Climate change mitigation, development and the role of energy

Jan Steckel

Berlin, November 19, 2013
Outline

• Some opening statements

• Development, emissions and their drivers

• Energy and development

• Energy system transformations – Opportunities, trade-offs and risks
Climate change and development

Some opening statements:

• Developing countries suffer most from climate changes
  • Not only are impacts more severe; societies are also less prepared to adapt to climate changes
The Moral Dilemma of Climate Change

Highest vulnerability towards climate change vs. largest CO₂ emissions (from fossil fuel combustion and cement production, and including land use change, kg C per person and year from 1950 - 2003)

- Grey: Largest per capita CO₂ emitters
- Orange: Highest social and / or agro-economic vulnerability
- Brown: Largest per capita CO₂ emitters, and highest social and / or agro-economic vulnerability
- Green: Areas with highest ecological vulnerability

Füssel 2007
Climate change and development

Some opening statements:

• Developing countries suffer most from climate changes
  • Not only are impacts more severe; societies are also less prepared to adapt to climate changes

• Historically developing countries have not been responsible for carbon emissions, i.e. climate change
World map of wealth
Weltkarte des Vermögens

Capital stock per person
- very low
- low
- medium
- high
- very high

Füssel 2007
World map of carbon debt

Carbon emissions per person from fossil fuel burning (1950-2003)

very low  high
low  very high
medium

Füssel 2007
Wealth and carbon debt

Fitting line: \( \ln P = 0.987 \ln K + c \)

Füssel 2007
Climate change and development

Some opening statements:

• Developing countries suffer most from climate changes
  • Not only are impacts more severe; societies are also less prepared to adapt to climate changes

• Historically developing countries have not been responsible for carbon emissions, i.e. climate change

• Developing countries however play a key role also with respect to mitigation of emissions
Developing countries and mitigation

- Ambitious mitigation targets only feasible with emission reductions in developing and transition countries

- Scenarios for globally cost-efficient mitigation: largest share of mitigation in non-Annex-I countries

Jakob and Steckel 2013
Development, emissions and their drivers
Convergence of Emissions

Economic Convergence is closely related to convergence of CO$_2$ emissions

Jakob et al., in preparation
Drivers of GHG emissions

\[ \text{CO}_2 = \frac{\text{CO}_2}{\text{PE}} \times \frac{\text{PE}}{\text{GDP}} \times \frac{\text{GDP}}{\text{POP}} \times \text{POP} \]

Emissions = \text{Carbon Intensity} \times \text{Energy Intensity of primary energy} \times \text{Income per capita} \times \text{Population of production}
Who’s driving emissions?

- Global emissions growth in recent years mainly by newly industrializing and developing countries
- China’s role outstanding
  i. High GDP-growth
  ii. Slower improvement of energy intensity
  iii. Scaling effects of traditional coal use in China

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<td>Population</td>
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<td>GDP per capita</td>
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<td>Energy intensity</td>
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<td>1.2</td>
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<td>Coal</td>
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<td>Gas</td>
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<td>−0.06</td>
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<td>Nuclear</td>
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<td>−0.37</td>
<td>0.15</td>
<td>−0.04</td>
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<td>Biomass and Waste</td>
<td>−0.18</td>
<td>−0.09</td>
<td>−0.18</td>
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<td>Renewables (incl. Hydro)</td>
<td>−0.08</td>
<td>−0.05</td>
<td>−0.11</td>
<td>−0.24</td>
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<td>Net annual CO₂ growth</td>
<td>2.02</td>
<td>0.76</td>
<td>4.71</td>
<td>5.88</td>
<td>8.97</td>
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Steckel et al. 2011
Pronounced differences between OECD and non-OECD countries w.r.t. energy use patterns on the level of primary energy carriers and economic sectors...

Jakob et al. 2012
Economic and energy use convergence

... and economic convergence is closely related to convergence of energy use patterns.

Jakob et al. 2012
Another view point on emissions growth

With rising energy use and CO2 emissions per capita, poverty ratio have fallen significantly!

Jakob and Steckel 2013
Drivers on the micro level

- Energy use and consumption patterns (lifestyles) differ considerably within countries between income groups.
- Last 20 years have seen high growth and rising inequality in many developing countries (including India), alongside rising emissions.
- Are the rich responsible for rising carbon emissions?
- Footprint analyses for India, Indonesia, Philippines reveal comparable results:
  - Income largest driver of carbon footprint
  - Rising middle class will strongly increase emissions (move to carbon-intensive lifestyles)
  - Higher emission due to urbanization and education (over and above income effect)

Grunewald et al. 2012
Carbon Footprints and Macro-Economic Developments

The "Carbon-Footprint" in a cross-section of households is very similar to nationwide development of emissions over time.

This suggests a characteristic relationship between income and CO₂ emissions.

Jakob et al., in preparation
The world energy system today

Shares of Primary Energy Supply 2008

- Oil: 34.6%
- Gas: 22.1%
- Coal: 28.4%
- Nuclear Energy: 2.0%
- Renewable Energy (RE): 12.9%
- Bioenergy: 10.2%
- Traditional biomass: 6%
- Modern bioenergy: 4%
- Direct Solar Energy: 0.1%
- Ocean Energy: 0.002%
- Wind Energy: 0.2%
- Hydropower: 2.3%
- Geothermal Energy: 0.1%

Edenhofer et al. 2011
No decarbonization on the horizon!

Decomposition of the carbon intensity

Steckel et al. 2011
Fossil fuel price development

- Coal gets increasingly attractive
- Renaissance of coal rather than decarbonization

Prices of Energy Commodities
(U.S. dollars a barrel of oil equivalent)

- Asian liquefied natural gas
- U.S. gas
- Australian coal
- Oil

IMF 2011
Fossil Fuel Scarcity vs. Limited Atmospheric Space

Kalkuhl, Edenhofer and Lessmann 2009
Energy and development
The role of energy in development processes

Steckel et al. 2013
The energetic metabolism of societies

**Socio-ecological regime transitions (Haberl):**

Hunter-gatherer society: Unmanaged solar metabolism

Traditional agricultural society: Managed solar metabolism

Industrial society: Tapping energy stored in fossil fuel resources allows decoupling from solar metabolism (and restrictions on population size due to limited land area)
Energy-development nexus I
Energy mix

Production + availability $\rightarrow$ Energy mix

Fuel mix moves up the energy ladder over the course of economic development

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**Level 1**
Basic Human Needs
- Electricity for lighting, health, education, communication and community services (50-100 kWh per person per year)
- Modern Fuels and Technologies for Cooking and Heating (50-100 kgoe of modern fuel or improved biomass cook stove)

**Level 2**
Productive Uses
- Electricity, Modern Fuels and Other Energy Services to improve productivity e.g.
  - Agriculture: water pumping for irrigation, fertilizer, mechanized tilling
  - Commercial: agricultural processing, cottage industry
  - Transport: fuel

**Level 3**
Modern Society Needs
- Modern Energy Services for many more domestic appliances, increased requirements for cooling and heating (space and water), private transportation (electricity usage is around 2,000 kWh per person per year)

Edenhofer et al. 2011
The energy transition(s)

Three aspects of energy transitions (Grübler, 2004):
- Changing energy quantities
- Changing energy qualities
- Changing energy structures
The energy transition(s)

Schäfer 2005
Energy-development nexus II
Access to (modern) energy

Availability of electricity and (modern) energy carriers + improved end-use devices such as cook stoves at affordable prices for all (GEA 2012)

• Energy availability affects economic development through different channels (Toman/Jemelkova 2003, GEA 2012)

  • Technological challenges (e.g. grid integration)
  • Reallocation of household time (women and children) → education, income generation, gender equality
  • Access to transportation and information infrastructure
  • Medical services, reduced smoke exposure, refrigeration, clean water
  • Electric driven machinery → agricultural productivity, business development, employment

→ Electricity plays a fundamental role for health care, education and production
Health impacts of household air pollution

Premature annual deaths per household air pollution and other diseases

[Bar chart showing premature annual deaths for conditions like Malaria, Tuberculosis, Smoke from biomass, and HIV/AIDS in 2008 and 2030.]
Global access to electricity ...

From satellite data to ...

http://geology.com/articles/satellite-photo-earth-at-night.shtml
Access to electricity: a global overview

Doll and Pachauri 2010, GEA 2012
Electricity access vs. poverty

% of population with electricity access vs. % of population living in poverty.

Countries: India, South Africa, Bolivia, Peru, Mongolia, Honduras, Pakistan, Ghana, Cote d'Ivoire, Botswana, Yemen, Madagascar, Ethiopia, Mozambique, Burkina Faso, Lesotho, Kenya.
Electricity access: urban-rural divide

- 1/3 of the global rural population has no access to electricity
- Lowest electrification level in Sub-Saharan Africa (11%)
- Electrification speed: 2 bln. people gained access to electricity between 1990 and 2008

![Graph showing population without access to electricity](image)
... at the bottom of the energy ladder

- 75% of people living in rural areas in developing countries use traditional biomass for cooking (vs. 35% in urban areas)
- Only ¼ uses improved cooking stoves

GEA 2012, Pachauri et al. 2010
Energy-development nexus III
Energy for production

- **Energy availability → Production**: Capital, labor and energy are the primary factors of production
  - Low substitutability between energy and capital (depletion of energy resources)
  - Energy necessary for capital (energy-intensive service) and labor (households, food)

→ energy availability can constrain economic growth, abundance of energy sources alleviates this constraint

- **Production → Energy intensity**: Shifts in energy intensity of output
  - Decreasing energy intensity in manufacturing sector (technical development)
  - Increasing energy intensity for households and service sector

Stern 2011
Production patterns of cement and steel over development

Developing Countries will catch up
(Scenario data in blue)

Steckel et al. 2013
Pathways to a low carbon energy transition
How to grow without increasing emissions?

• Breaking the convergence between economic development and energy use patterns

• Trade-offs
  • Often more expensive than fossil fuels
  • Higher energy prices
    • With adverse distributional implications
    • With negative externalities for economic development (industrialization!)
  • Technological challenges (e.g. grid integration)

• Covering the additional costs of RE would require large financial transfers from industrialized countries
The role of energy in development processes

Basic needs
Threshold on the society level at approximately 40 GJ / capita

Steckel et al 2013
Transformation of the Energy System

Mitigation technologies: 450ppm  World

- **Renewable energy**
- **Biomass (+ CCS)**
Climate Change and the role of land

Land is central for human well-being: food production, water, ecosystem services, etc.

Land will become scarcer: population growth, economic growth, urbanisation, climate change...

Cumulative fraction of global land area crossing “affection threshold” for crop production (10th percentile of the reference period distribution 1980–2010)

Climate impacts will depress yields...

... but ambitious mitigation is related to large biomass use

Opens up new concerns regarding food security, food prices and development ...
Role of renewable in future scenarios

Luderer et al., in press
Transformation of the Energy System

Many different pathways to transform the energy system

→ Different possibilities to reach low stabilisation
→ 400ppm can be achieved by all models

Knopf et al. 2009
Costs of mitigation

Costs hinge critically on:
• The stabilization target
• The biomass potential
• The availability of technologies, RE and CCS in particular

Edenhofer et al. 2011
How to grow without increasing emissions?

• Breaking the convergence between economic development and energy use patterns

• Trade-offs
  • Technological challenges (e.g. grid integration)
  • Currently often more expensive than fossil fuels
  • Higher energy prices
    • With adverse distributional implications
    • With negative externalities for economic development (industrialization!)

• Covering the additional costs of RE would require large financial transfers from industrialized countries
System LCOE are defined as the sum of generation and integration costs.
System LCOE – magnitude and shape

- Integration costs of wind power can be in the same range as generation costs at moderate shares (~20%)
- A significant driver of integration costs are profile costs, especially the reduced utilization of capital-intensive thermal plants.
  - Integration costs can become an economic barrier to deploying VRE at high shares.
  - An economic evaluation of wind and solar power must not neglect integration costs.

From literature: Grid and balancing costs (Holttinen et al. 2011; Gross et al. 2006; Hirth 2012a, dena 2010)
From a simple model: profile costs.
Parameterized from German data, representative for thermal systems in Europe
Caveats that increase integration costs
  - No import/export
  - No demand elasticity
  - No storage
  - Power sector only

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Ueckerdt et al., in press
Renewable Energy in Developing Countries (DCs)

- **Hydropower**
  - Wide-spread adoption: generated by 83% of all DCs
  - Average share of total electricity: 38 percent (11 percent weighted with total country electricity consumption)
  - Top 3 DC producers (billion kWh in 2009): China (549), Brazil (387), Russia (162), also have top technically exploitable capability

- **Non-hydropower (biomass, geothermal, solar, and wind)**
  - Generated by about 45% of DCs
  - Average share of total electricity: 1.4 percent
  - Most important: biomass, geothermal
  - Very uncommon: solar and wind
  - But: High growth rates from low basis
Macro analysis of RET adoption

• Study of diffusion of non-hydro renewable energy technologies for electricity generation (NHRE) across 108 developing countries (between 1980 and 2010)

• Main findings: NHRE diffusion accelerates with
  • Implementation of economic and regulatory instruments
  • Higher per capita income and schooling levels
  • Stable, democratic regimes

• NHRE diffusion is slower with
  • Greater openness and aid
  • Institutional and strategic policy support programs
  • Growth of electricity consumption
  • High fossil fuel production

Pfeiffer and Mulder 2013
Micro analysis: Solar home systems in Kenya

• Kenya's SHS market one of the biggest worldwide
• Data on households from the Kenyan Integrated Household Budget Survey (KIHBS) 2005/06, 13,430 households
• With information on SHS use and potential drivers
  • Income, education, residence (rural, urban), housing situation
  • Kerosene price
  • Potential grid access, prevalence of SHS

Evidence for a cross-sectional energy ladder with very high income threshold for modern fuel use – including solar energy use – to move beyond traditional and transitional fuel

Income, education and SHS clustering are key determinants of SHS adoption

Lay et al. 2012
How to grow without increasing emissions?

• Breaking the convergence between economic development and energy use patterns: Renewables as one pathway

• Trade-offs
  • Often more expensive than fossil fuels
  • Higher energy prices
    • With adverse distributional implications
    • With negative externalities for economic development (industrialization!)
  • Technological challenges (e.g. grid integration)

• Covering the additional costs of RE would require large financial transfers from industrialized countries
Climate Finance – Non-Market Transfers

a) Mitigation costs 2020

b) Mitigation costs 2050

c) Incremental investments 2020

d) Incremental investments 2050

Jakob et al., submitted
Climate Finance – Market-Based

Different allocation schemes: Contraction and Convergence, equal per capita, and based on current GDP (i.e. grandfathering)

Financial transfers crucially depend on allocation scheme, particularly large for equal per-capita allocation of permits

Jakob et al., submitted
Comparing Financial Inflows

For some regions and allocation schemes, financial transfers in the order of magnitude as revenues from resource exports.

Data Resource Exports, FDI: Year 2009; Aid: Year 2008; ETS: ReMIND scenarios with differently ambitious mitigation targets and different allocation schemes.
A Climate Finance Curse?

- Largest financial inflows to countries with weak institutions
- This could induce problems similar to revenues from natural resource exports (volatility, "Dutch Disease", corruption) → ‘Climate Rent Curse’?

Jakob et al., in preparation
Conclusions
Conclusions

• Development and carbon emissions highly correlated
• At current (relative) prices of fossil fuels it is not realistic to expect a decarbonization of development patterns in the short term (w/o policy intervention)
• Low carbon technologies, particularly renewable energy not cost competitive in the short run
• Even on smallest scale, high income threshold
• Strategies to decarbonize energy systems on large scale are necessary and feasible, but might collide with other development goals
• Short term strategy: Improve institutional quality and provide minimum access to basic infrastructures to help the poor
Discussion

Thank you for your attention.

http://www.pik-potsdam.de/members/steckel
Further Reading

Sectoral use of energy