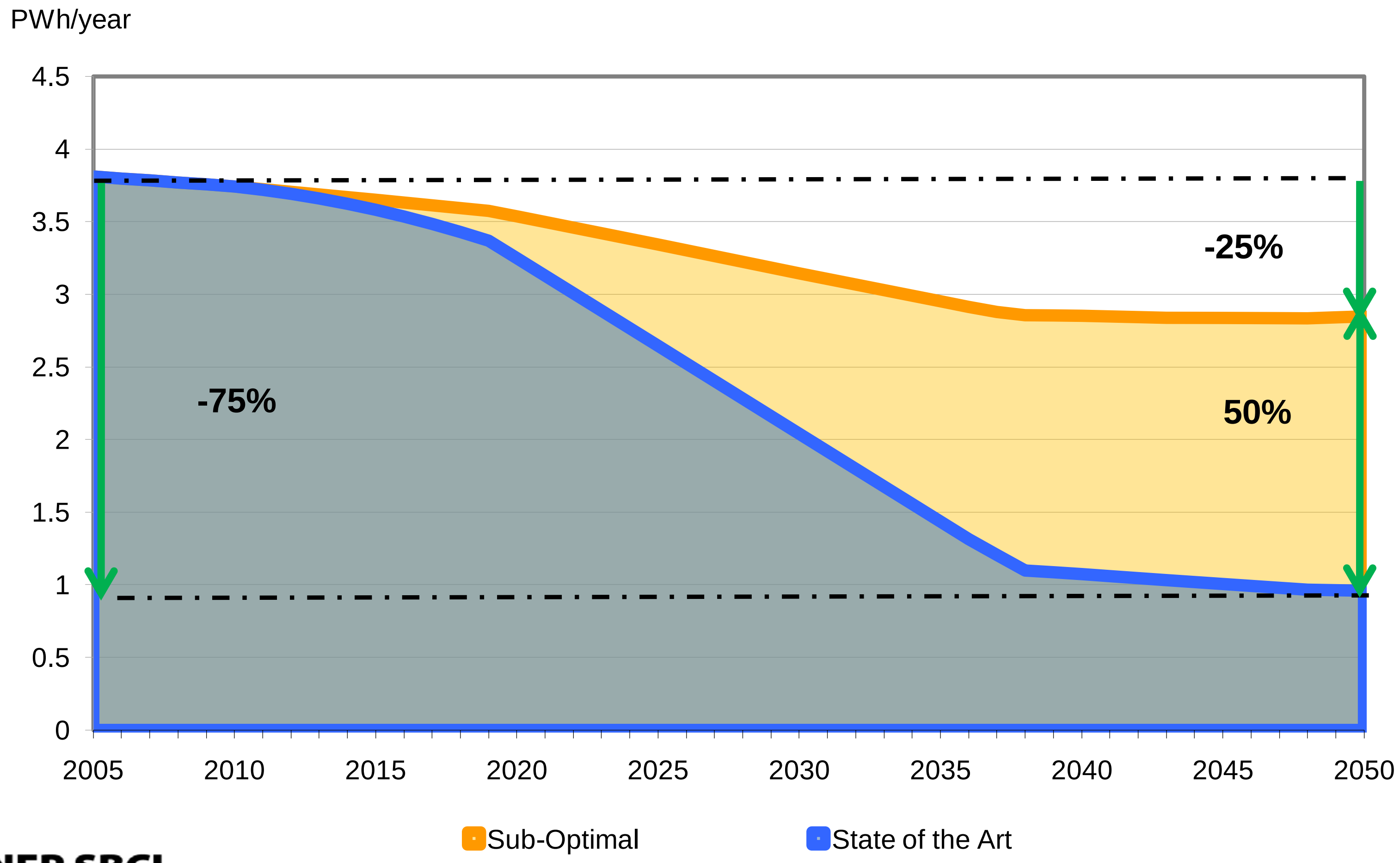
Lock-in Effect
North America



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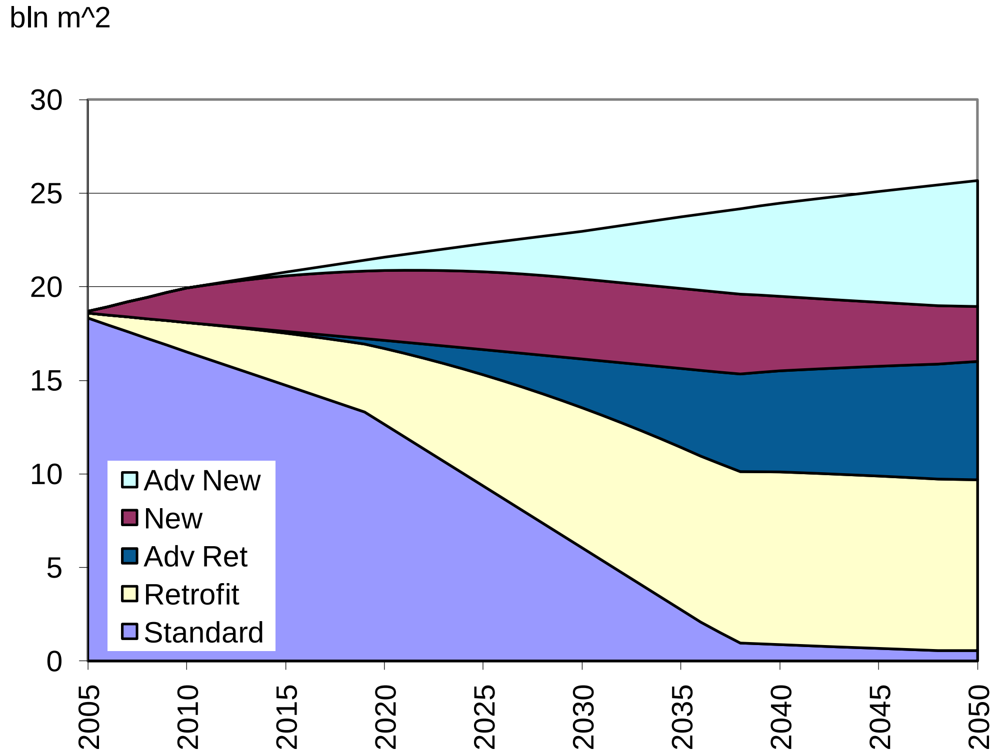
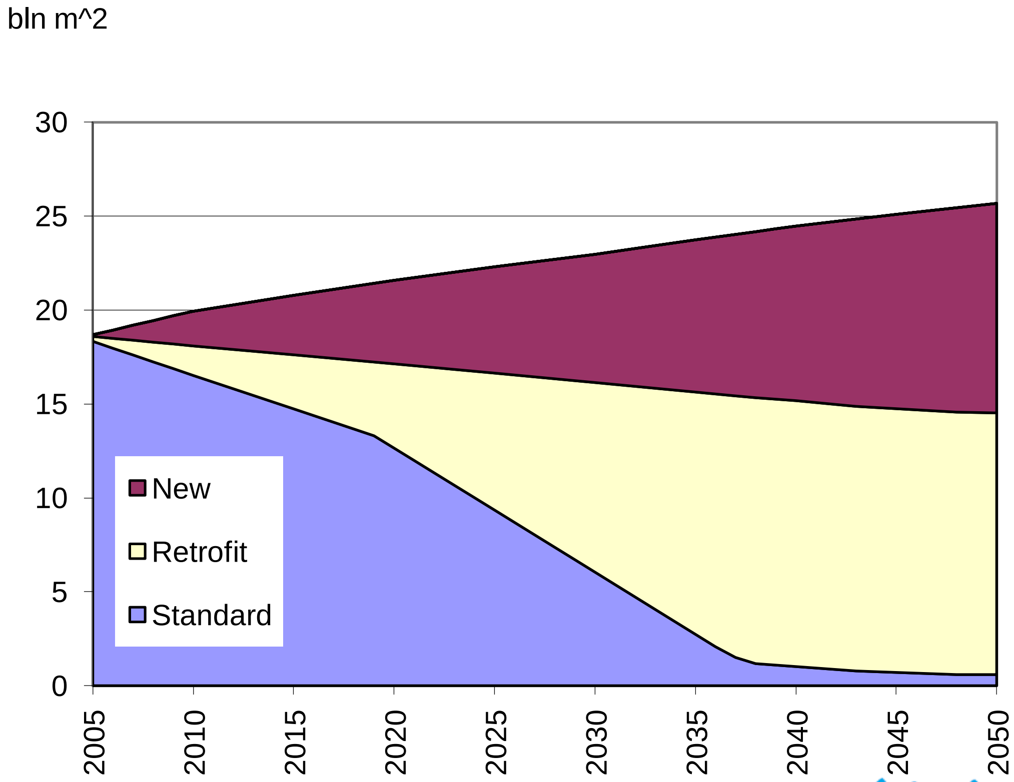
Scenario Results
North America - Floor Area

State-of-the-Art Scenario



Sub-Optimal Scenario



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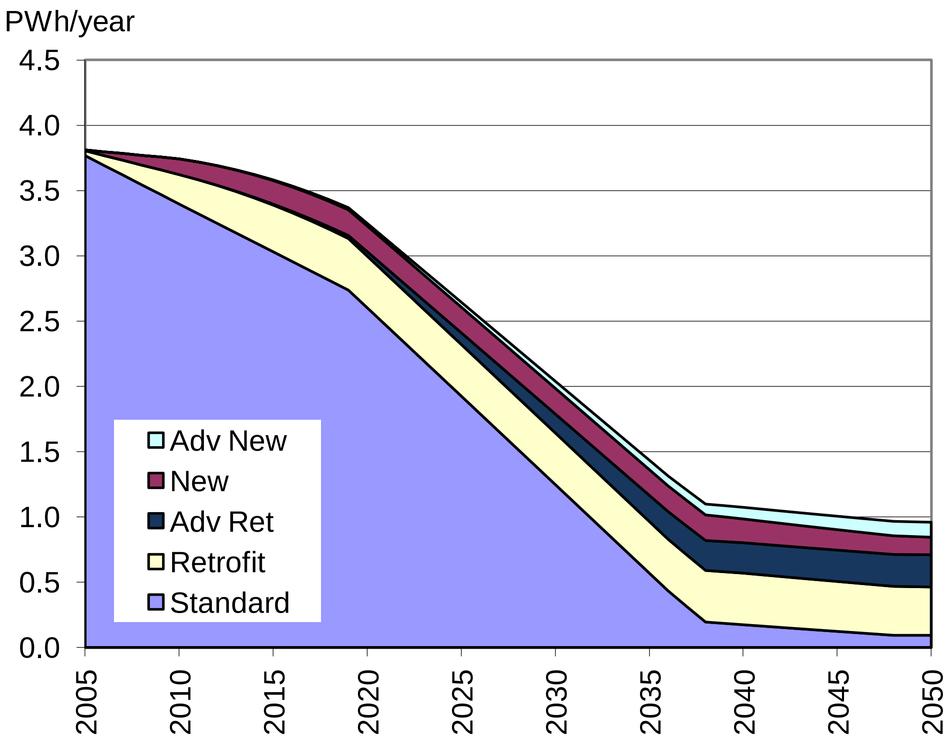
Scenario Results
North America – Energy Use

State-of-the-Art Scenario



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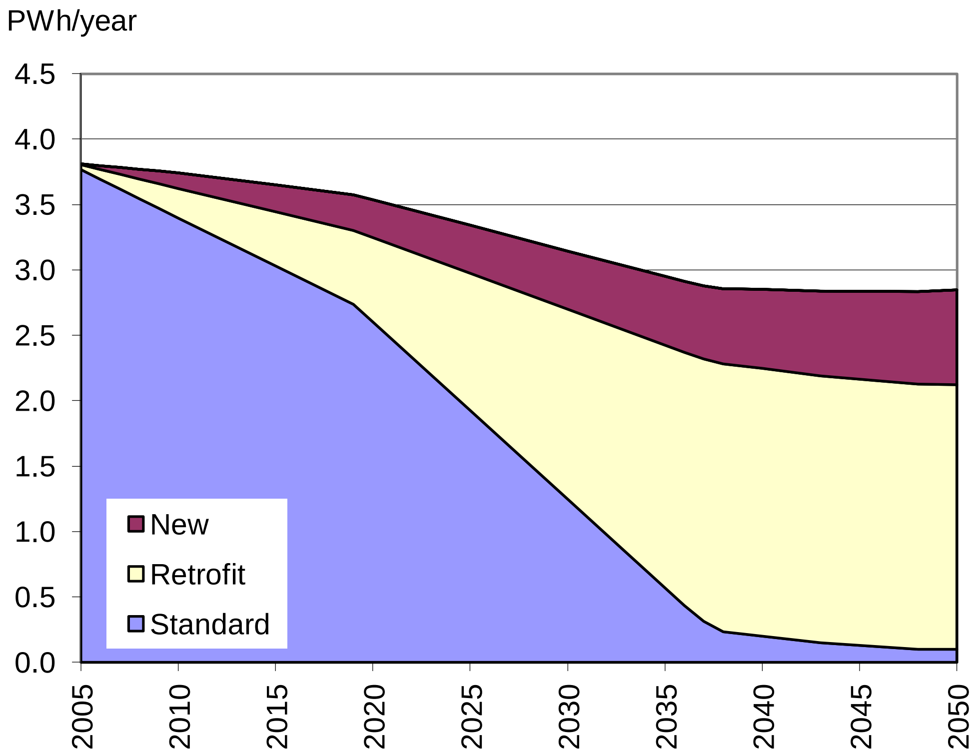

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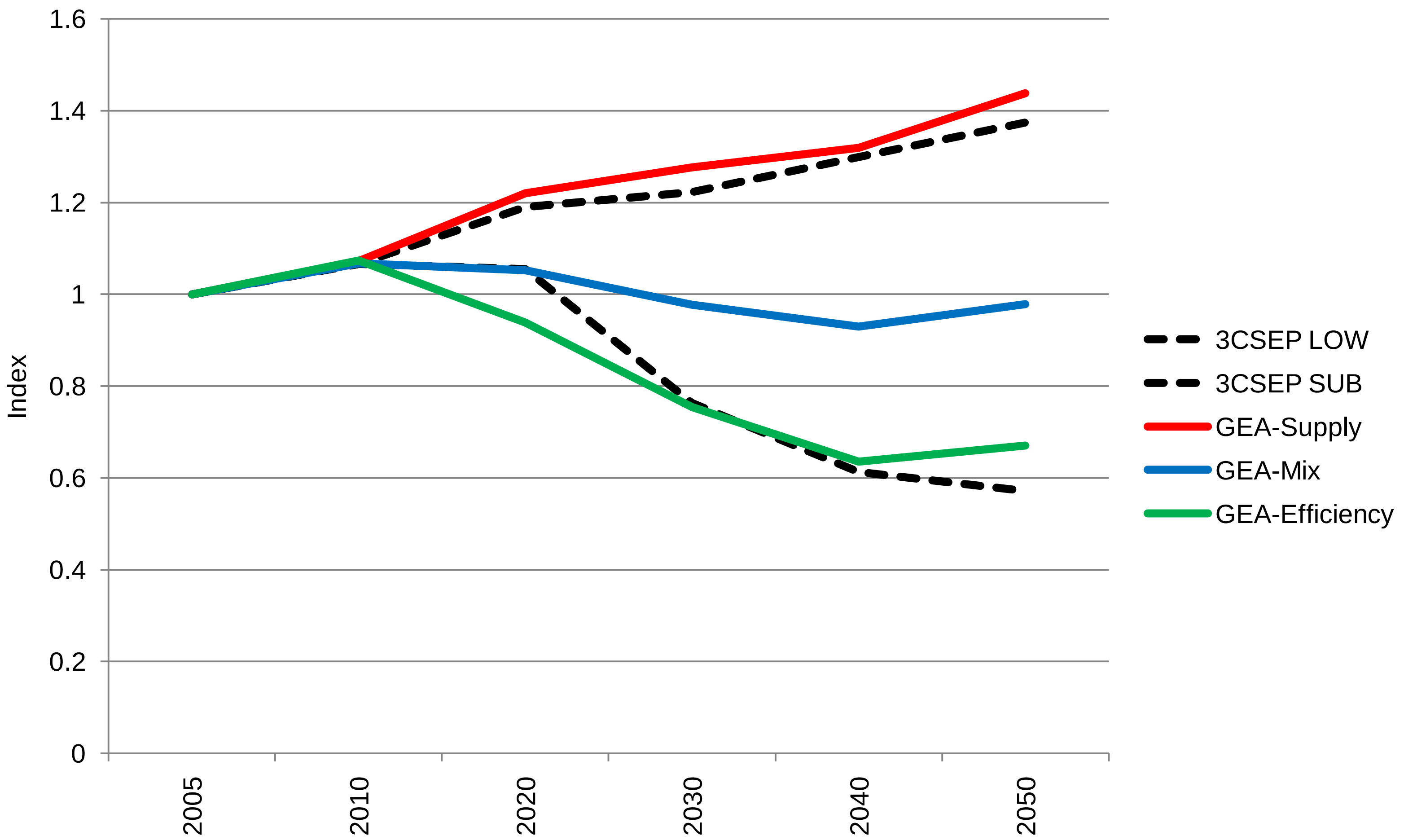
Comparison of the results to GEA scenarios



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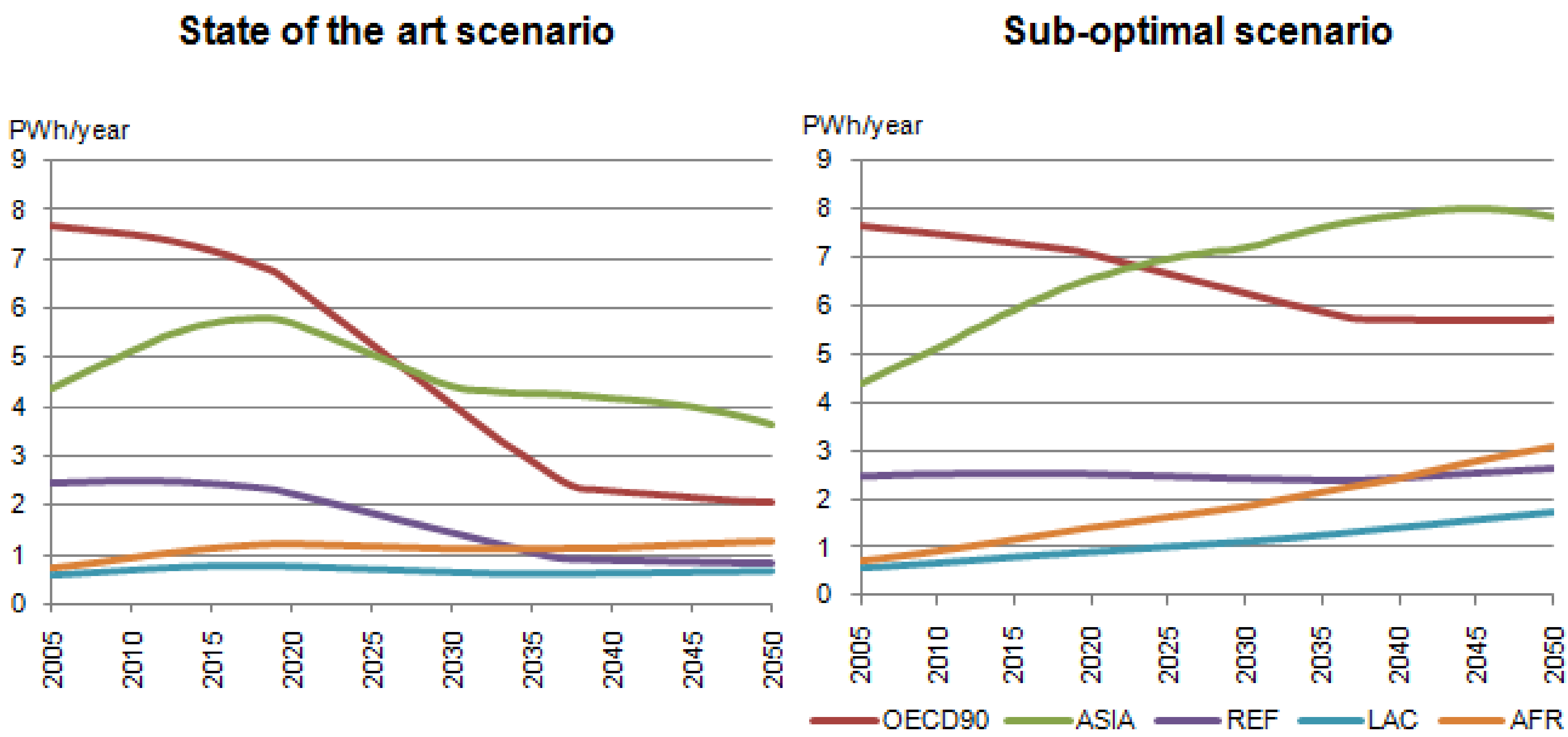
Thermal final energy use for two scenarios and for the five regions



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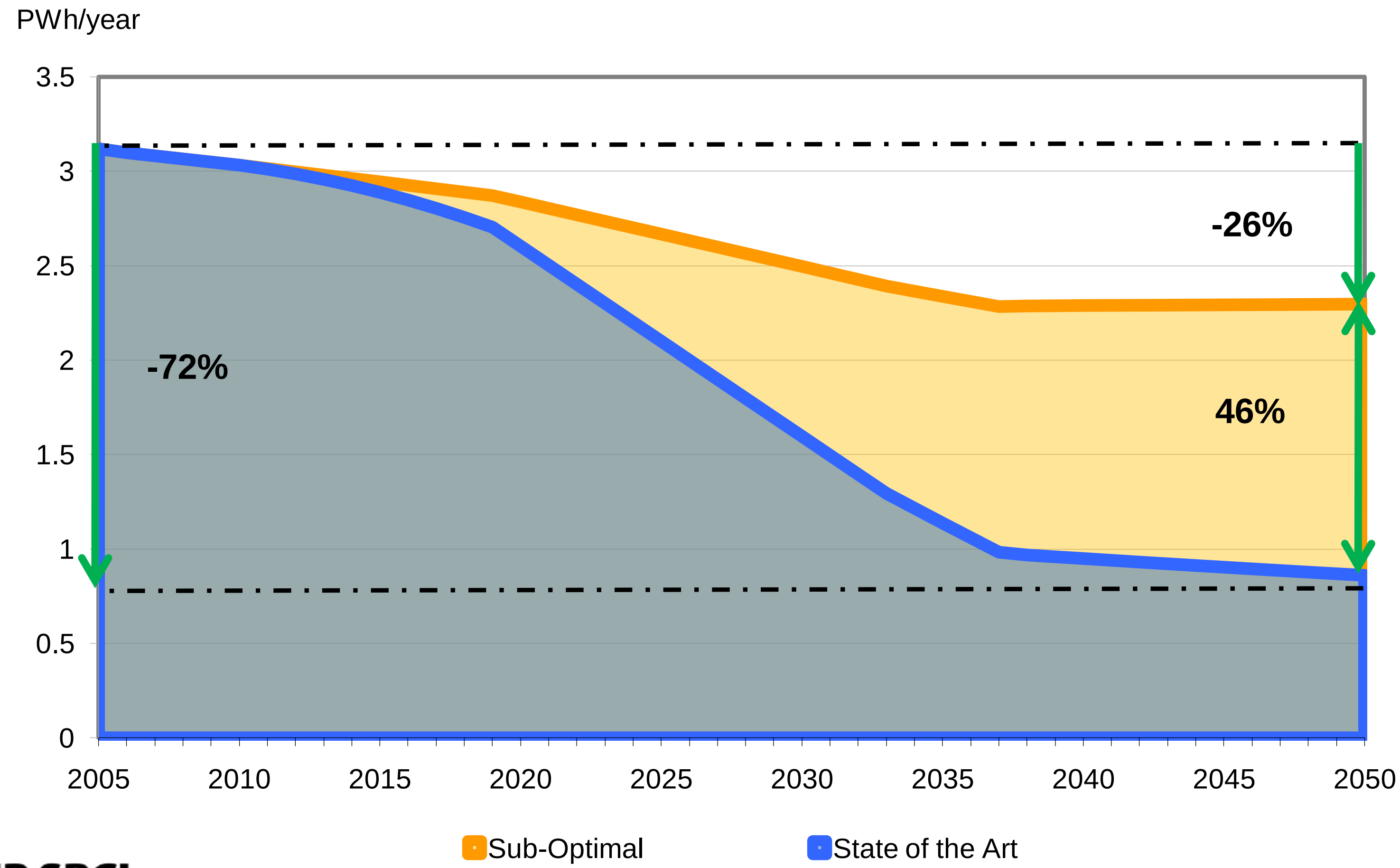
Lock-in Effect
Western Europe



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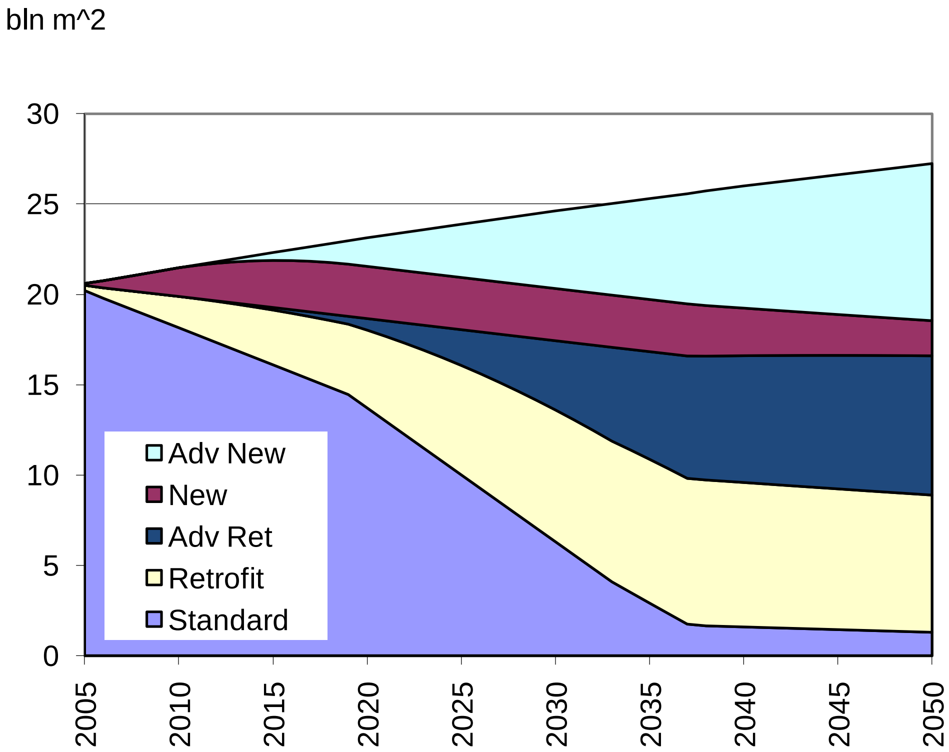
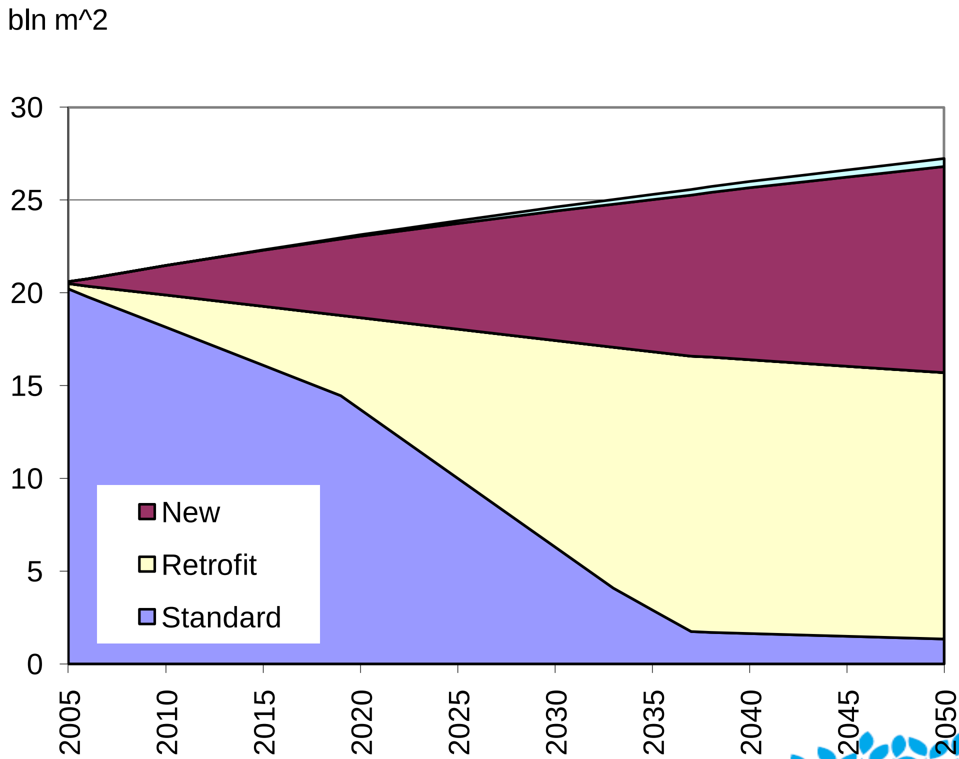
Scenario Results
Western Europe – Floor Area

State-of-the-Art Scenario



Sub-Optimal Scenario



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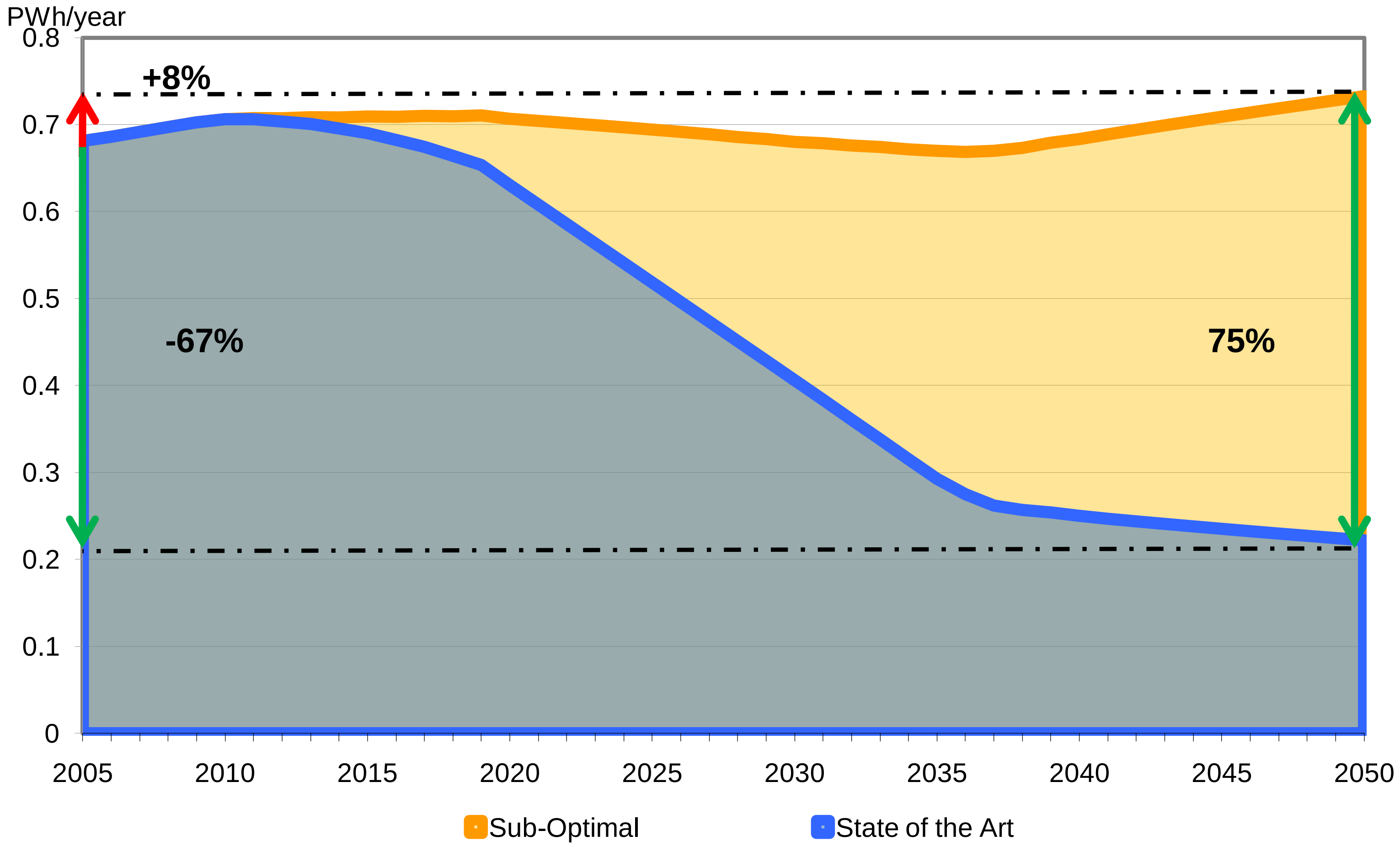
Lock-in Effect
Eastern Europe



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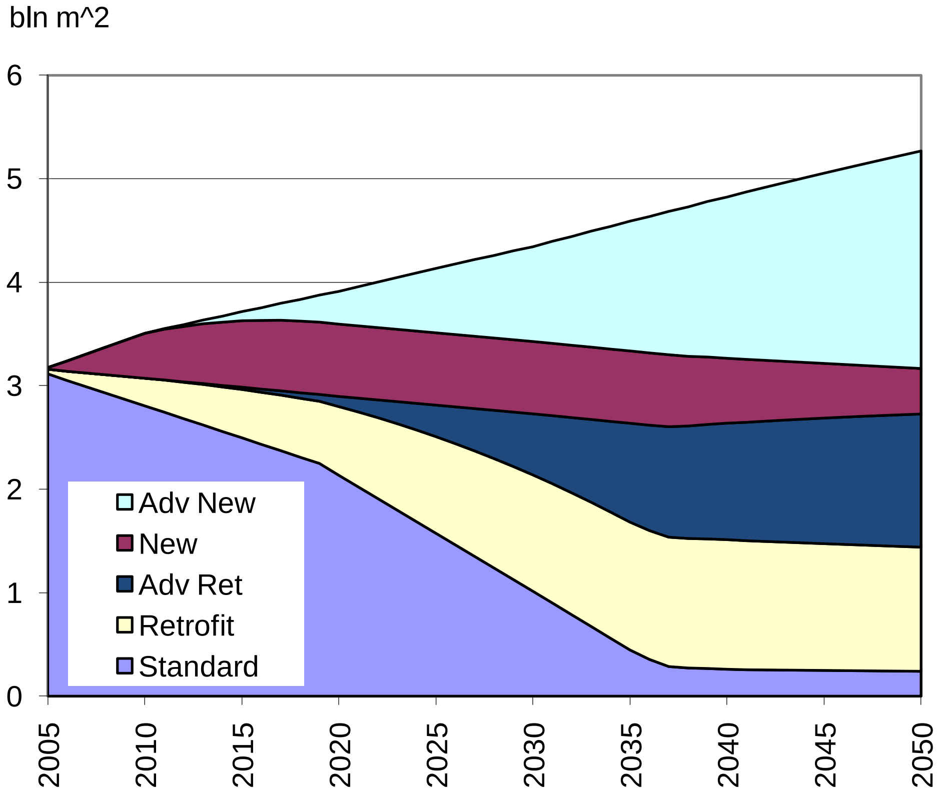
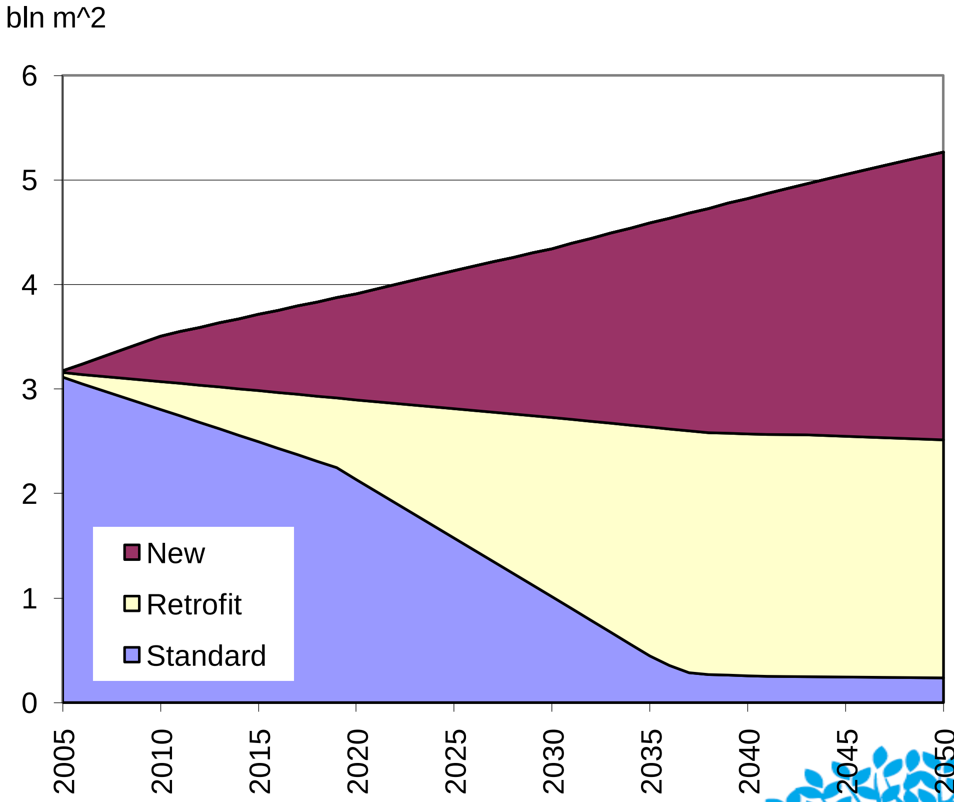
Scenario Results
Eastern Europe – Floor Area

State-of-the-Art Scenario



Sub-Optimal Scenario



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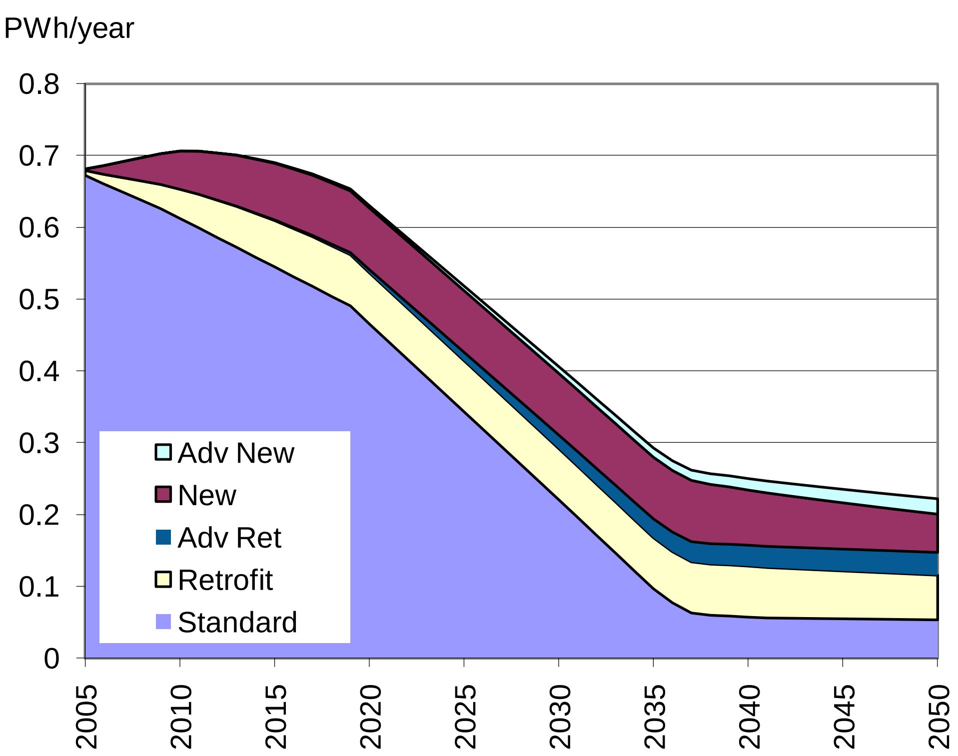
Scenario Results
Eastern Europe – Energy Use

State-of-the-Art Scenario



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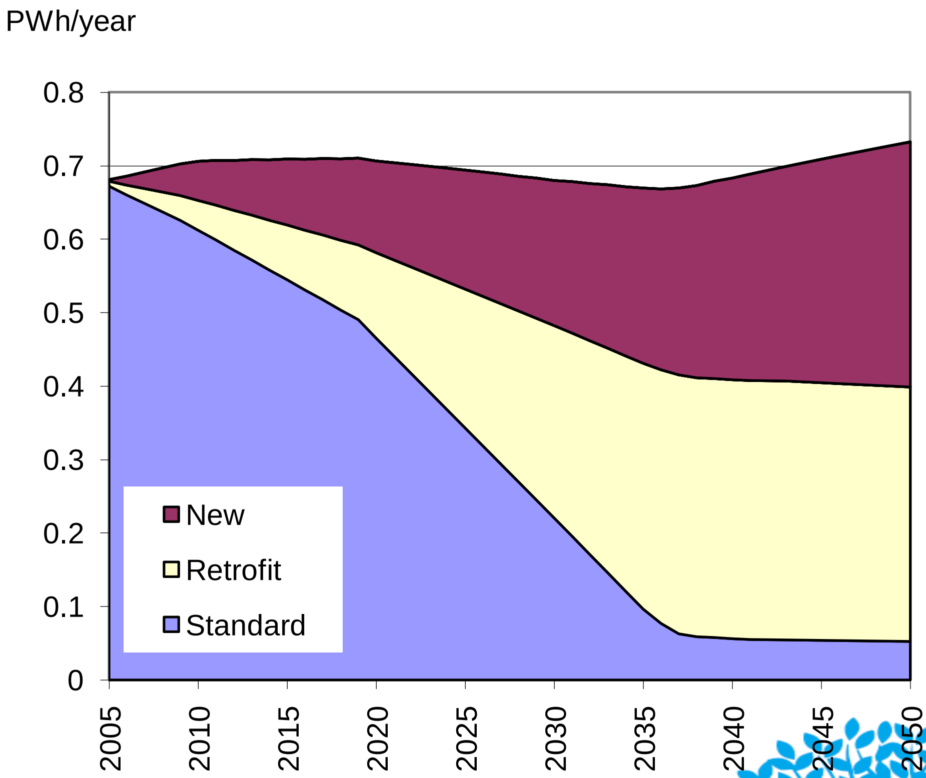

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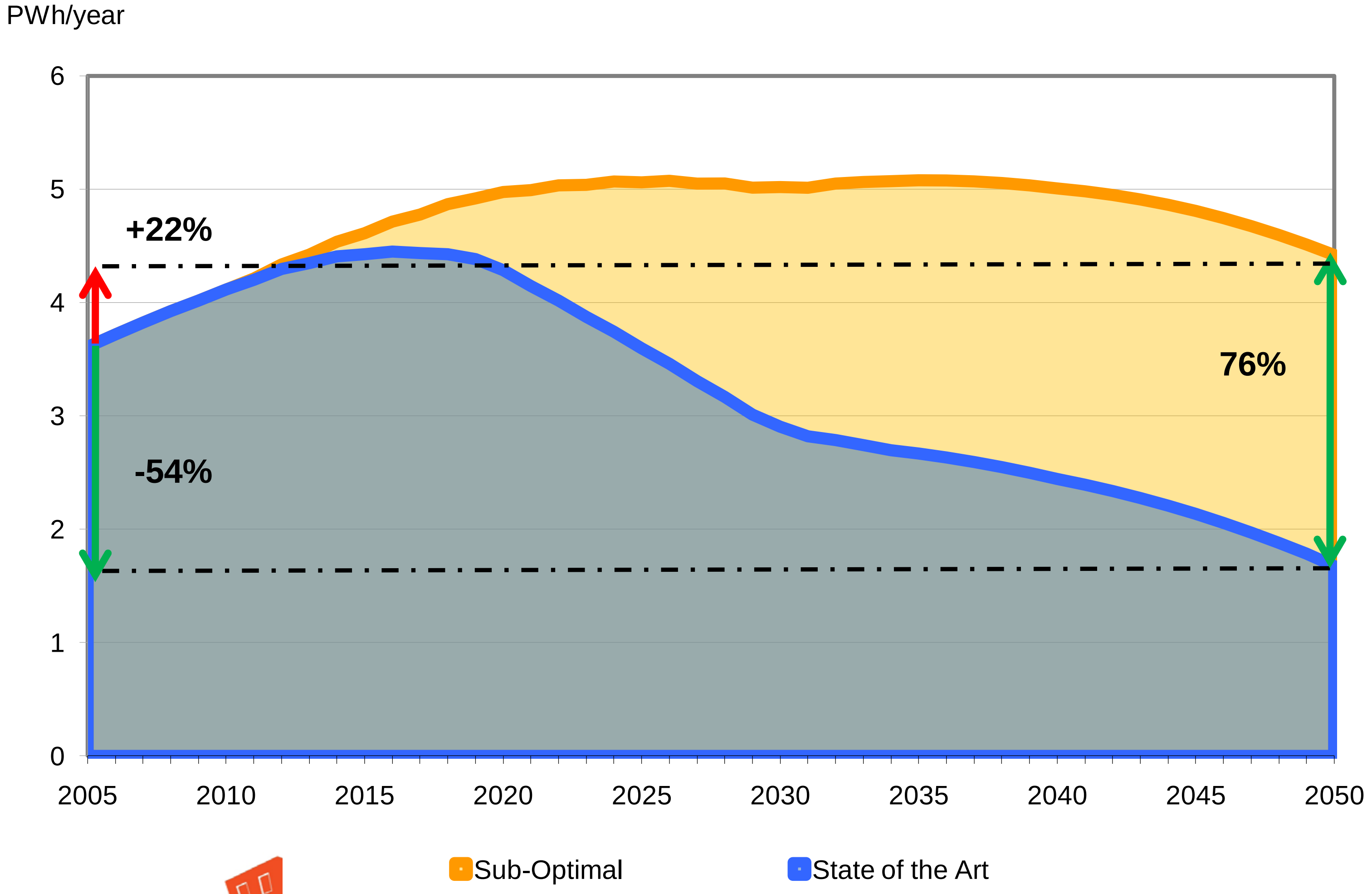
Lock-in Effect
Centrally Planned Asia



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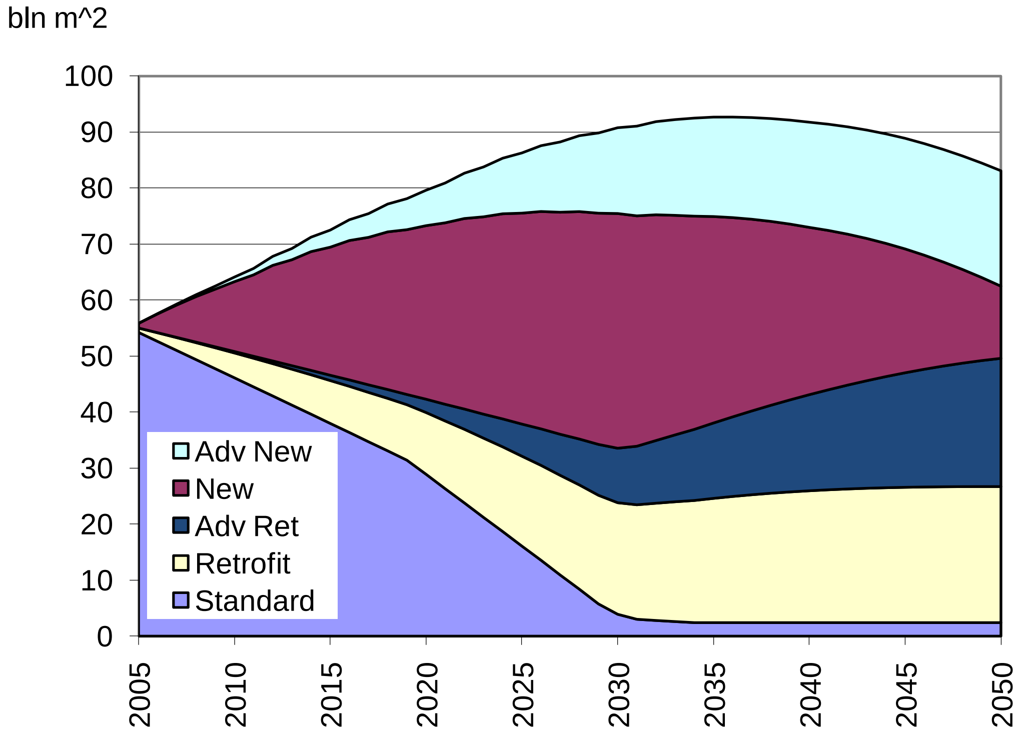
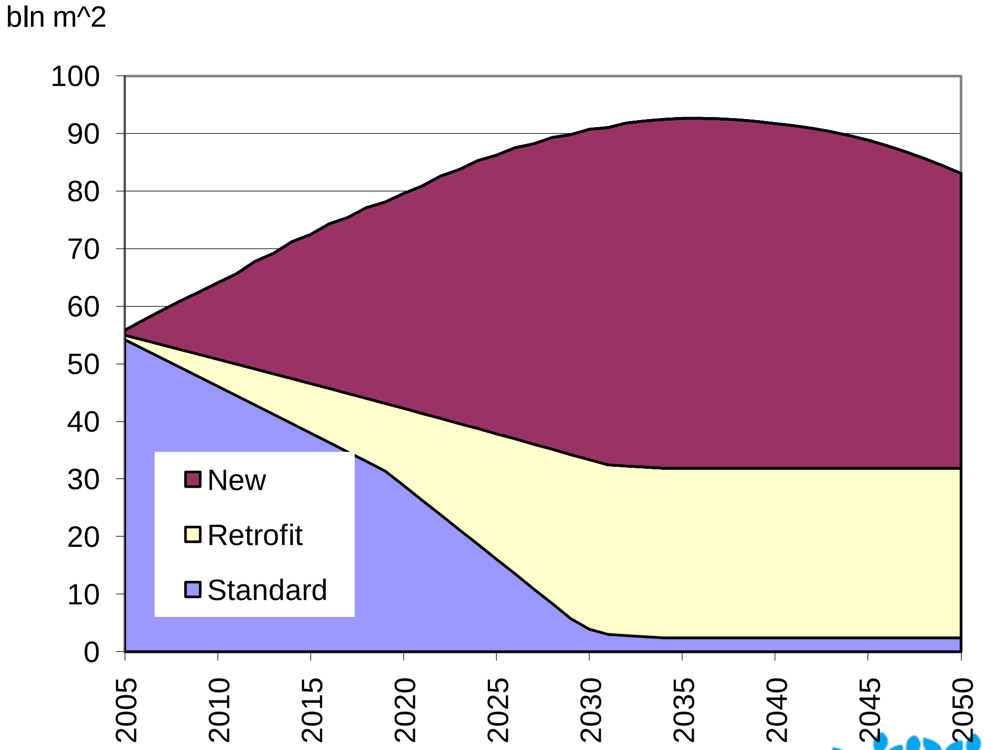
Scenario Results
Centrally Planned Asia – Floor Area

State-of-the-Art Scenario



Sub-Optimal Scenario



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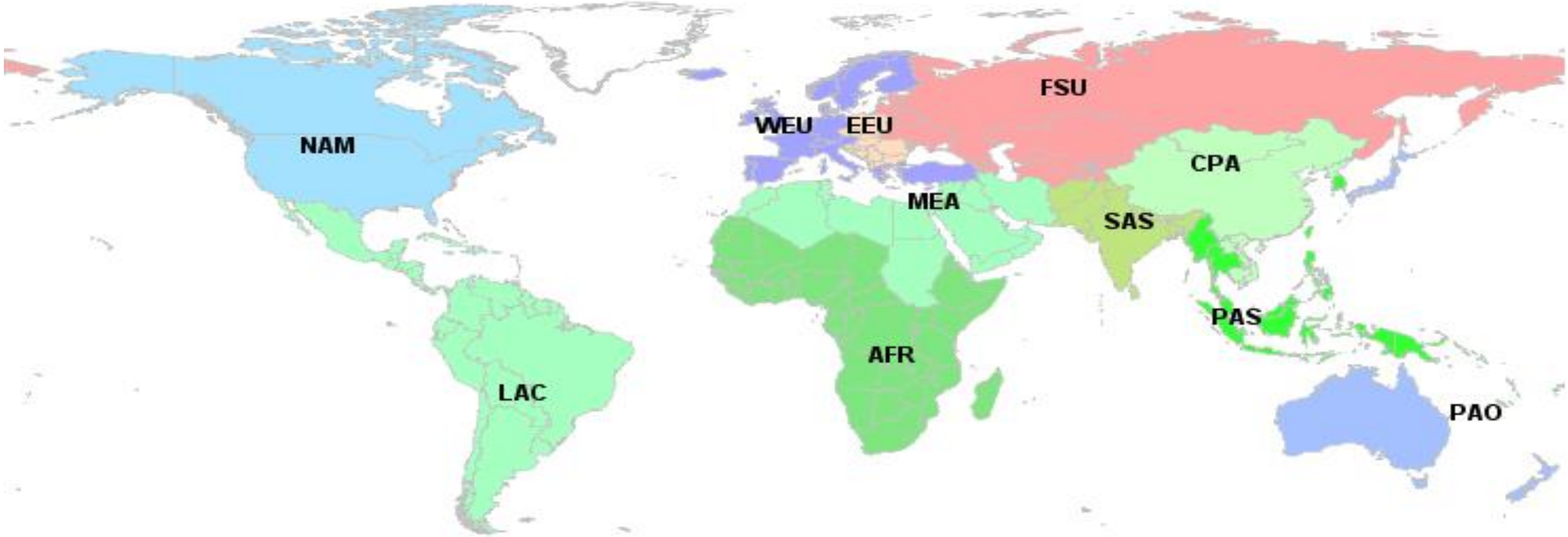
11 Regions



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A novel approach to global building energy modeling

- Considers buildings as complete systems rather than sums of components

- Recognizes that
  - state-of-the-art building energy performance can be achieved through a broad variety of designs and component combinations
  - Systemic gains are important when buildings are optimised to very high energy performance, not typically captured by modeling buildings by components
  - If loads are minimised, and siting, design and solar gain optimised, thermal energy performance is not a strict function of degree-days, but main climate type

- Assumes that state-of-the-art construction know-how can be transferred within climate type to different regions
- Assumes that existing best practices become the standard (both in new construction AND renovation) after a certain transition time
- Costs also follow best practice philosophy rather than averages

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Sponsoring Organizations

International Organizations

GEF
IIASA
UNDESA
UNDP
UNEP (incl. UNEP SBCI)
UNIDO
ESMAP (World Bank)

Industry groups

First Solar
Petrobras
WBCSD
WEC

Governments/Agencies

Austria - multi-year
European Union
Germany
Italy
Norway
Sweden - multi-year
USA (EPA, DoE)

Foundations

UN Foundation
Climate Works Foundation
Global Environment & Technology Foundation

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