



Wir schaffen Wissen – heute für morgen

Paul Scherrer Institut

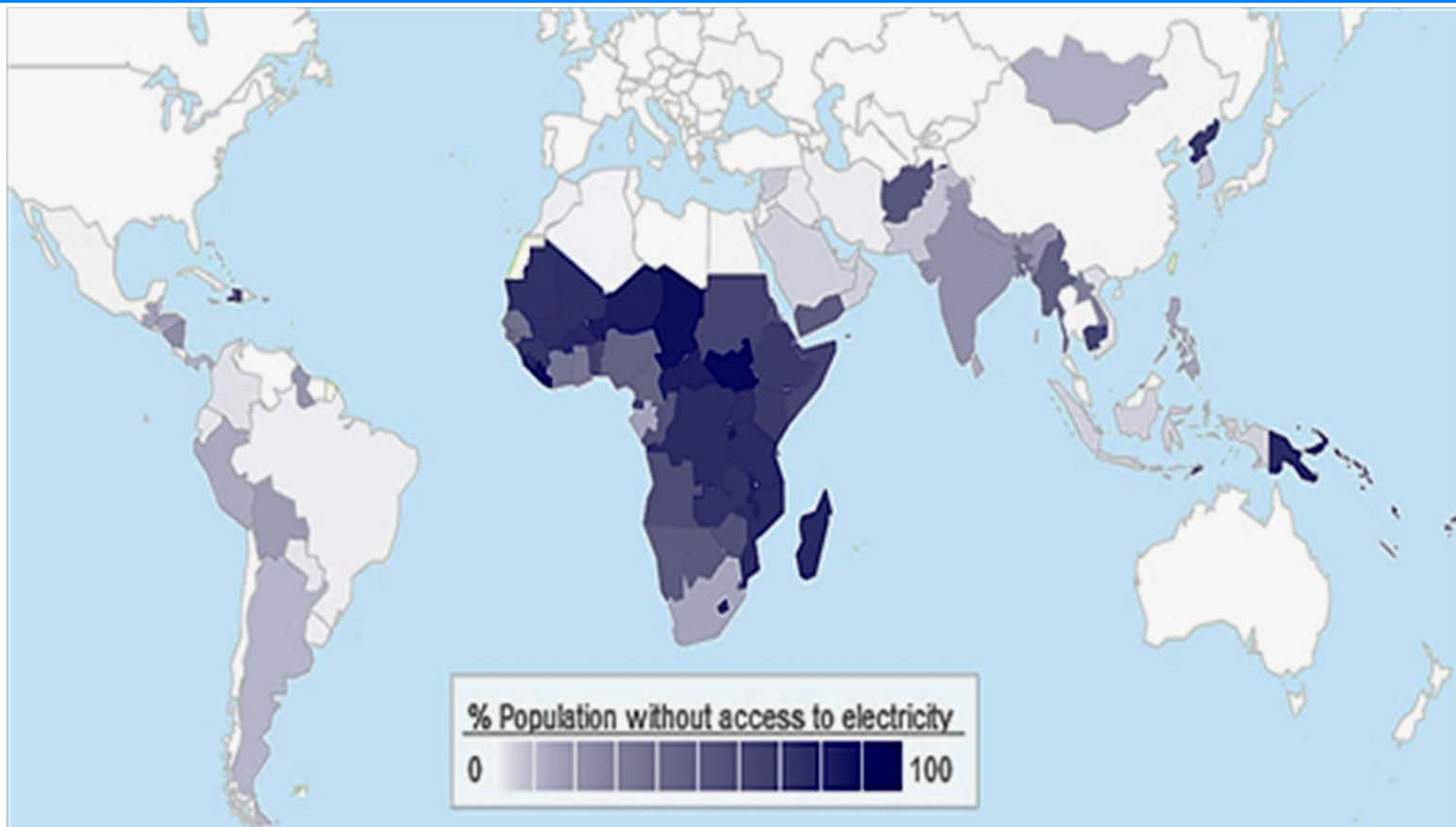
Evangelos Panos, Martin Densing, Kathrin Volkart

**Achieving universal electricity access by 2030
in a sustainable way**

IEW 2015, Abou Dhabi

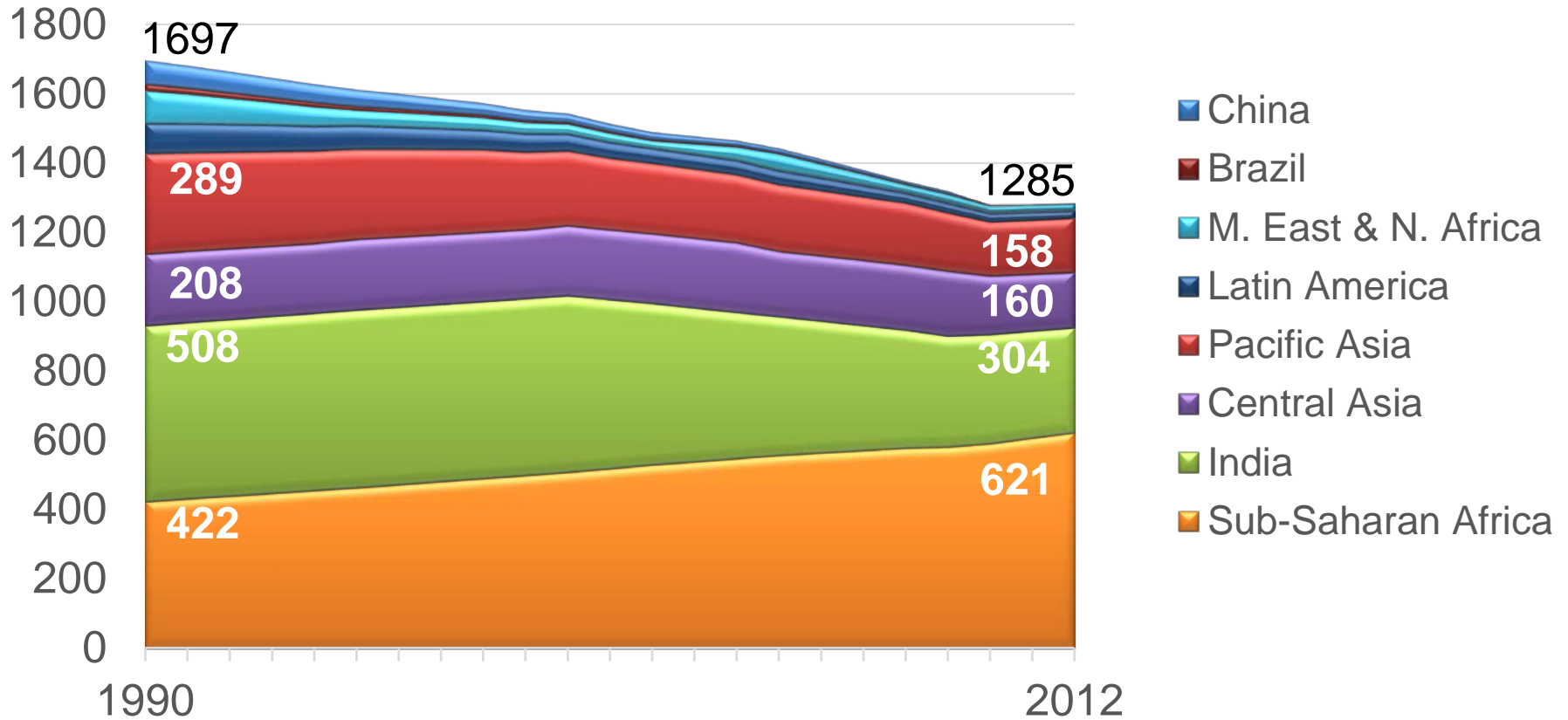
Earth at night: A dark or a bright planet?





- Electricity access (IEA definition): initial connection to a household and then increasing consumption to reach country's average

Millions of people w/o access to electricity



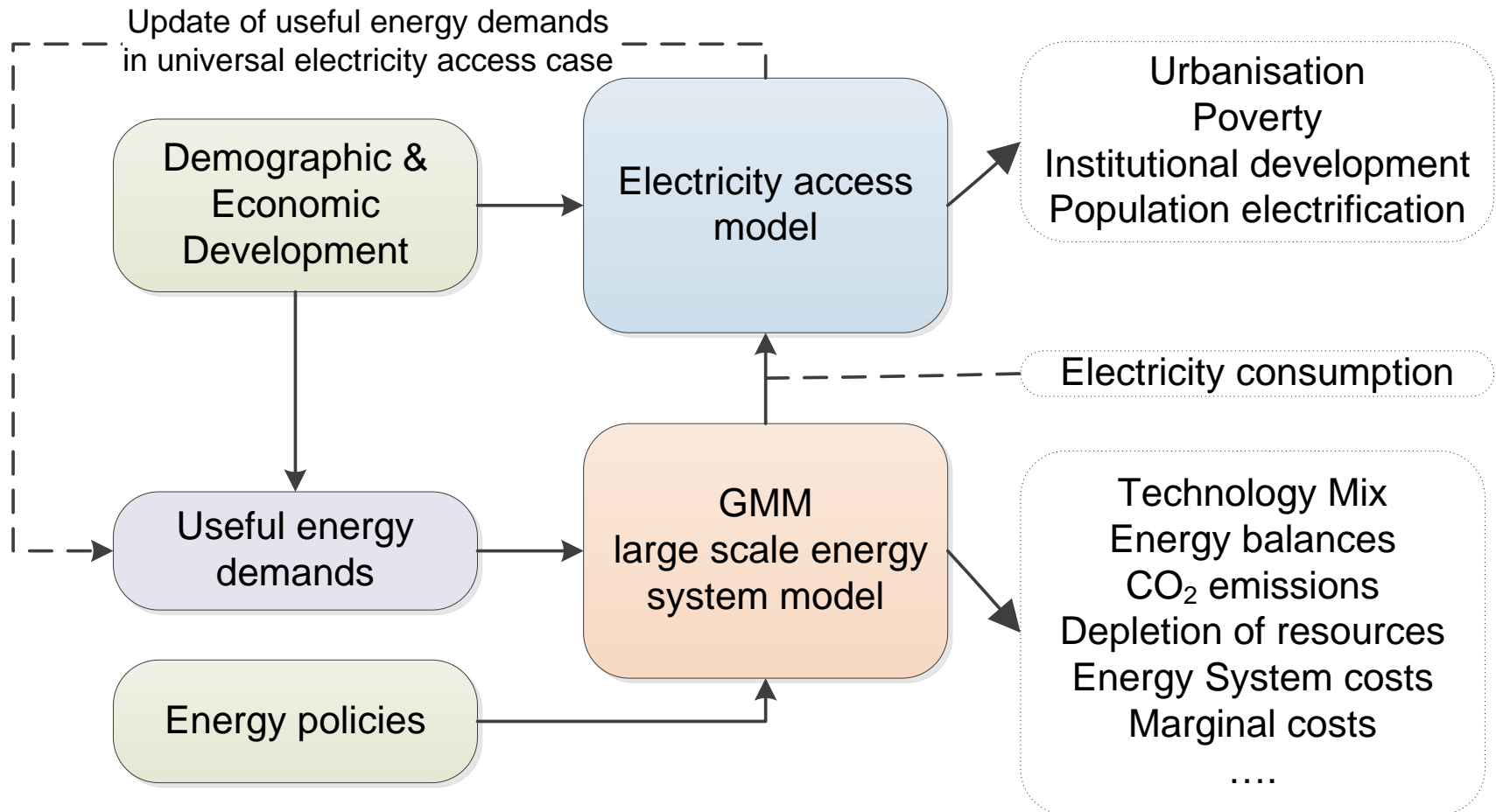
UN SE4ALL initiative aims at universal electricity access by 2030

Goal of the study: Assessment of the effort required to achieve this target in the two WEC global energy scenarios

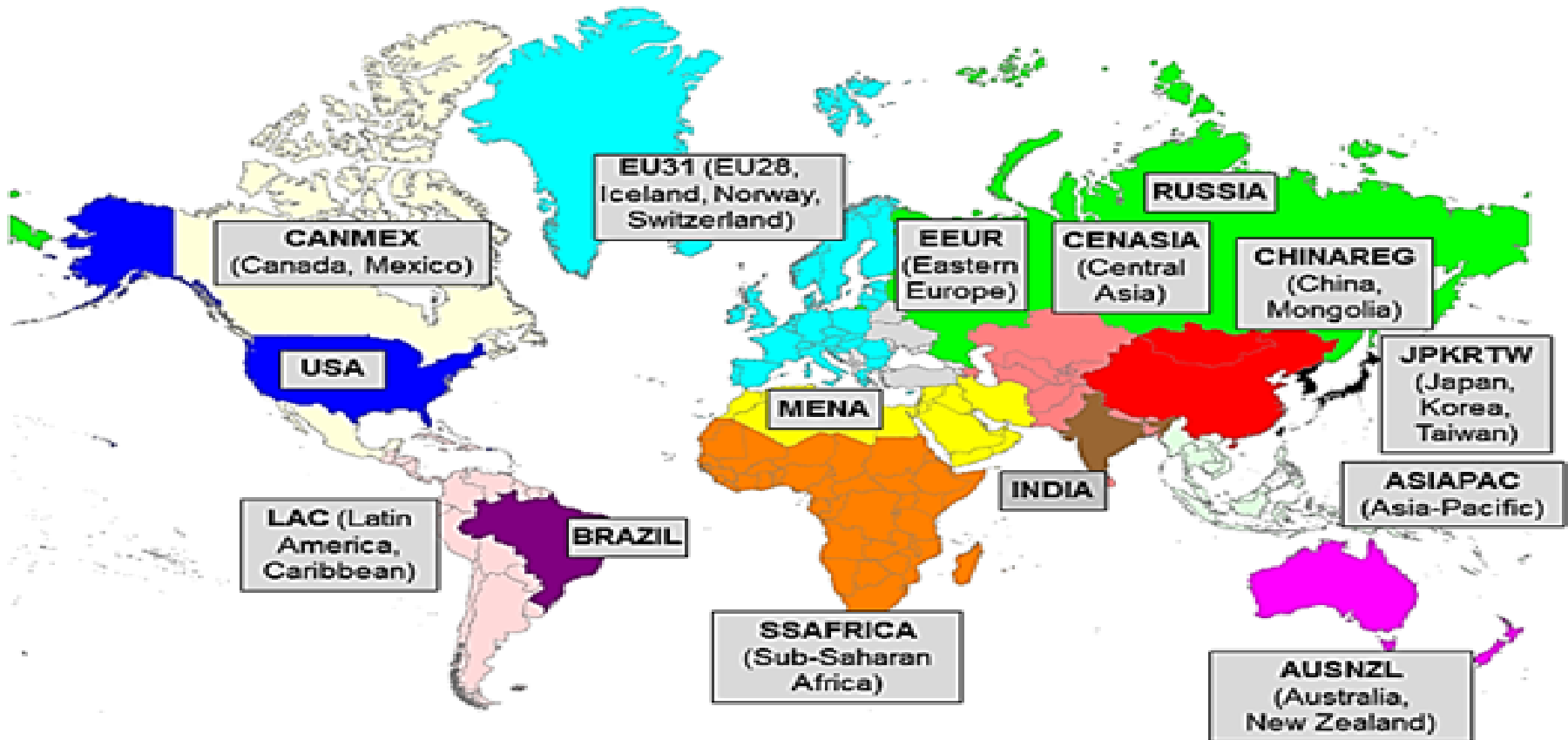
Modelling framework used in the study

Coupling an energy system model with an electricity access model:

- Common economic & demographic assumptions between them
- The interface is established at electricity consumption



- ❑ Cost optimisation of the energy system
- ❑ Perfect foresight → takes the position of a central planner
- ❑ Bottom-up → 400 energy supply & demand technologies
- ❑ Non-cost, policy & behavioural assumptions modelled as constraints
- ❑ Detailed representation of the energy systems of 15 world regions

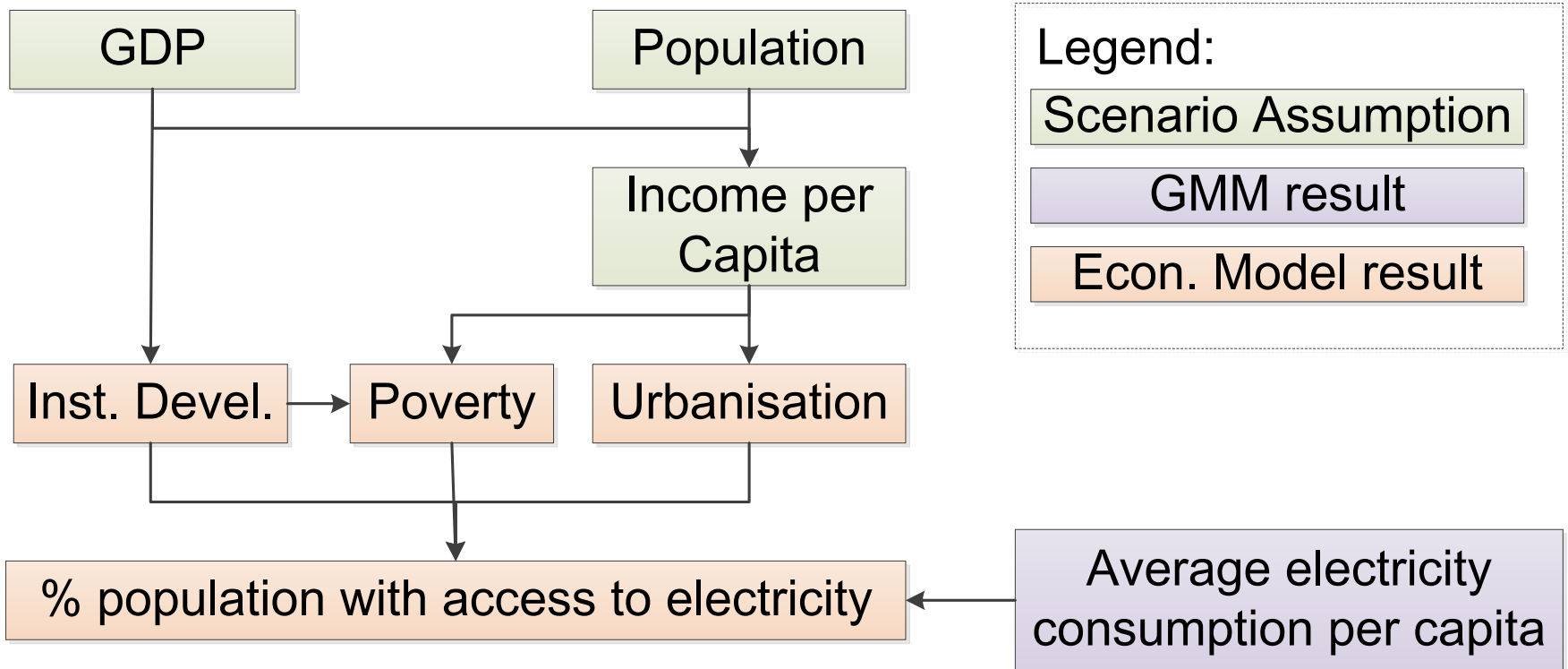


Correlations with electricity access, 1970-12

	Poverty	Urbanisation	CPIA Index	Electricity per capita
Pacific Asia	-0.96	0.99	0.89	0.98
Central Asia	-0.97	0.97	0.34	0.58
India	-0.97	0.99	0.98	0.96
Latin America	-0.41	0.99	0.76	0.96
Middle East & North Africa	-0.68	0.83	0.74	0.77
Sub-Saharan Africa	-0.82	1.00	0.45	0.83

- ❑ 80% of the people w/o access are located to the poorest regions
- ❑ 85% of the people w/o access are located to rural areas
- ❑ Government effectiveness important for success in electrification programmes
- ❑ Energy equity is reflected in electricity per capita correlation

- ❑ Reduced-form econometric model
- ❑ Based on time series 1970-2012 from IEA and World Bank
- ❑ Takes into account key drivers affecting access
- ❑ Polynomial distribution lag estimation



WEC – PSI on-going partnership in “Composing Energy Future to 2050”

<http://www.worldenergy.org/publications/2013/world-energy-scenarios-composing-energy-futures-to-2050/>

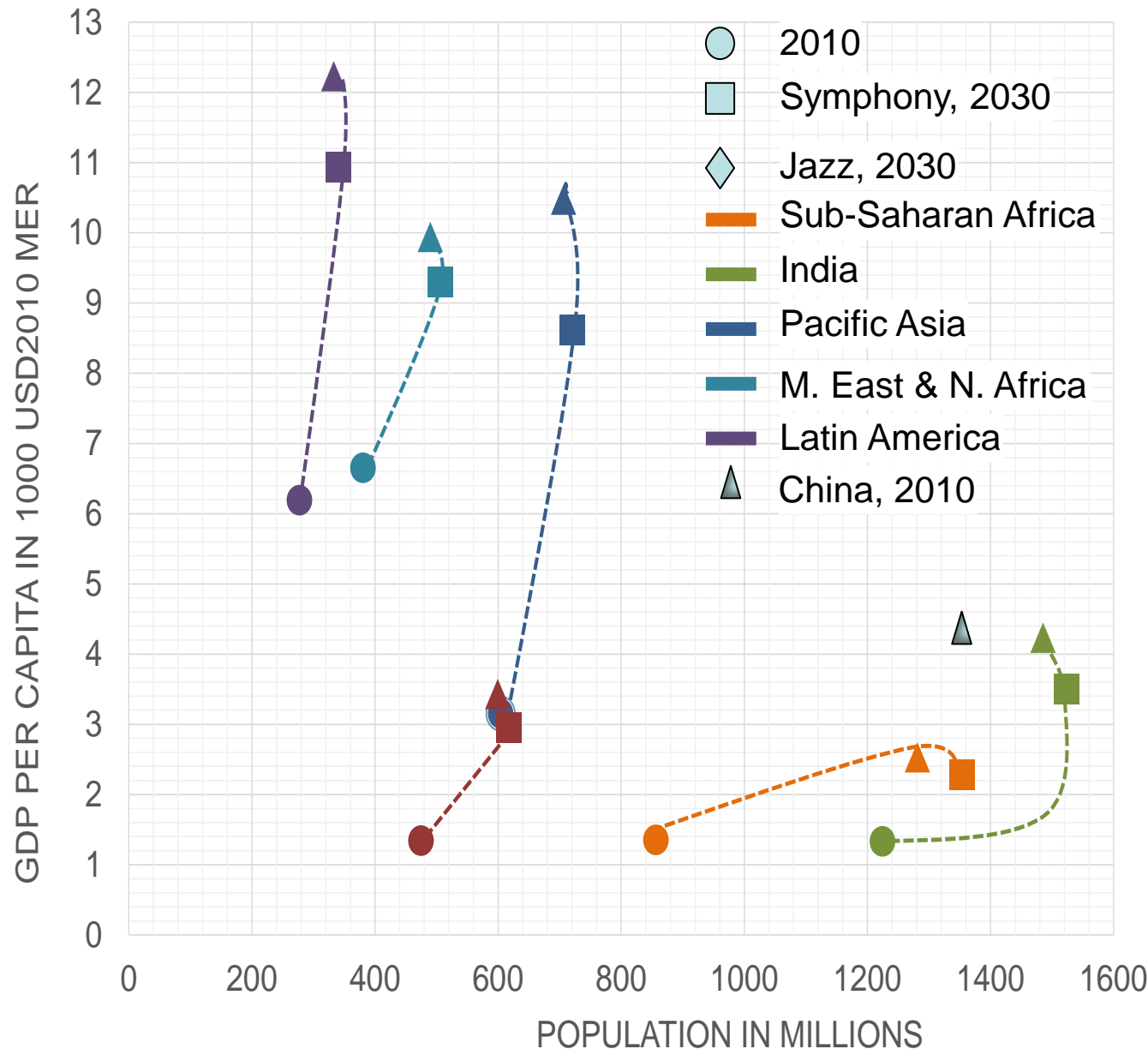
Jazz: Focus on economic growth via low cost energy

- Economy liberalisation, increased FDI, high economic growth
- Lower population fertility
- Technology choice driven by energy markets
- Delayed climate policy action (adaptation)

Symphony: Focus on environmental sustainability & energy security

- Market regulation, energy policy set by governments, limited FDI
- Medium population fertility
- Technology choice driven by government support to low-carbon options
- Strong climate policy with global convergence (mitigation)

Jazz & Symphony: GDP & population



□ In 2010:

- 3.9 billion people
- 2.5 k\$ per capita

□ Jazz in 2030:

- +1 billion people
- 5.7 k\$ per capita (+4.2% p.a.)
- \$5/t CO₂ price

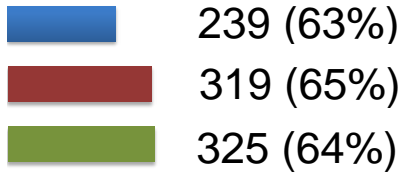
□ Symphony in 2030:

- +1.2 billion people
- 4.9 k\$ per capita (+3.4% p.a.)
- \$32/t CO₂ price

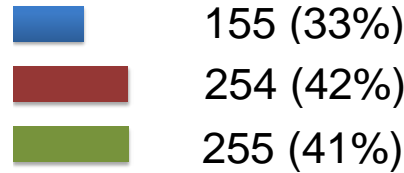
Jazz & Symphony: Urbanisation

Urban population in millions and as % of regions' total population

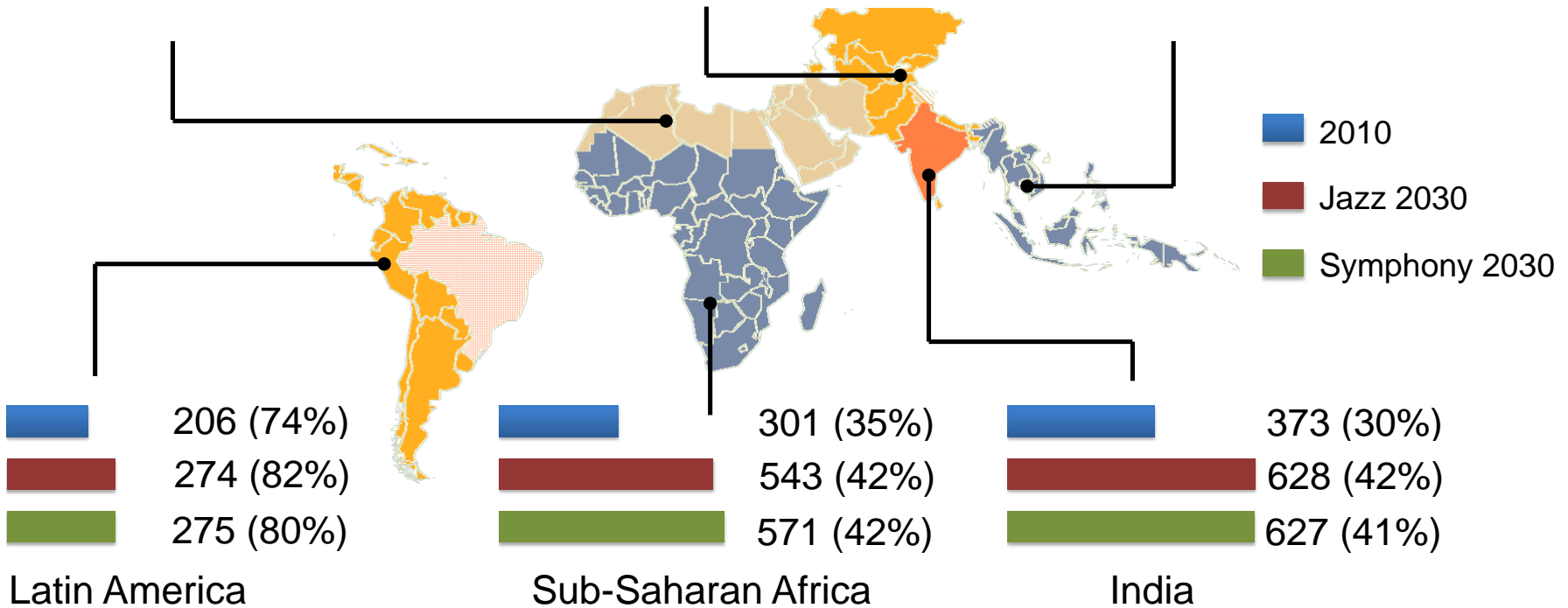
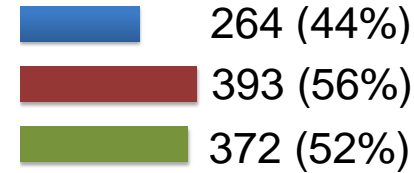
Middle East & North Africa



Central Asia



Pacific Asia



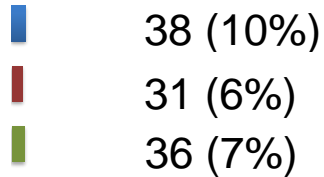
Urbanisation rate: in 2010 40%, in 2030 49% in Jazz, 48% in Symphony

Internal migration contributes to >50% in urban population increase

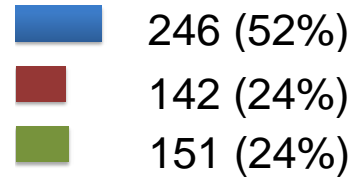
Jazz & Symphony: Poverty

Population living with <\$2 per day, in millions and as % of regions' total

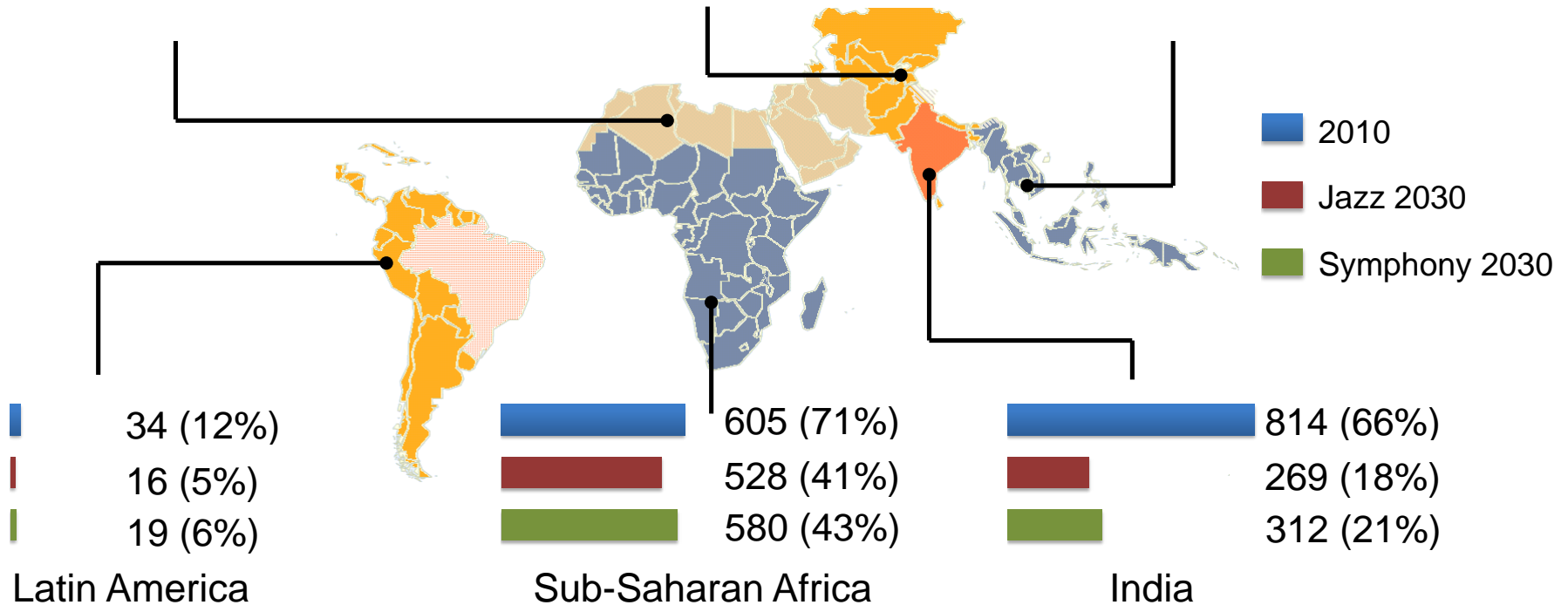
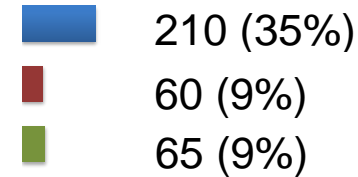
Middle East & North Africa



Central Asia



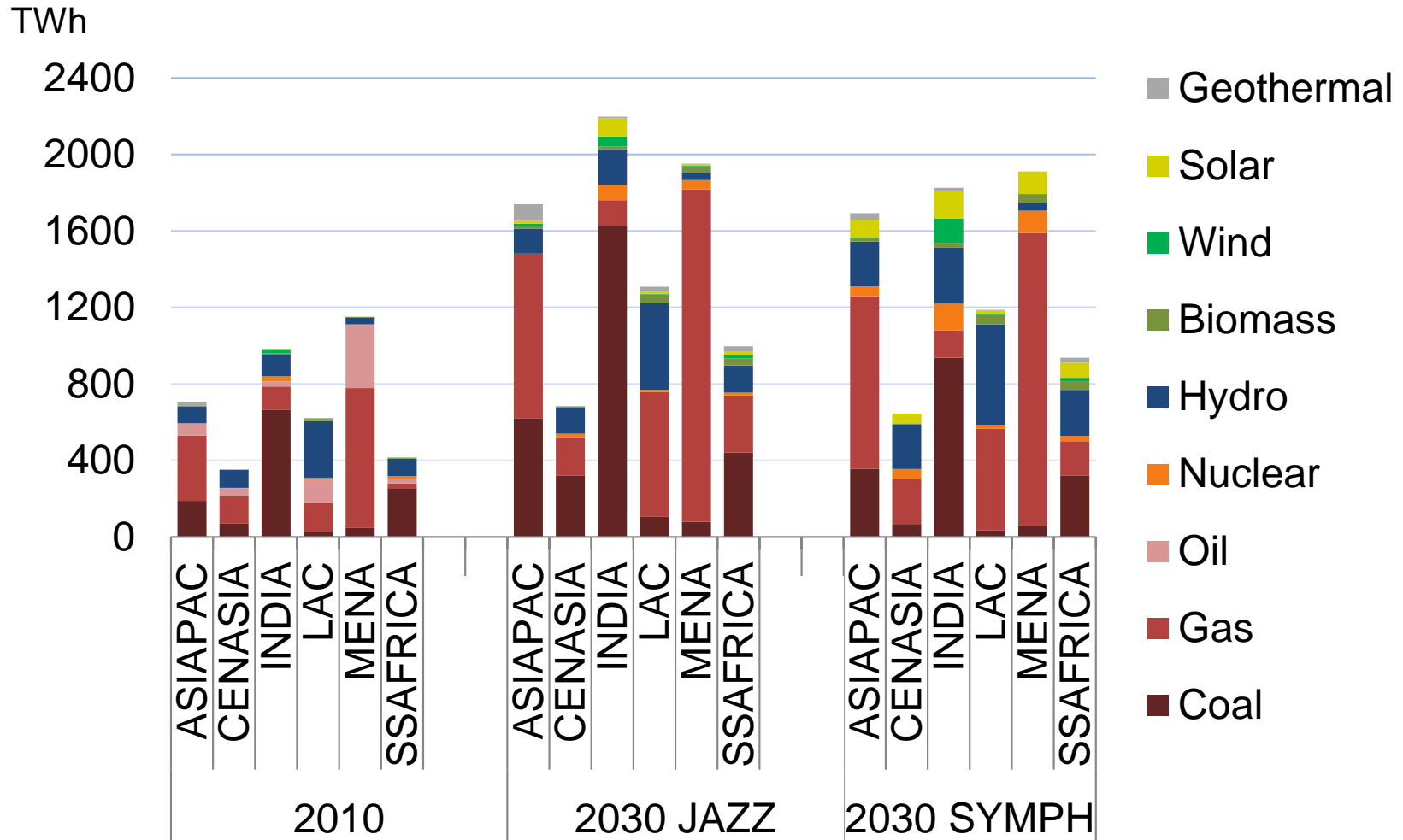
Pacific Asia



□ Poverty: in 2010 51%, in 2030 21% in Jazz, 23% in Symphony

□ Poverty is reduced in Asia, remains significant in Sub-Saharan Africa

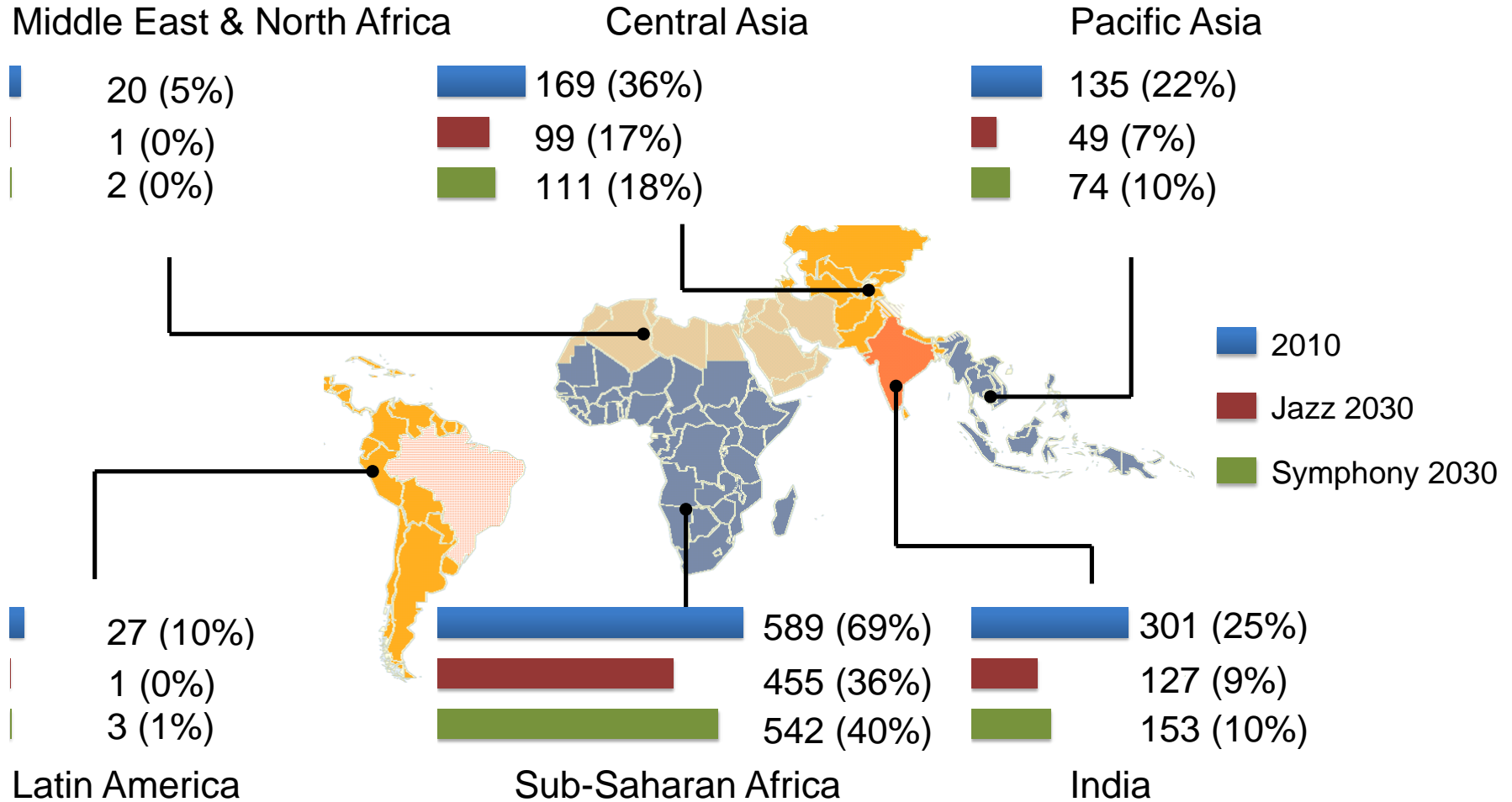
Electricity generation by major fuel and region



- Jazz: flexible projects with short construction times, coal & gas dominate
- Symphony: lower-carbon pathway driven by climate policy and subsidies

Jazz & Symphony: Electricity access

Population without access to electricity in millions and as % of total



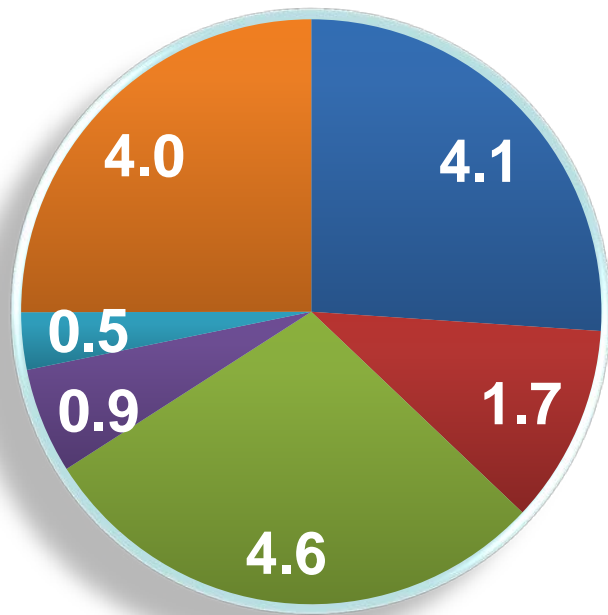
- Assumption: no additional policies are enacted over the projection period
- Population w/o electricity access: Jazz 733 million, Symphony 885 million

Jazz & Symphony: Electricity access

Annual investment to electricity access over the period 2011-30, USD2010

Jazz: \$15.8 billion

Symphony: \$17.0 billion



■ Pacific Asia

■ Central Asia

■ India

■ Latin America

■ M. East & N. Africa

■ Sub-Saharan Africa

□ Investment for electricity access in 2009 was \$9 billion (IEA)

□ Connection cost per capita: Jazz \$370, Symphony \$440

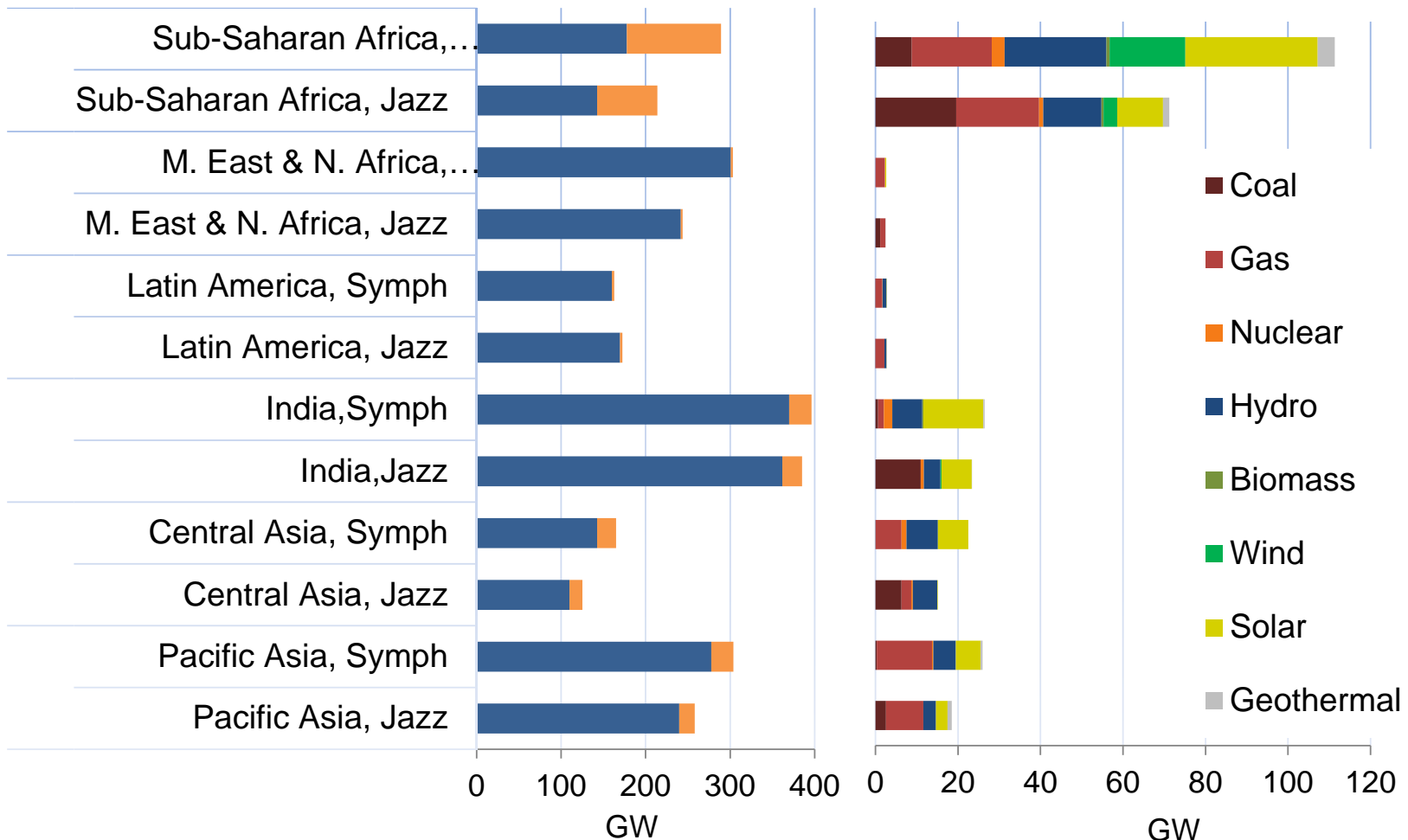
Initial annual consumption of 120 kWh per person

(equivalent to the use of a floor fan, a mobile telephone, an efficient refrigerator, a small TV and two bulbs for about 5h/day in a household of 5 persons)

- Reaching the regional average levels after 5 years to ensure energy equity

Electricity demand	Jazz (in TWh)		Symphony (in TWh)	
	Base Case	Additional	Base Case	Additional
<i>In 2030</i>				
Pacific Asia	922	69	788	90
Central Asia	301	59	302	66
India	942	88	815	91
Latin America	543	2	489	4
M. East & N. Africa	1109	3	1086	4
Sub-Saharan Africa	387	285	369	329
Total	4203	507 (+12%)	3848	585 (+15%)

Cumulative electricity capacity investment in GW

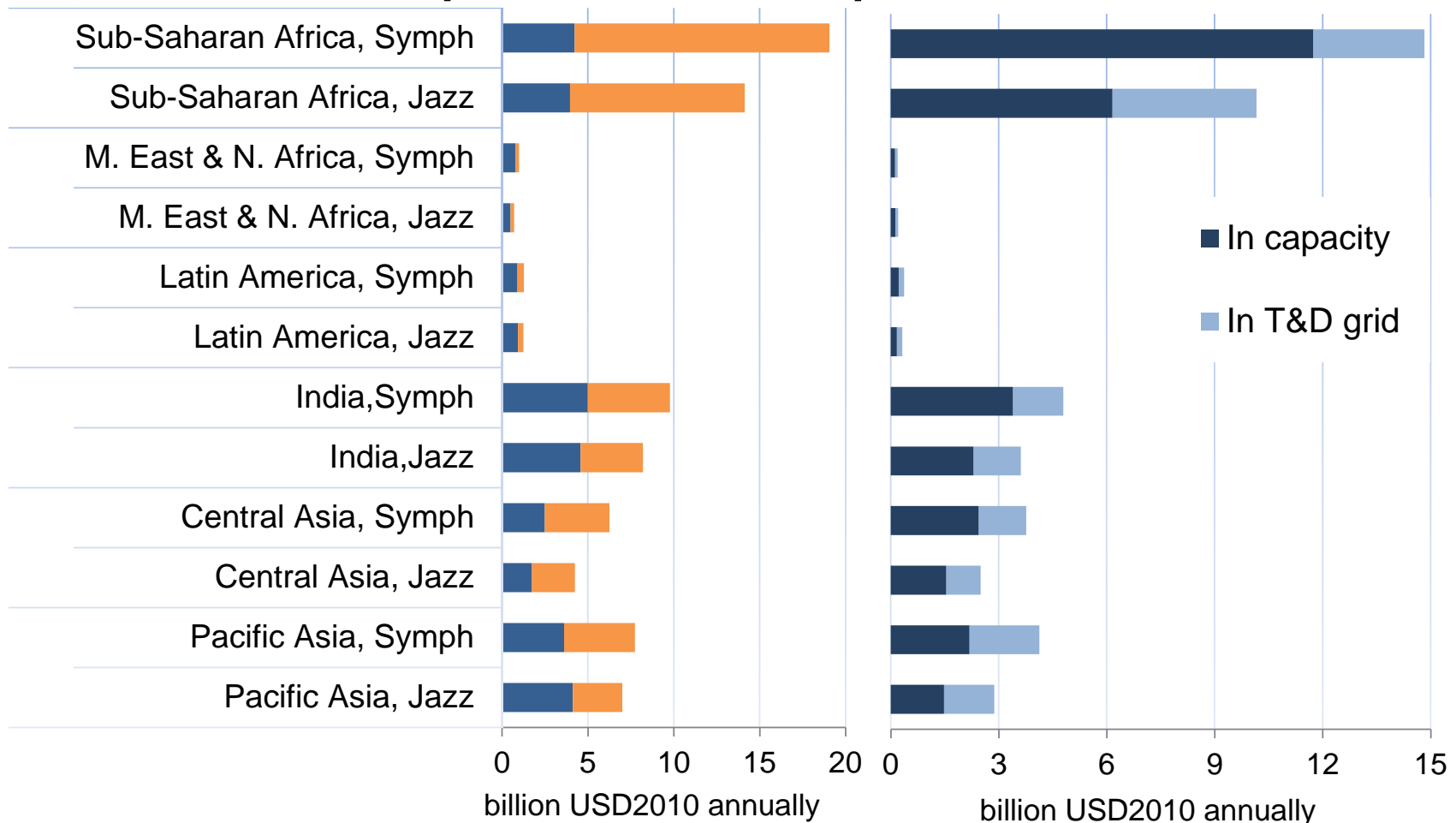


■ Base case ■ Additional in 100% access Breakdown of the additional investment

□ Additional electricity capacity: Jazz +133 GW, Symphony +192 GW

□ Solar and hydro for rural electrification, fossil for on-grid urban electrification

Annual investment expenditure over the period 2011-30, billion USD2010



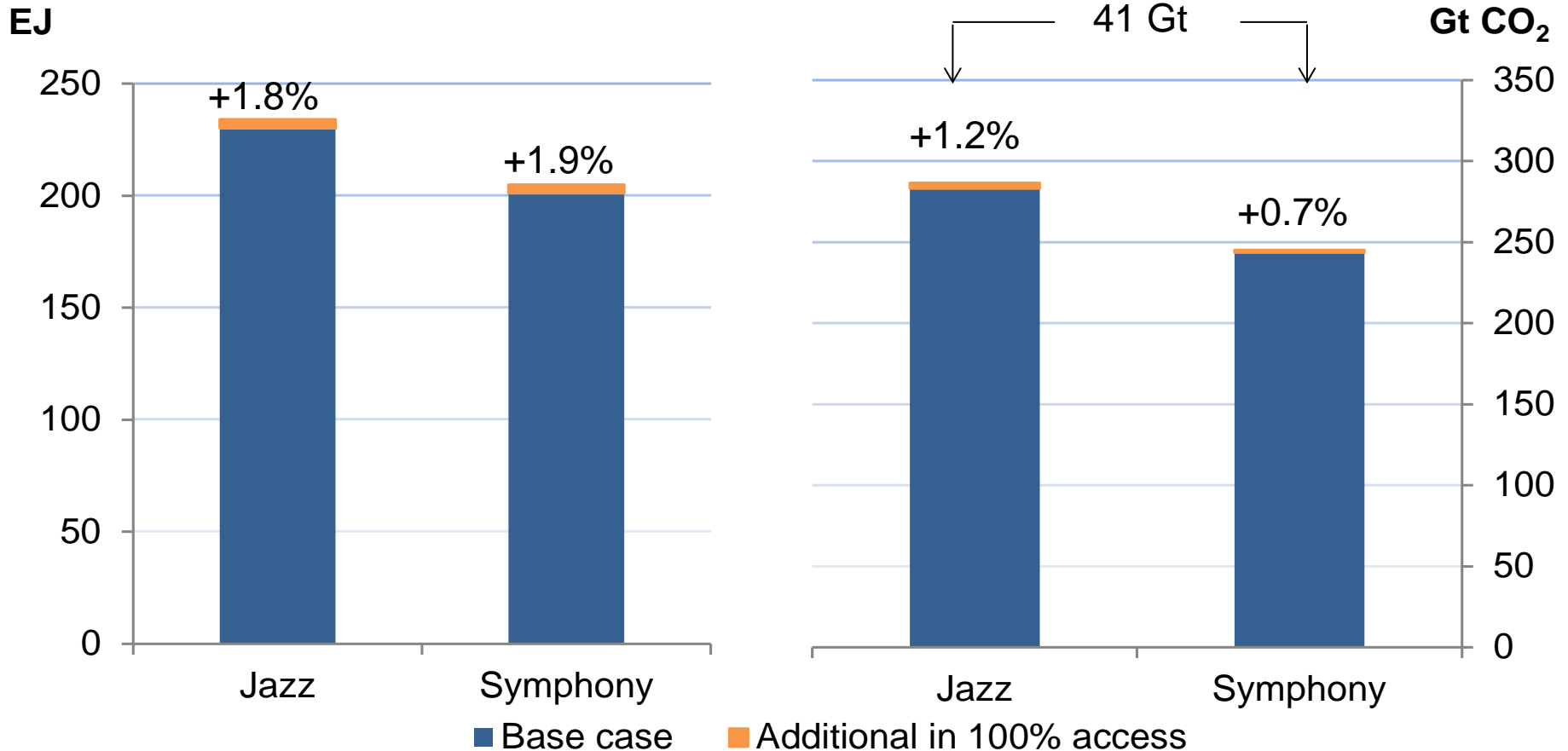
■ Base case ■ Additional in 100% access

Breakdown of the additional investment

■ Total annual investment 2011-30: Jazz \$36 billion, Symphony \$45 billion

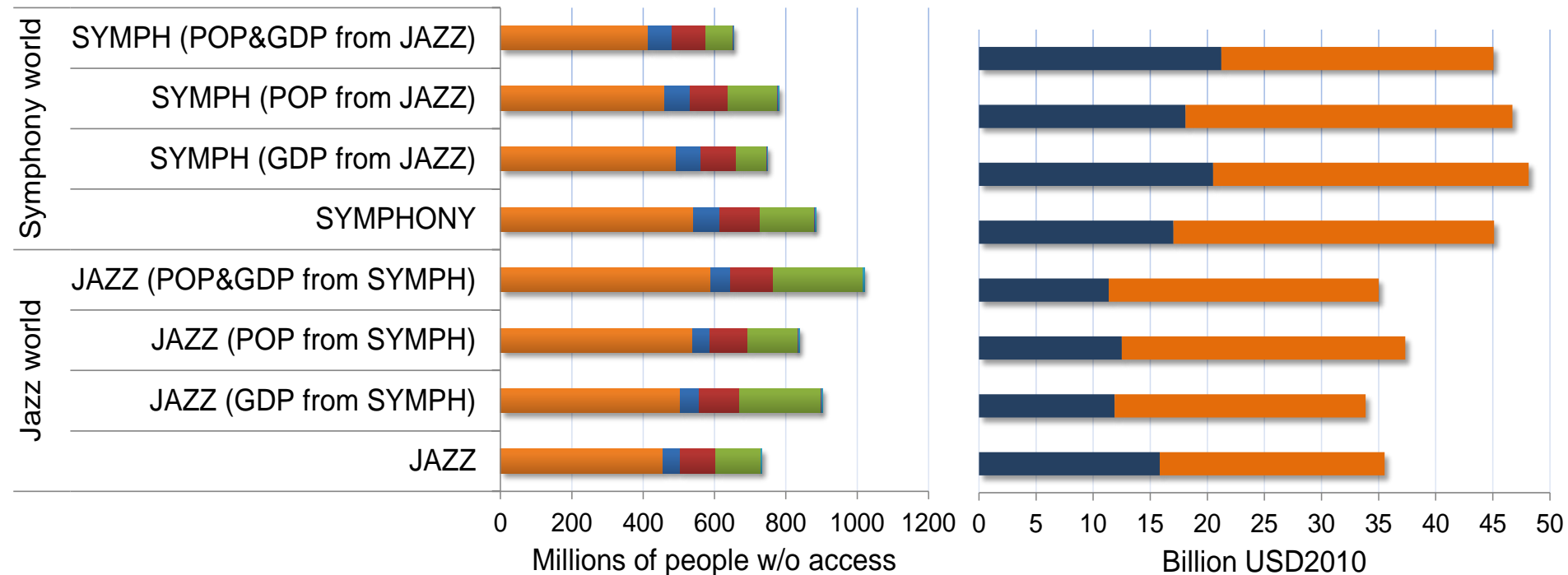
■ < 4% of the global investment in the power sector in the WEC/PSI scenarios

Impacts on primary energy supply in 2030 (left) & cumulative CO₂ emissions 2011-30 (right)



- Low levels of consumption by people gaining access → minor impacts on TPES
- High proportion of renewable solutions adopted → minor impacts on CO₂
- Symphony vs Jazz: -13% energy consumption, -25% cum. CO₂ emissions

Sensitivity analysis on GDP and population assumptions



- Sub-Saharan Africa
- Pacific Asia
- Base case investment
- Central Asia
- India
- Incremental investment to achieve universal access
- Latin America
- Middle East and North Africa

□ Annual investment expenditure over the period 2011-30:

- In a Jazz-like world \$34 – 37 billion
- In a Symphony-like world \$45 – 48 billion
- *For reference: IEA \$45 billion , IIASA \$33 – 38 billion*

- ❑ Meeting the SE4ALL objective of universal access in the WEC scenarios requires annual investment of **\$34 to \$48 billion** over the period 2011-30
- ❑ This is **less than 4% of the global investment** in the electricity sector over the same period
- ❑ **Solar and hydro power** are key options for increasing the electrification of the population (especially in rural areas)
- ❑ Establishing universal electricity access results in **minor impacts on energy demand and CO₂ emissions**
- ❑ A lower-carbon pathway is about **27% more expensive**, but it requires **13% less energy consumption** and produces **25% less cumulative CO₂ emissions**
- ❑ Methodological issues:
 - The diversity of the regions is not fully captured; next step is to further increase the spatial level of the analysis
 - Coupling with CGE models could provide more insights on the socio-economic drivers of electricity access and on investment financing possibilities

Thank you for the attention !

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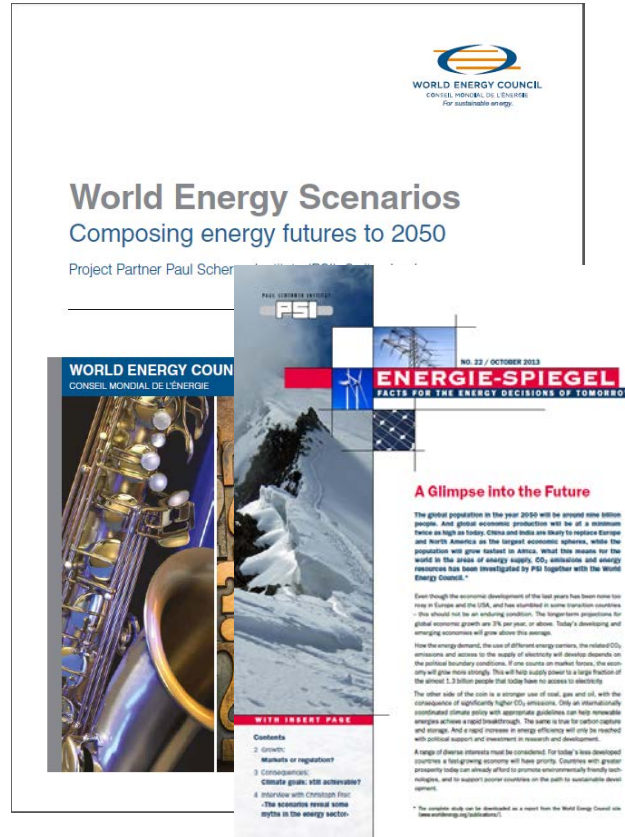
SUPPORT SLIDES

Global Transport Scenarios 2050



2011

World Energy Scenarios 2050



2013

Regional Deep Dives



2014-2015

<http://www.worldenergy.org/publications/2011/global-transport-scenarios-2050/>

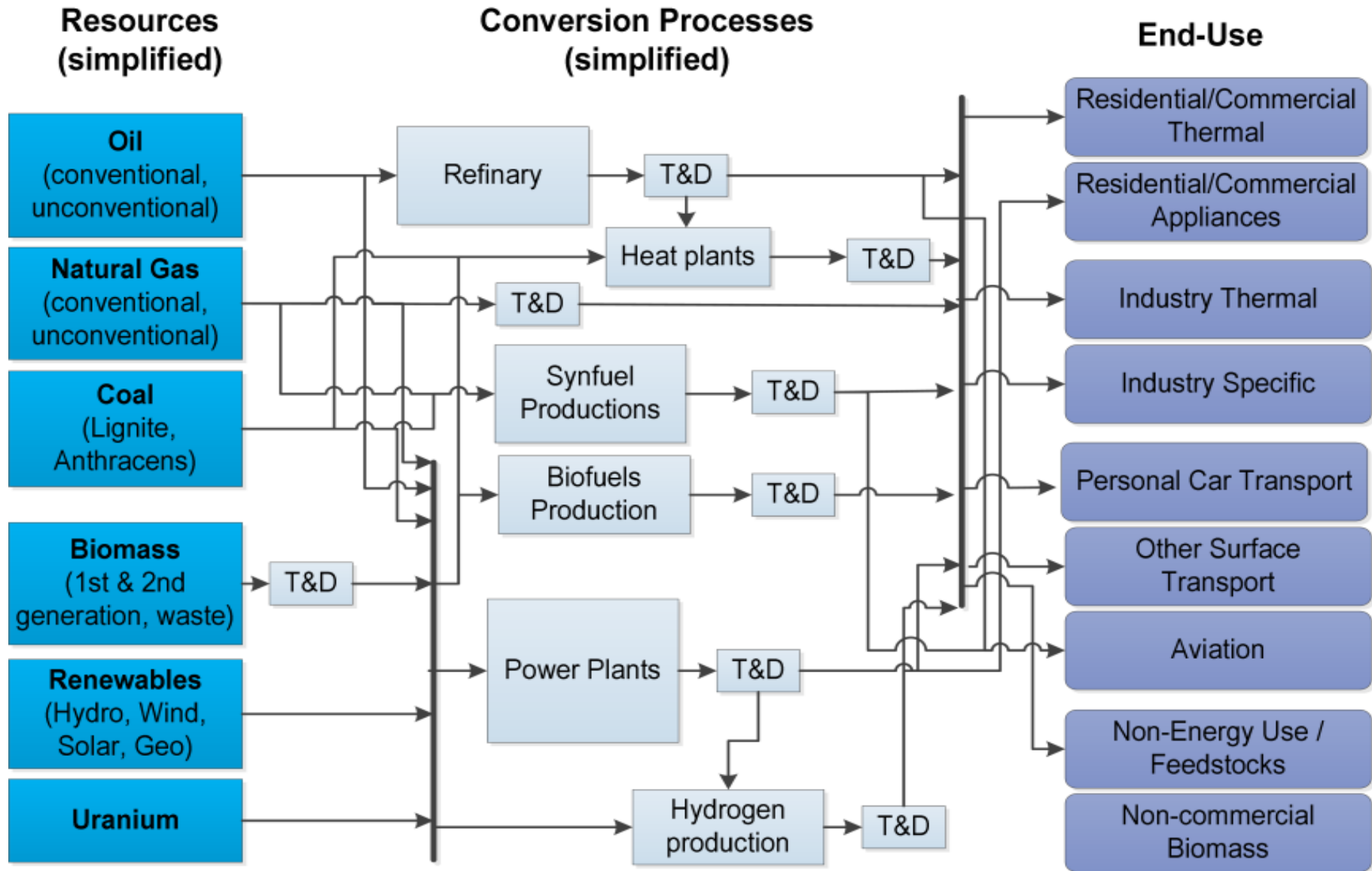
<http://www.worldenergy.org/publications/2013/world-energy-scenarios-composing-energy-futures-to-2050/>

http://www.psi.ch/info/MediaBoard/Energiespiegel_22_e.pdf

Data used in the econometric model

Variable	Unit	Source
Income per capita	USD2005 (PPP)	World Bank
Urbanisation	% of population	UNPD
Poverty	% of population living with less than \$2 per day	World Bank
Institutional development	Average of CPIA indices	World Bank
Electricity per capita	kWh per capita in residential/commercial sectors	IEA energy balances
Electrification of demand	% of electricity in final energy consumption in residential/commercial	IEA energy balances
Electricity access	% of population with access to electricity	IEA WEO series

The GMM Reference System (example)



$$\ln\left(\frac{elcaces_{r,t}}{1-elcaces_{r,t}}\right) = \beta_{r,0} + \beta_{r,1} \cdot \sum_{k_r} (\gamma_{r,k_r,1} \cdot poverty_{r,t-k_r}) + \beta_{r,2} \cdot \sum_{\lambda_r} (\gamma_{r,\lambda_r,2} \cdot urbanisation_{r,t-\lambda_r}) + \beta_{r,3} \cdot \sum_{\nu_r} (\gamma_{r,\nu_r,3} \cdot elccap_{r,t-\nu_r}) + a_{r,t} + \epsilon_{r,t}$$

$$\ln\left(\frac{povert_{r,t}}{povert_{r,t-1}}\right) = \beta_{r,0} + \beta_{r,1} \cdot \sum_{k_r} \left(\gamma_{k_r} \cdot \ln\left(\frac{incom_{r,t-k_r}}{incom_{r,t-k_r-1}}\right) \right) + \beta_{r,2} \cdot \sum_{\lambda_r} (\gamma_{\lambda_r} \cdot \ln(cpia_{r,t-k_r})) + \epsilon_{r,t}$$

$$\ln\left(\frac{cpia_{r,t}}{6-cpia_{r,t}}\right) = \beta_{r,0} + \beta_{r,1} \cdot \sum_{k_r} (\gamma_{k_r} \cdot gdp_{r,t-k_r}) + \epsilon_{r,t}$$

$$\ln\left(\frac{migration_{r,t}}{1-migration_{r,t}}\right) = \beta_{r,0} + \beta_{r,1} \cdot \sum_{k_r} (\gamma_{k_r} \cdot income_{r,t-k_r}) + \epsilon_{r,t}$$

$$urbanisation_{r,t} = urbanisation_{r,t-1} \cdot \frac{pop_{r,t}}{pop_{r,t-1}} + migration_{r,t} \cdot pop_{r,t} \cdot \frac{pop_{r,t-1} - urbanisation_{r,t-1}}{pop_{r,t-1}}$$

Example of estimation using PDLs

Dependent Variable: LOG(POV_SSAFRICA/POV_SSAFRICA(-1))
 Method: Least Squares
 Date: 01/31/14 Time: 10:11
 Sample (adjusted): 1983 2010
 Included observations: 28 after adjustments
 Convergence achieved after 8 iterations

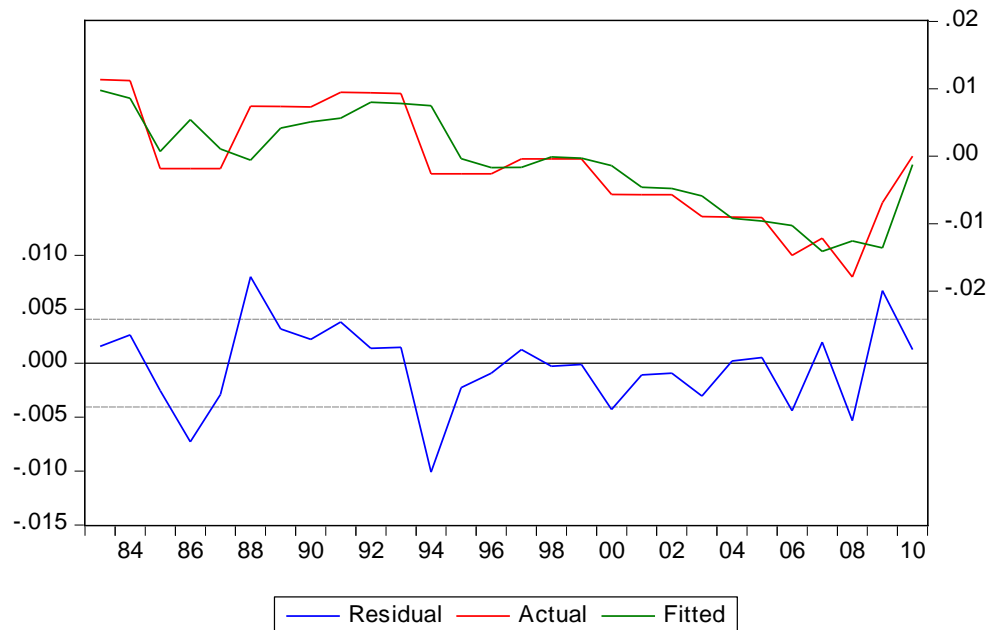
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D_POV_SSAFRICA	0.007861	0.002816	2.791170	0.0099
PDL01	-0.038314	0.010728	-3.571341	0.0015
AR(1)	0.522063	0.179656	2.905910	0.0076

R-squared	0.761904	Mean dependent var	-0.001334
Adjusted R-squared	0.742856	S.D. dependent var	0.008014
S.E. of regression	0.004064	Akaike info criterion	-8.072339
Sum squared resid	0.000413	Schwarz criterion	-7.929603
Log likelihood	116.0127	Hannan-Quinn criter.	-8.028703
Durbin-Watson stat	1.844041		

Inverted AR Roots .52

Lag Distribution of LOG(GDPP... i	Coefficient	Std. Error	t-Statistic
0	-0.07024	0.01967	-3.57134
1	-0.06386	0.01788	-3.57134
2	-0.05747	0.01609	-3.57134
3	-0.05109	0.01430	-3.57134
4	-0.04470	0.01252	-3.57134
5	-0.03831	0.01073	-3.57134
6	-0.03193	0.00894	-3.57134
7	-0.02554	0.00715	-3.57134
8	-0.01916	0.00536	-3.57134
9	-0.01277	0.00358	-3.57134
...	-0.00639	0.00179	-3.57134
Sum of Lags	-0.42145	0.11801	-3.57134

$$\ln\left(\frac{poverty_t}{poverty_{t-1}}\right) = \beta_0 + \beta_1 \cdot \sum_{k=0}^{10} \gamma_k \cdot \ln\left(\frac{income_{t-k}}{income_{t-k-1}}\right) + AR(1) + \epsilon_t$$



Some of the electrification programmes considered in the study

Country	Programme name	Objective
North & South Latin America	Enabling Electricity - ENEL	Implementing more than 30 projects in 20 Latin America Countries to improve electricity access in isolated communities [57]
Brazil	Luz para Todos	Aiming at increasing rural electrification in Brazil (2003-2014) [58]
India	Rajiv Gandhi Grameen Vidyutikaran Programme	Electrification of more than 17 million rural households [59]
Bangladesh	Master Plan for Electrification	Electricity for all by 2020 [60]
Nepal	Rural Electrification Programme	Electricity for all by 2027 [61]
Philippines	Philippines Energy Plan	Electrification of 90% of households by 2017 [62]
Indonesia	Rural Electrification Programmes	Electricity access for 95% of the population by 2020 [63].
Vietnam	National energy development programme	Universal electrification by 2020 [64]
Ghana	National Electrification Scheme	100% electricity access by 2020 [65]
South Africa	Integrated National Electrification Programme	100% electricity access by 2020 [66]
Zambia	Rural Electrification Master Plan	Electricity access for 78% in urban and 15% in rural areas by 2015 [67]