Paul Scherrer Institut

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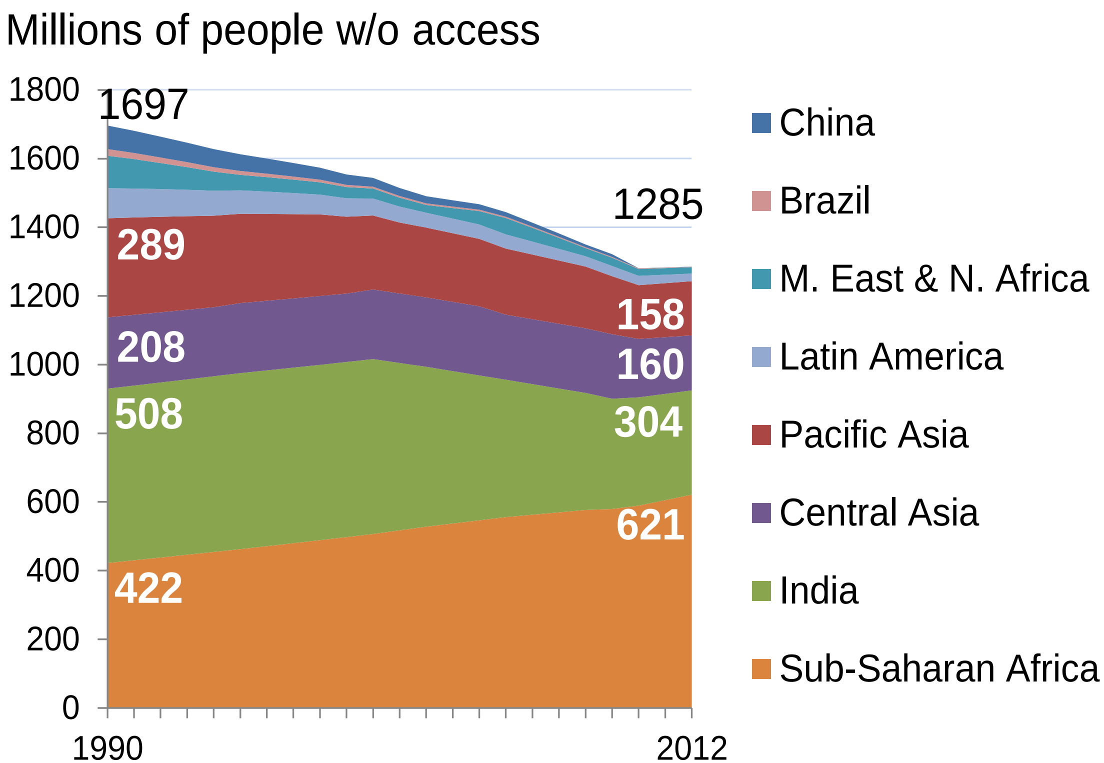
Achieving universal electricity access by 2030 in a sustainable way

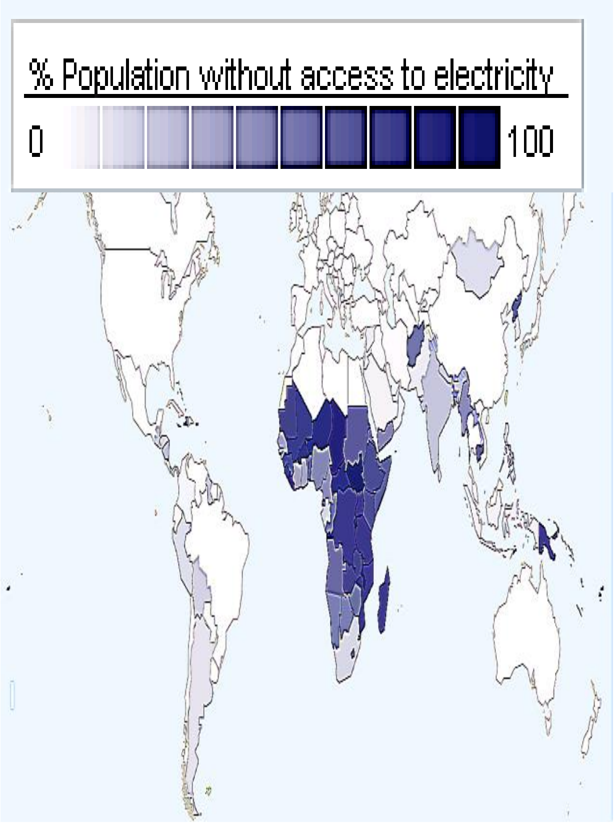
IEW 2015, Abou Dhabi

Presentation structure

- Population without access to electricity and the SE4All objective
- Methodology used to address the SE4All objective
  - The modelling framework
  - The World Energy Council/PSI global energy scenarios “Jazz” and “Symphony”
- Electricity access in the original WEC/PSI scenarios and its drivers
- Universal electricity access in the WEC/PSI scenarios
- Conclusions

Population w/o access to electricity



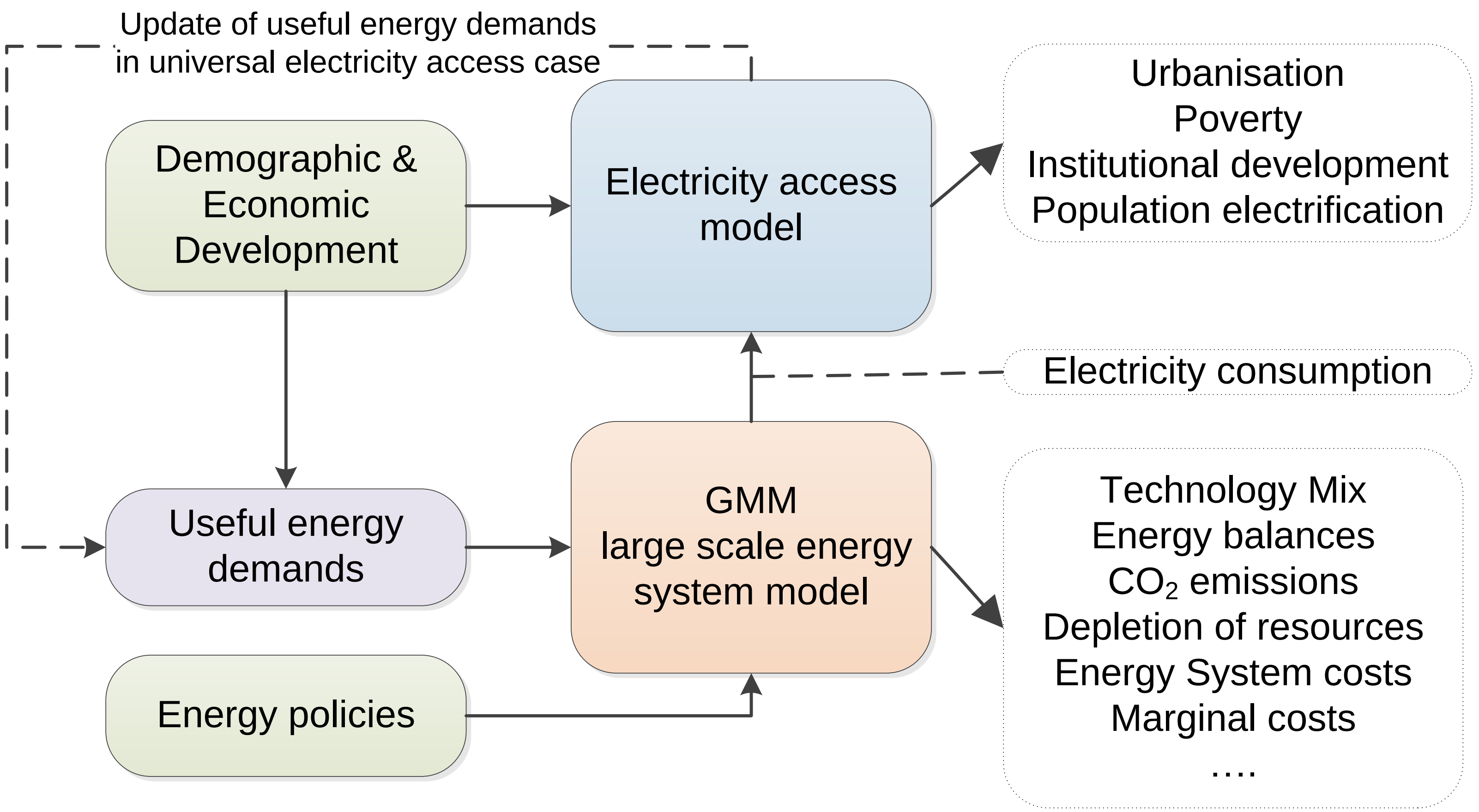


- Electricity access (IEA definition): initial connection to a household and then increasing consumption to reach country's average
- UN SE4ALL initiative (launched in 2011) aims at universal electricity access by 2030
- **Goal of the study: Assessment of the effort required in the two WEC energy scenarios: a) "Jazz": focus on low cost energy ; b) "Symphony": focus on sustainability**

Modelling framework for electricity access

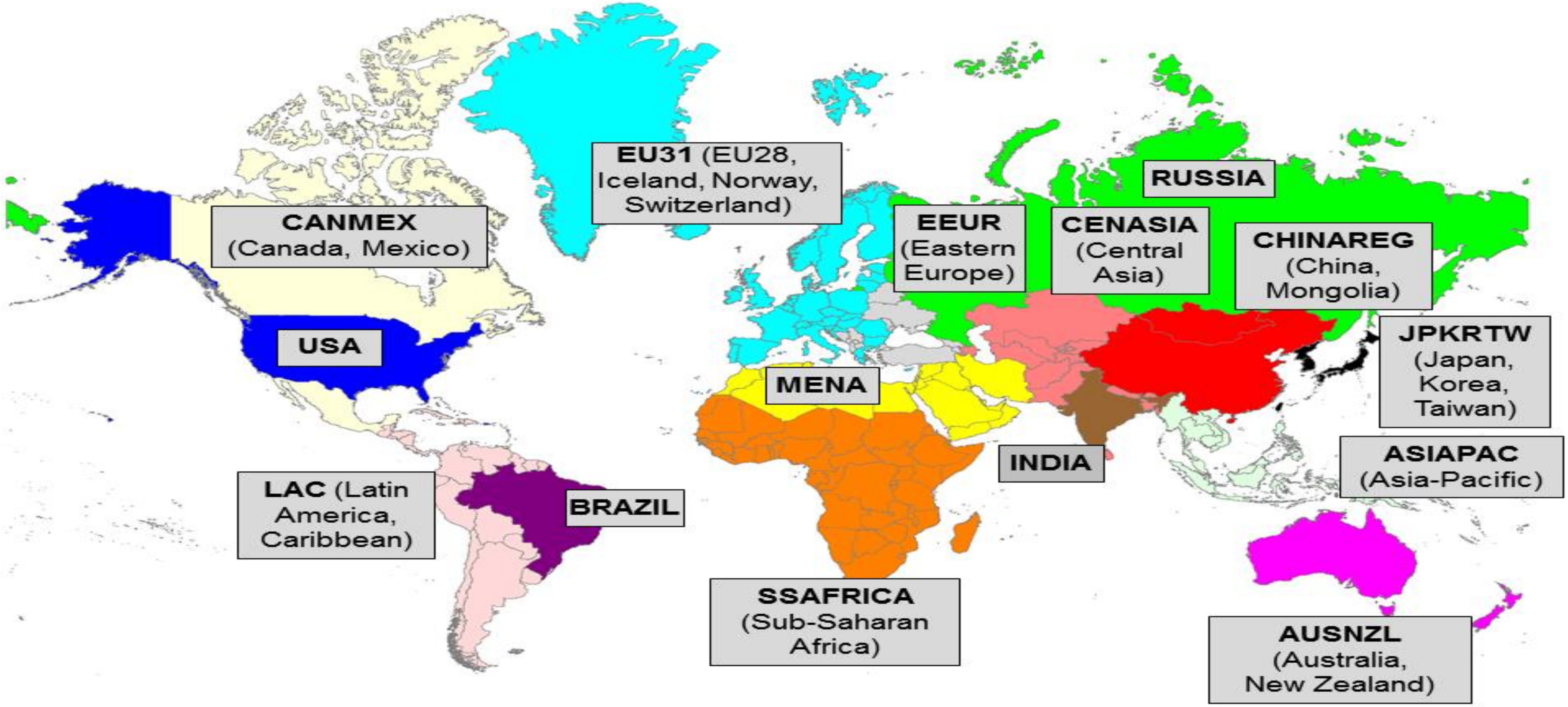
Coupling an energy system model with an electricity access model:

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



The Global Multi-regional MARKAL Model

- 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

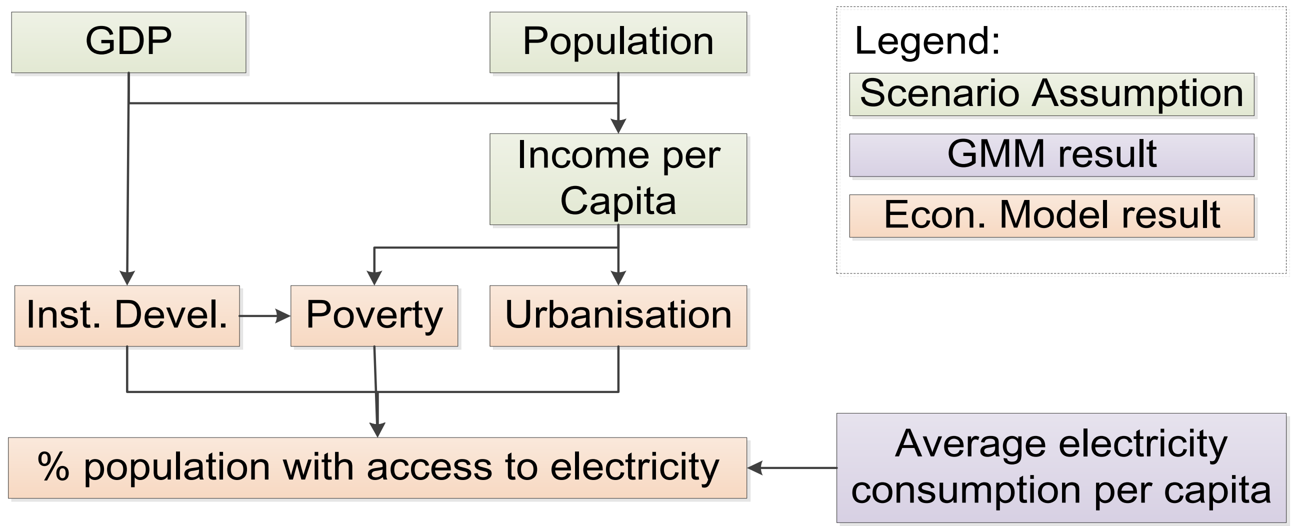


The electricity access model

- 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

Correlations of electricity access and its main drivers, 1970-2012

	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
M. East & N. Africa	-0.68	0.83	0.74	0.77
Sub-Saharan Africa	-0.82	1.00	0.45	0.83



The Jazz and Symphony scenarios

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

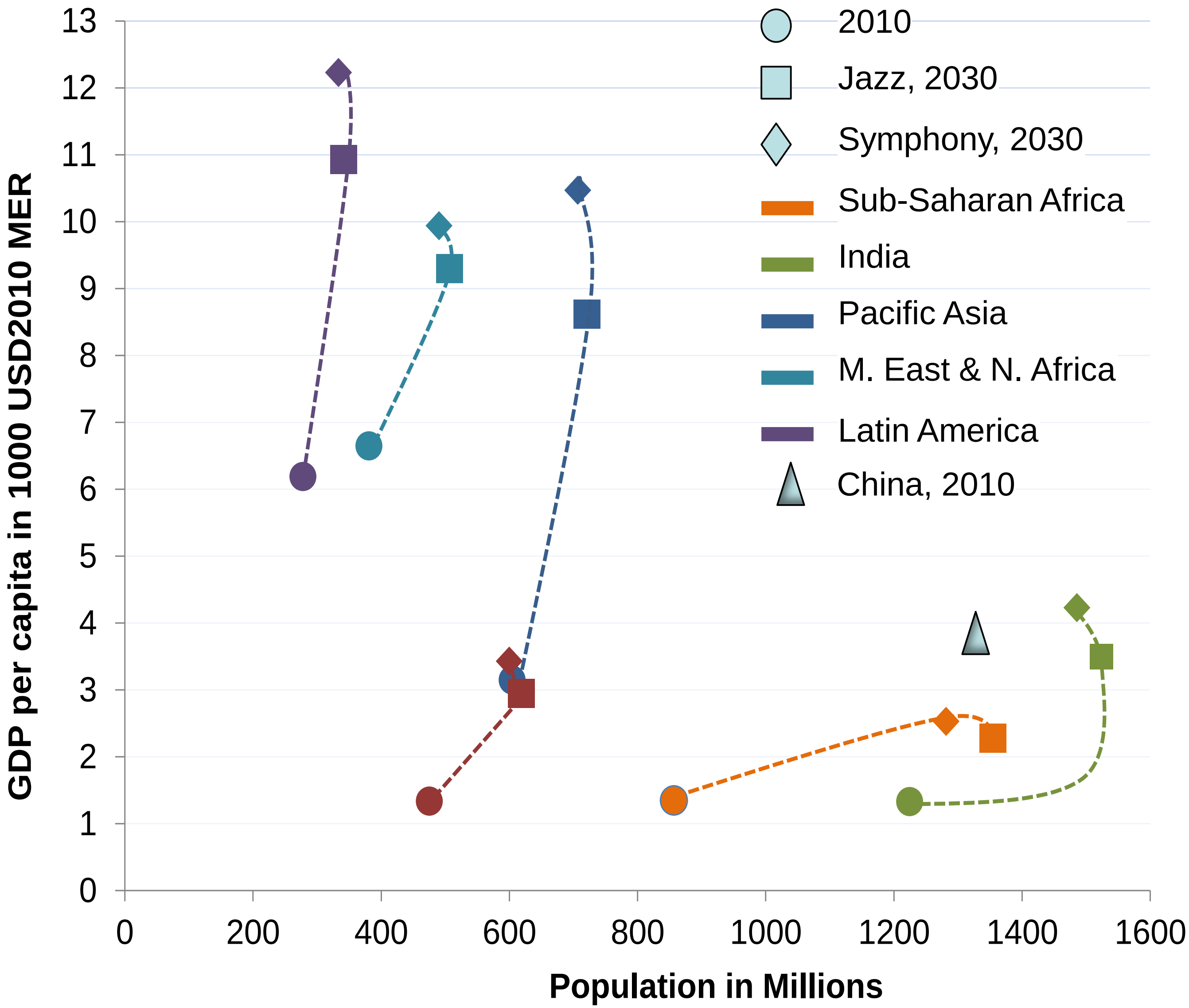
Jazz: Focus on economic growth via low cost energy

- 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 and 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)

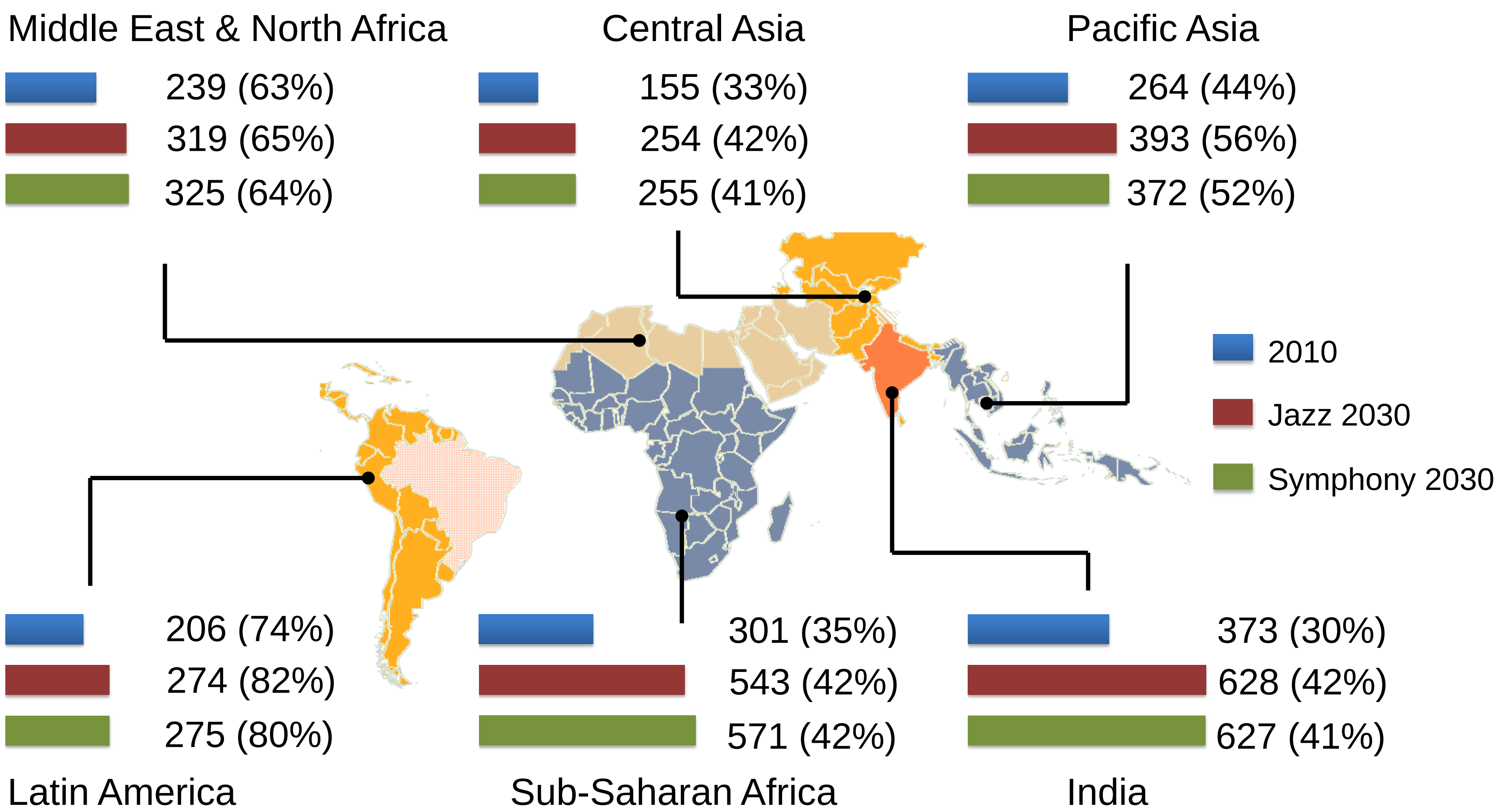
Jazz & Symphony: GDP & population



- 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.)
  - $5/t CO_2 price
- Symphony in 2030:
  - +1.2 billion people
  - 4.9 k$ per capita (+3.4% p.a.)
  - $32/t CO_2 price

Jazz & Symphony: Urbanisation

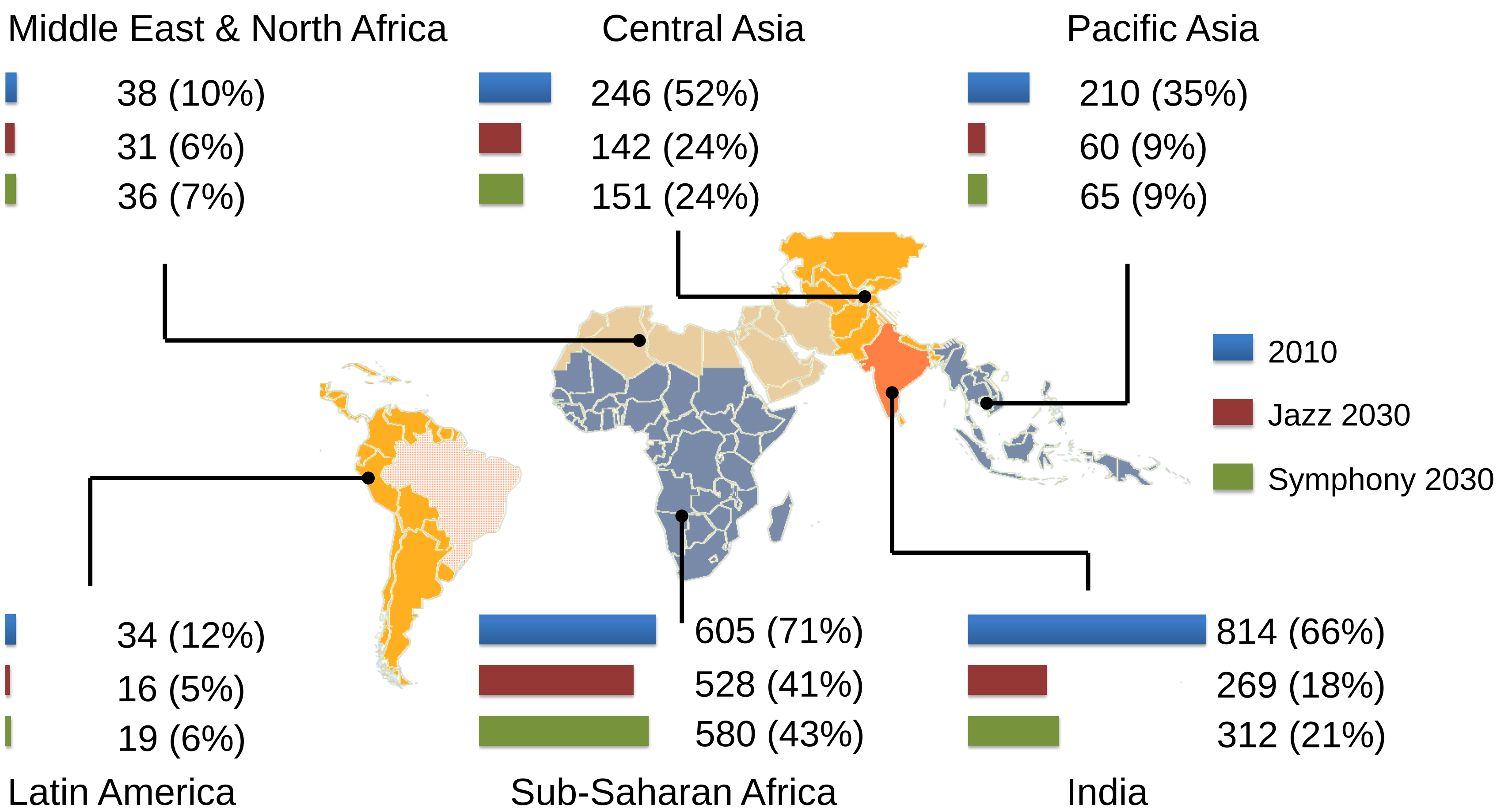
Urban population in millions and as % of the regions' total population



- 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

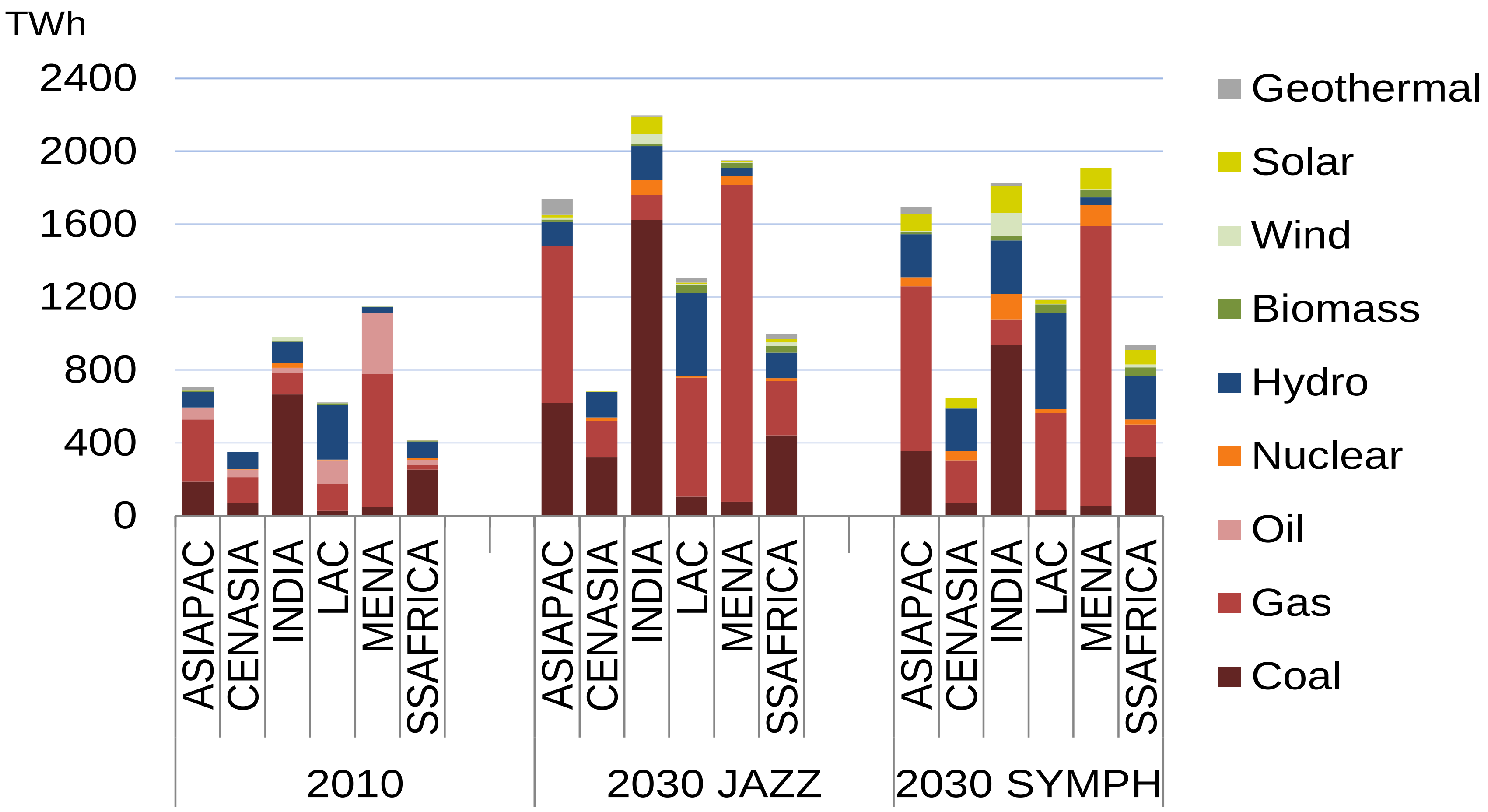
Population living with <$2 per day, in millions and as % of total



- Poverty: in 2010 51%, in 2030 21% in Jazz, 23% in Symphony
- Poverty is reduced in Asia, remains a problem in Sub-Saharan Africa

Jazz & Symphony: Electricity supply

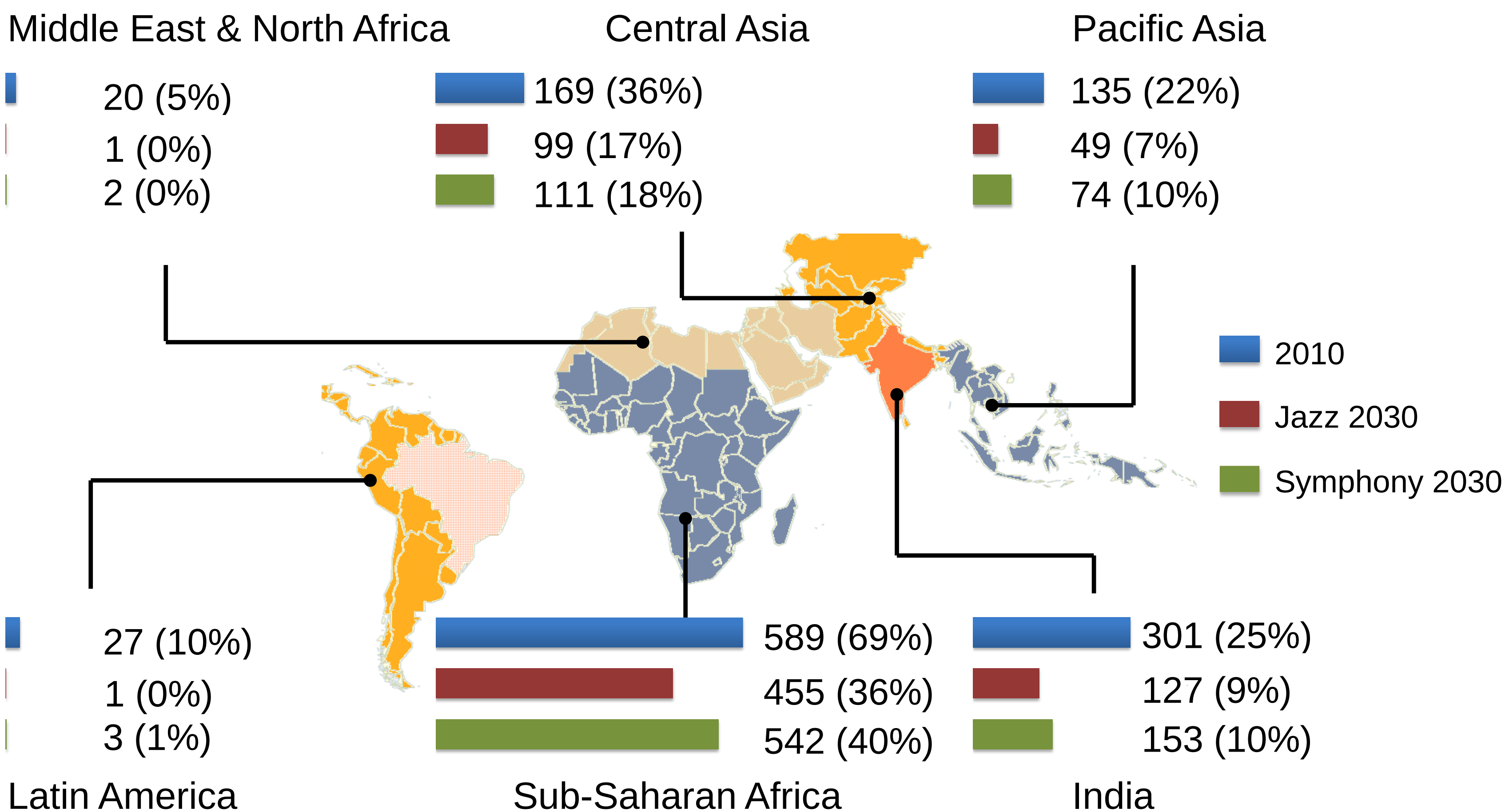
Electricity generation by major fuel per region



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

Jazz & Symphony: Electricity access

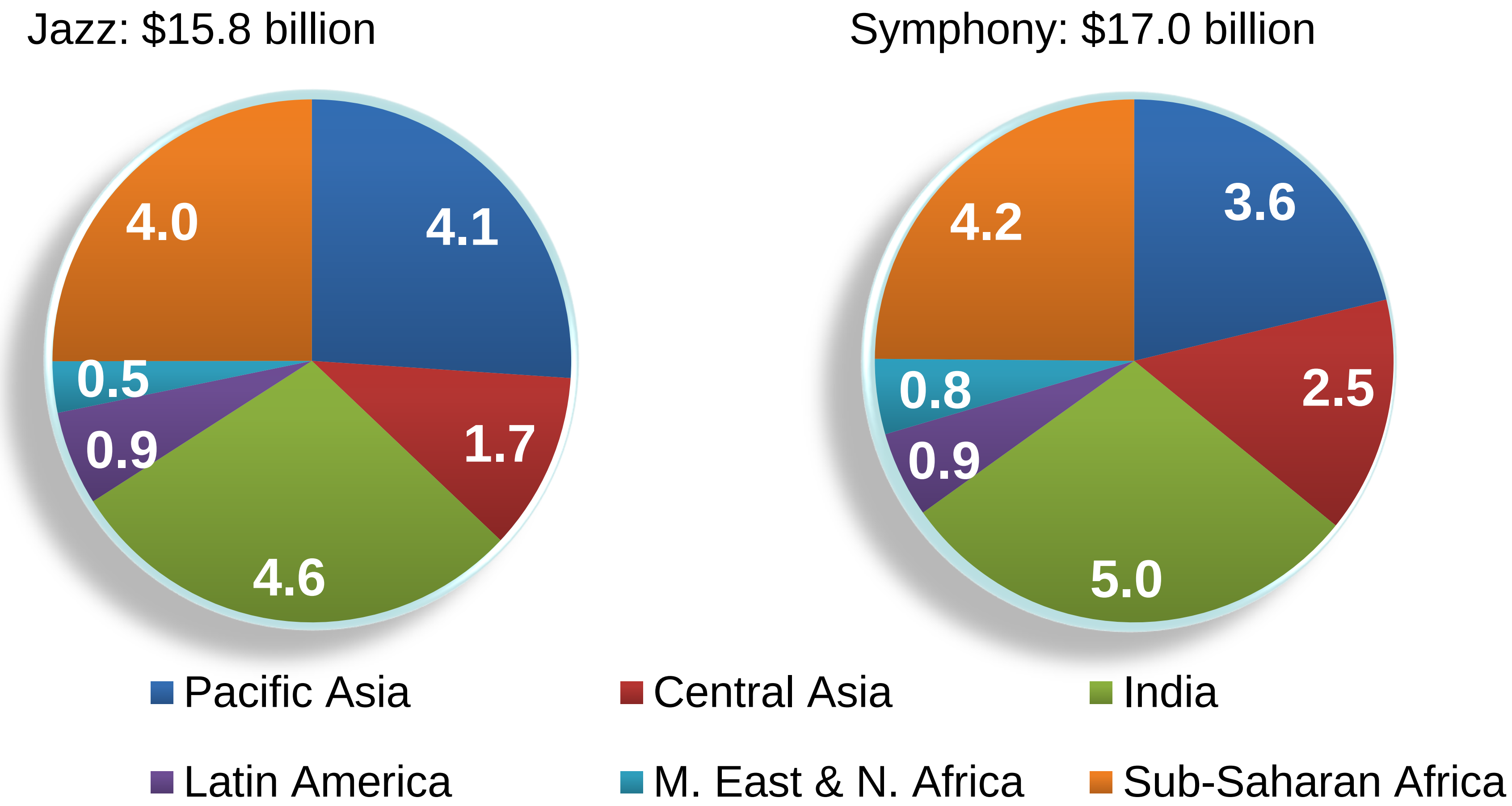
Population without access to electricity in millions and as % of total



- 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



- Investment for electricity access in 2009 was $9 billion (IEA)
- Connection cost per capita: Jazz $370, Symphony $440

Universal electricity access by 2030

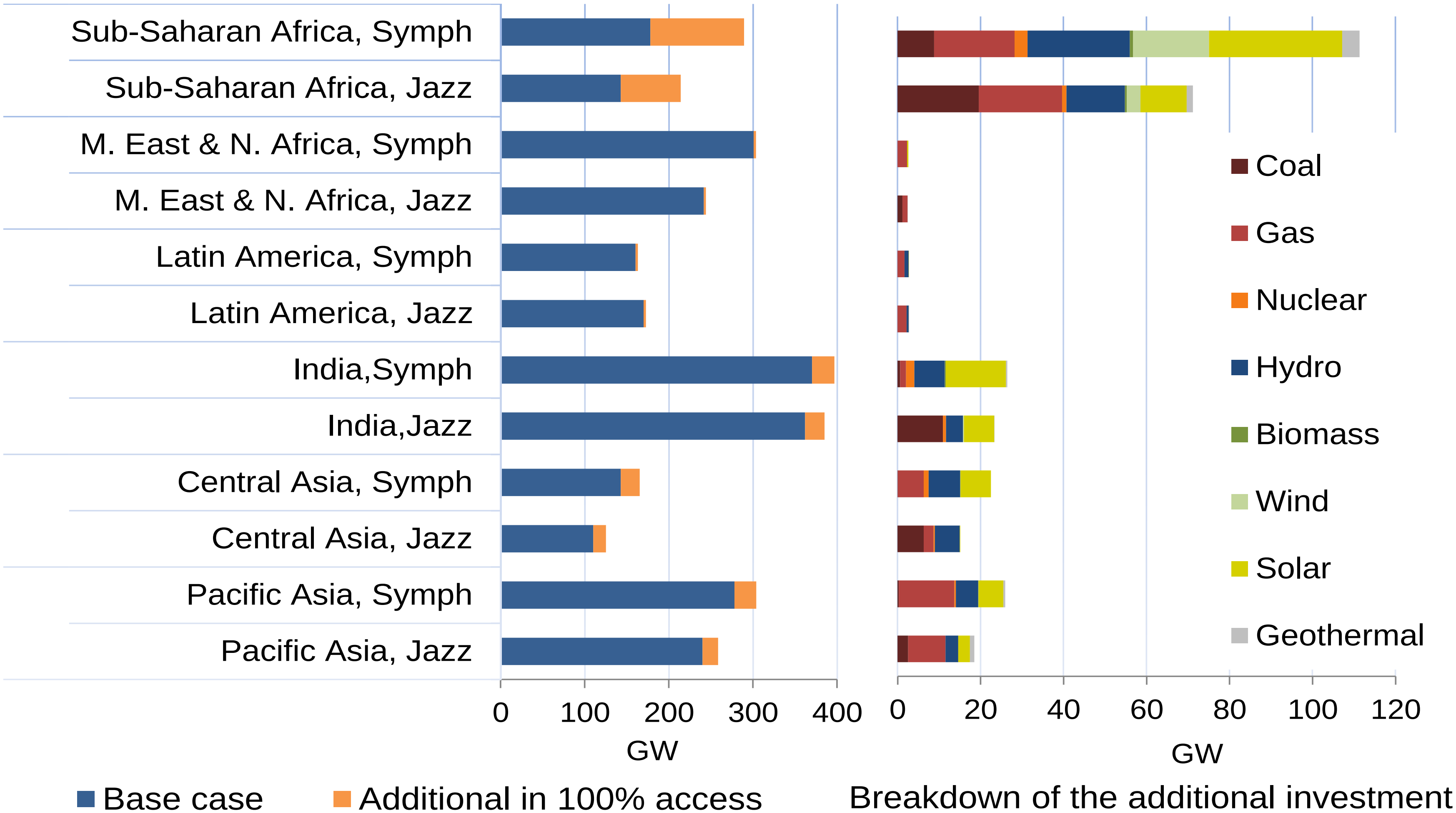
Initial annual consumption of 120 kWh per person

- Reaching the regional average levels after 5 years

Electricity demand	Jazz (in TWh)		Symphony (in TWh)	
	Base Case	Additional	Base Case	Additional
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**	3848	**585**

Universal electricity access by 2030

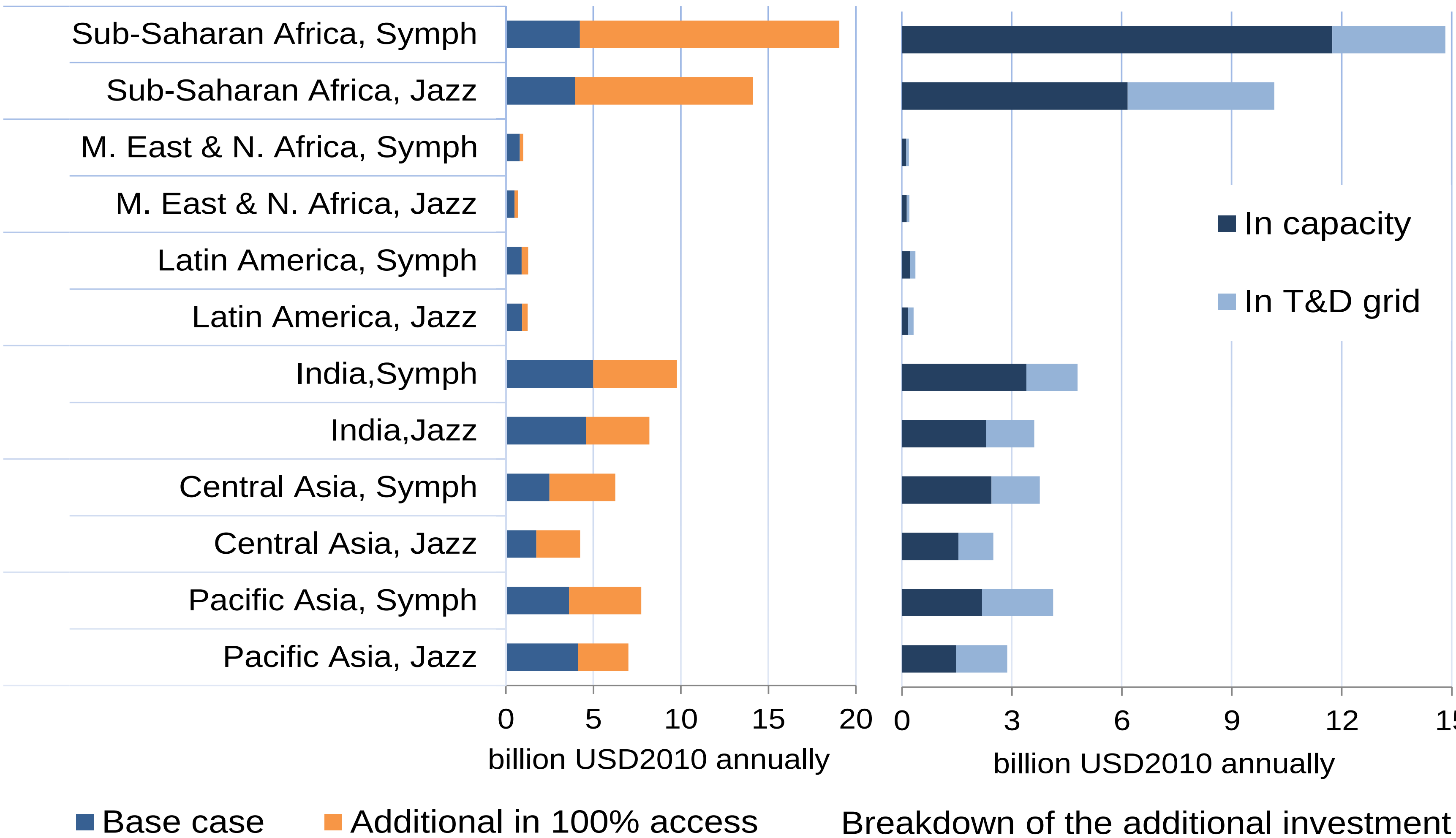
Cumulative electricity generation capacity investment:



- Additional electricity capacity: Jazz +133 GW, Symphony +192 GW
- Solar and hydro for rural electrification, fossil for on-grid urban electrification

Universal electricity access by 2030

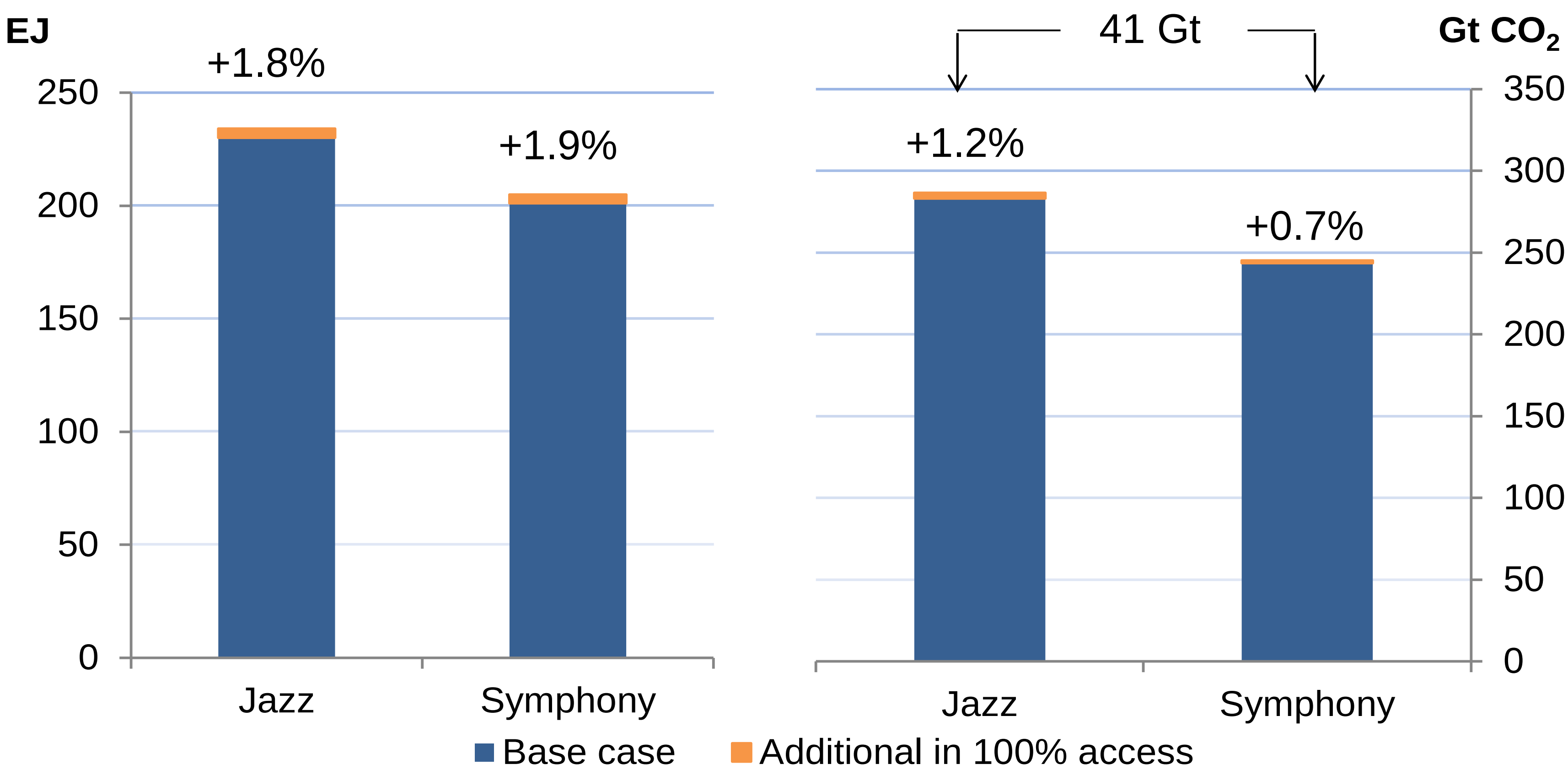
Annual investment expenditure over the period 2011-30, USD2010



- Total annual investment 2011-30: Jazz $36 billion, Symphony $45 billion
- Less than 4% of the global investment in the power sector in the WEC/PSI scenarios

Universal electricity access by 2030

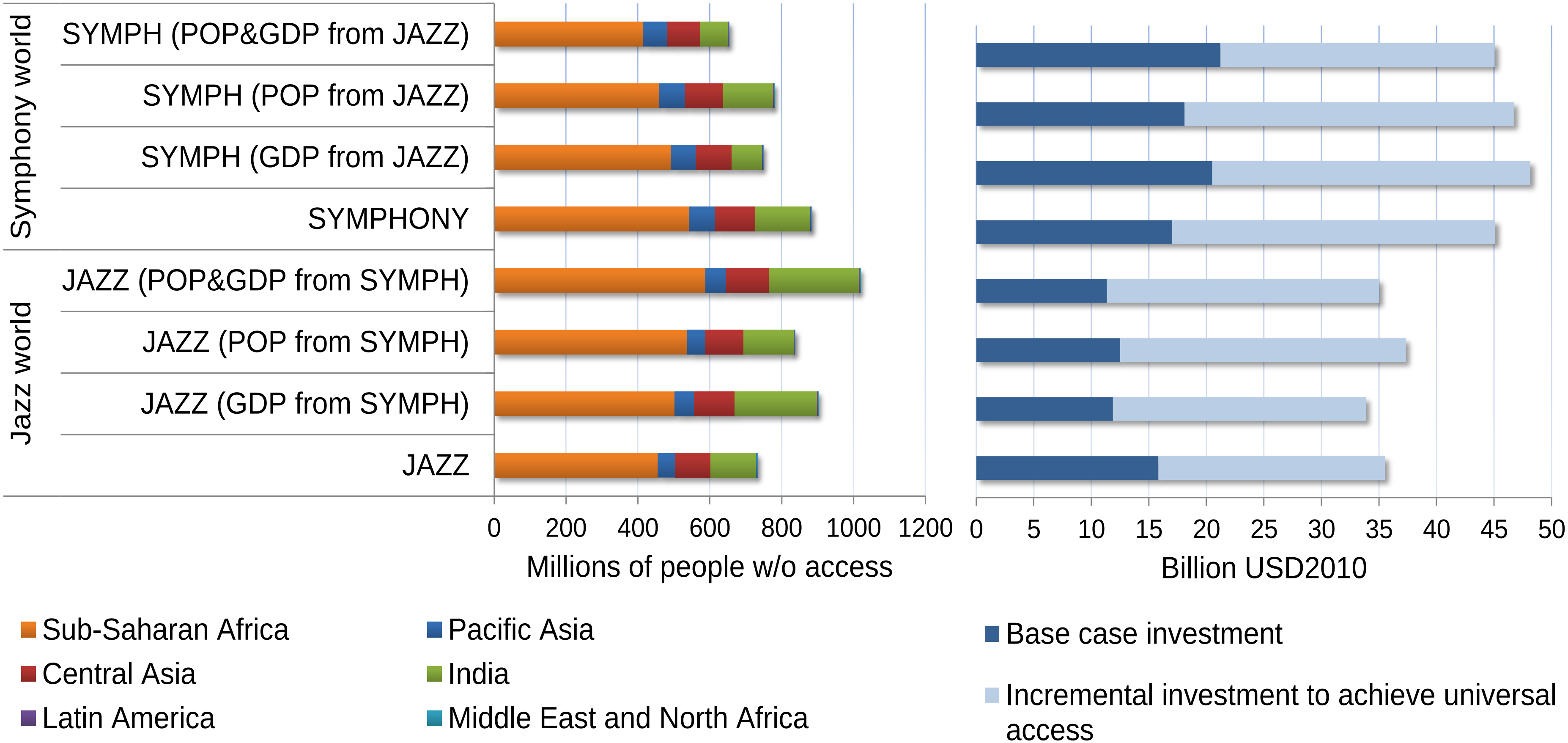
Impacts on primary energy supply in 2030 (left) & cumulative CO_2 emissions 2010-30 (right)



- Low levels of consumption by people gaining access ➔ minor impacts on TPES
- High proportion of renewable solutions adopted ➔ minor impacts on CO_2
- Symphony vs Jazz: -13% energy consumption, -25% cum. CO_2 emissions

Universal electricity access by 2030

Sensitivity analysis on GDP and population assumptions



- 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*

Conclusions

- Establishing universal electricity access in the WEC scenarios requires annual investment of **$34 to $48 billion** over the period 2011-30
- This is **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 CO_2 emissions**
- A lower-carbon pathway is about **27% more expensive**, but it requires **13% less energy consumption** and produces **25% less cumulative CO_2 emissions**

- Methodological issues:
  - The diversity of the regions is not fully captured
  - Coupling with CGE models could provide more insights regarding the socio-economic drivers of electricity access
  - Sensitivity analyses on scenario assumptions other than GDP and population could provide additional insights

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Thank you for the attention !

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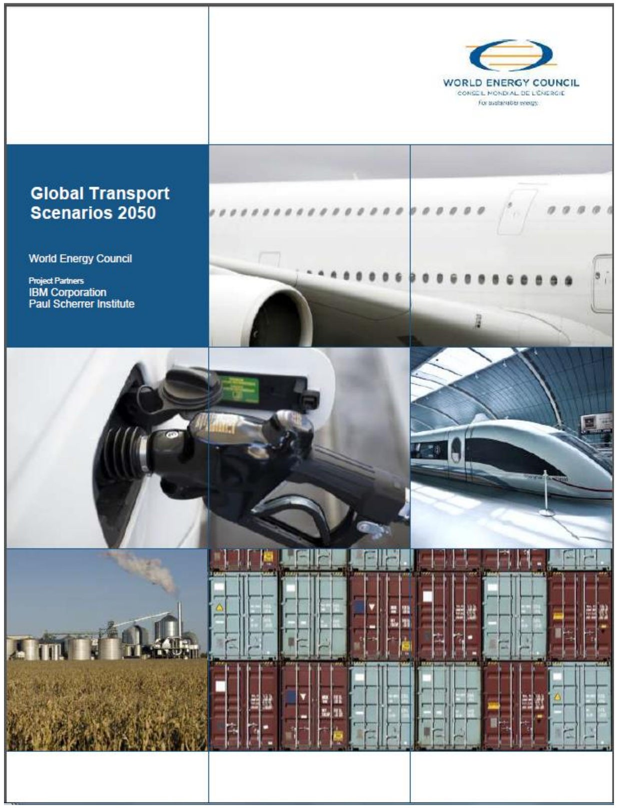
SUPPORT SLIDES

The WEC-PSI partnership

Global Transport Scenarios 2050	World Energy Scenarios 2050	Regional Deep Dives



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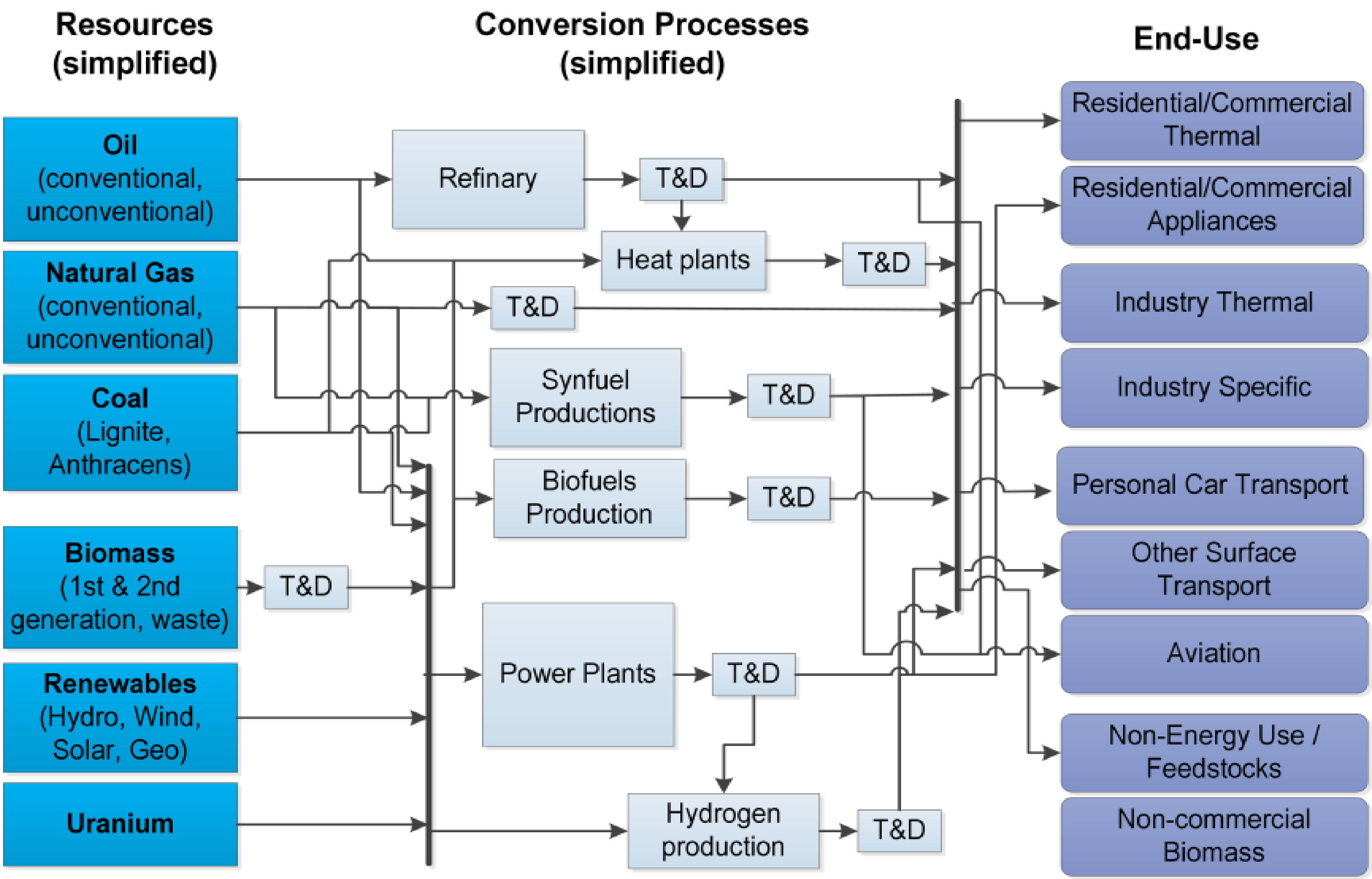
2011 — **2013** — **2014-2015**

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)



Mathematical specification of the econometric model

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

$$\ln\left(\frac{povert\ y_{r,t}}{povert\ y_{r,t-1}}\right) = \beta_{r,0} + \beta_{r,1} \cdot \sum_{k_r}\left(\gamma_{k_r} \cdot \ln\left(\frac{incom\ e_{r,t-k_r}}{incom\ e_{r,t-k_r-1}}\right)\right) + \beta_{r,2} \cdot \sum_{\lambda_r}\left(\gamma_\lambda \cdot \ln\left(cpia_{r,t-k_r}\right)\right) + \epsilon_{r,t}$$

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

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

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

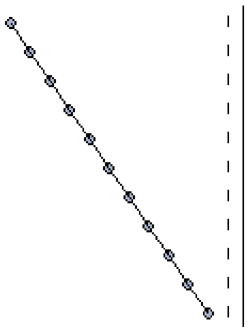
Example of estimation using PDLs

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]