PAUL SCHERRER INSTITUT

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Towards integration of energy-economic modelling and life-cycle assessment

Outline

- **Motivation**
- **Methodology**
  - Global MARKAL model (GMM)
  - Life-cycle assessment (LCA)
  - Idea and proposed methodology
- **Results**
  - Cost optimisation
  - CO_2 cost optimisation
  - CO_2 emission optimisation
- **Conclusions**
- **Next steps / Outlook**

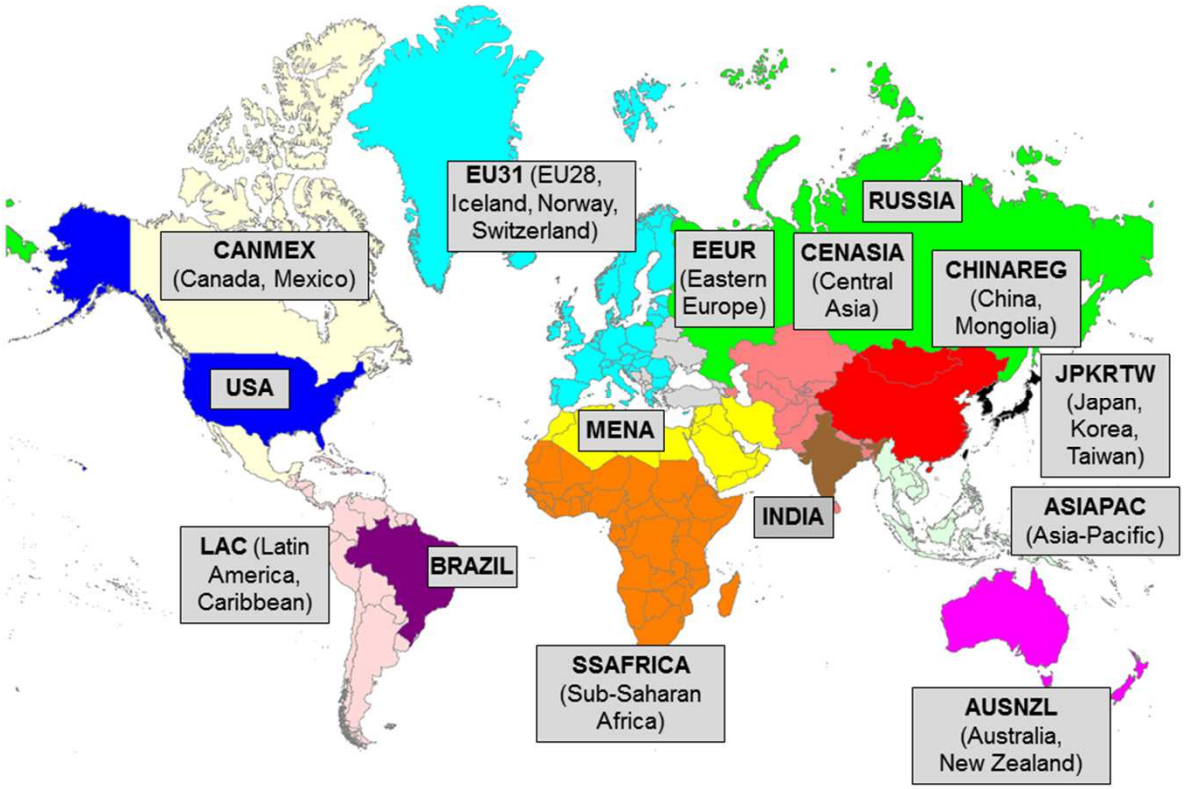
Motivation

- **The <u>global energy system</u> faces various challenges, e.g.**
  - Climate change
  - Resource depletion
  - Energy access
  - Security of supply

- **<u>Tools</u> to assess the development of the global energy system are e.g.**
  - Climate models
  - Energy-economic models
  - Life-cycle assessments
  - Risk assessments
  - Surveys

Global multi-regional MARKAL (GMM) model

- **Global**
  - All energy sectors
  - All energy resources
- **Multi-regional**
  - 15 world regions
  - Trade
- **MARKAL (MARKet-ALlocation)**
  - Technology rich (> 400)
  - Bottom-up
  - Perfect-foresight (2010 - 2100)
  - Partial-equilibrium ("Supply allocation")
  - Least cost optimization
    (Discounted total system costs)



➢ **Assessment of the global energy system**

➢ **Focus on the economic aspects**

Life-cycle assessment (LCA)

Some typical examples of LCA case studies

- **Functional unit, e.g.**
  - 1 vehicle-km in a car
  - 1 pair of dry hands
  - 1 kg of ready-to-eat tomatos
  - 1 kWh of electricity

- **Life-cycle indicators per functional unit, e.g.**
  - Ecosystem damages
  - Land use
  - Particulate matter emissions
  - Greenhouse gas emissions
  - Metal depletion

- **Assessment of single technologies or services**
- **Focus on environmental aspects**

Idea

Is there a possibility to combine different tools to gain a more comprehensive insight into the global energy system?

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+ ...

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➢ **Multi-objective optimisation**

Proposed methodology

Steps towards multi-objective optimisation

1) **Non-cost optimisation in GMM**
   - Change of the GMM objective function

2) **Life-cycle impacts in GMM**
   - Life-cycle indicators are calculated for the energy technologies (e.g. coal power plant)
   - *ex-post* analysis of the total environmental burden of the energy system

3) **External cost in GMM**
   - External cost factors are attached to the life-cycle indicators
   - *ex-post* or *ex-ante* analysis internalising the external costs of the energy system

4) **Multi-objective optimisation in GMM**
   - Various indicators (environment, risk, society, …) are defined for the energy technologies
   - Analysis including different weights for the indicators

$$\min cost \rightarrow \min(w_1 * INDICATOR_1 + w_2 * INDICATOR_2 + \ ...)$$

Non-cost optimisation

- **Case 1 (*COST*):**
  - Cost minimisation
  - CO_2 prices

$$\min cost\ (subject\ to\ system\ constraints) = z$$

Changes in the objective function of the model

- **Case 2 (*CO2_COST*)**
  - Direct CO_2 cost minimization
  - CO_2 prices

$$\min CO_2\ cost\ (subject\ to\ system\ constraints)$$

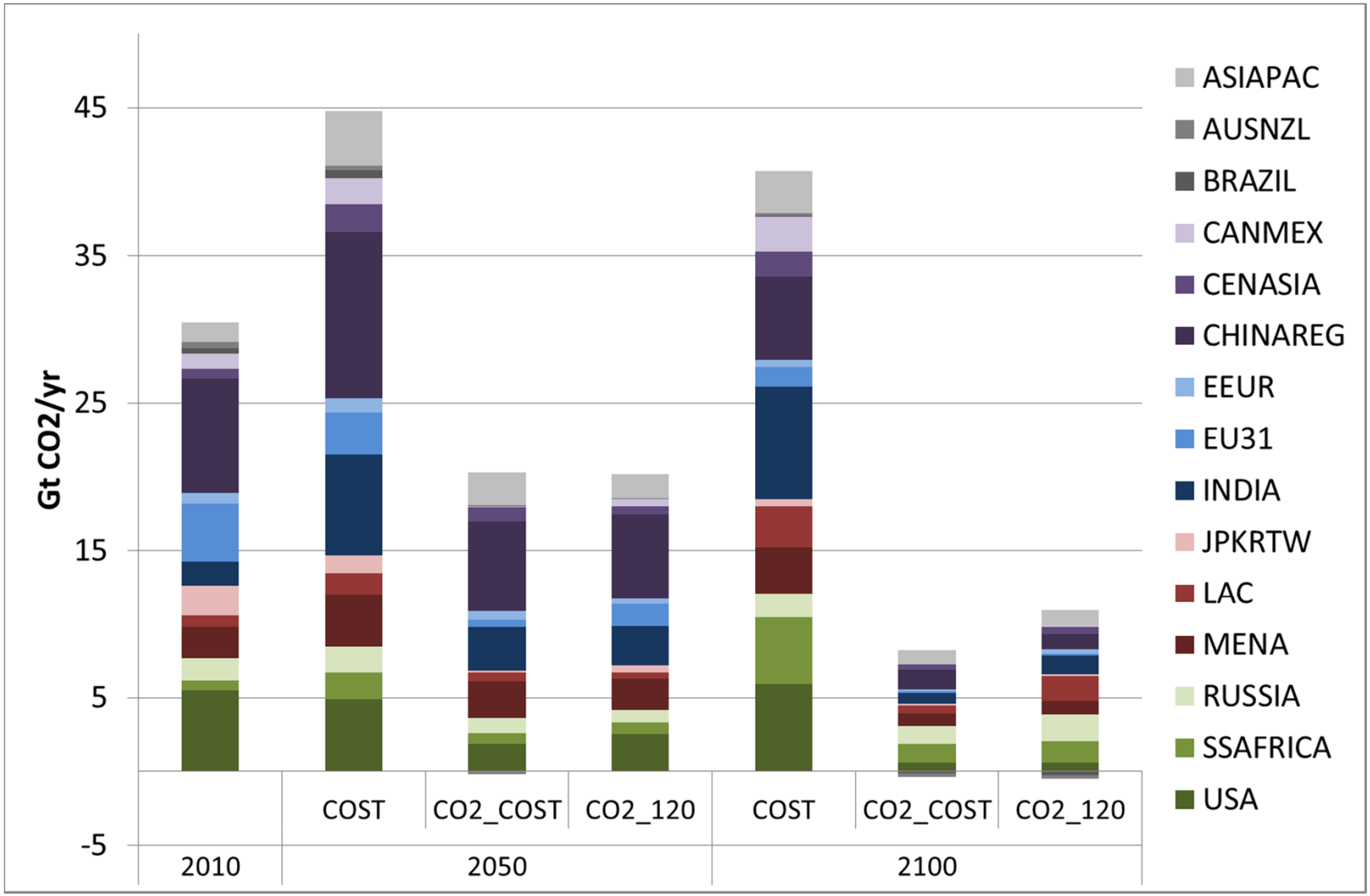
- **Case 3 (*CO2_120*)**
  - Direct CO_2 amount minimisation
  - No CO_2 prices
  - Total discounted system cost limited to 120% of the one of the *COST* case

$$\min CO_2\ amount\ (subject\ to\ system\ constraints, cost \leq 120\% * z)$$

- ➢ **One "normal" energy-economic run**
- ➢ **Two runs with different optimisation goals**

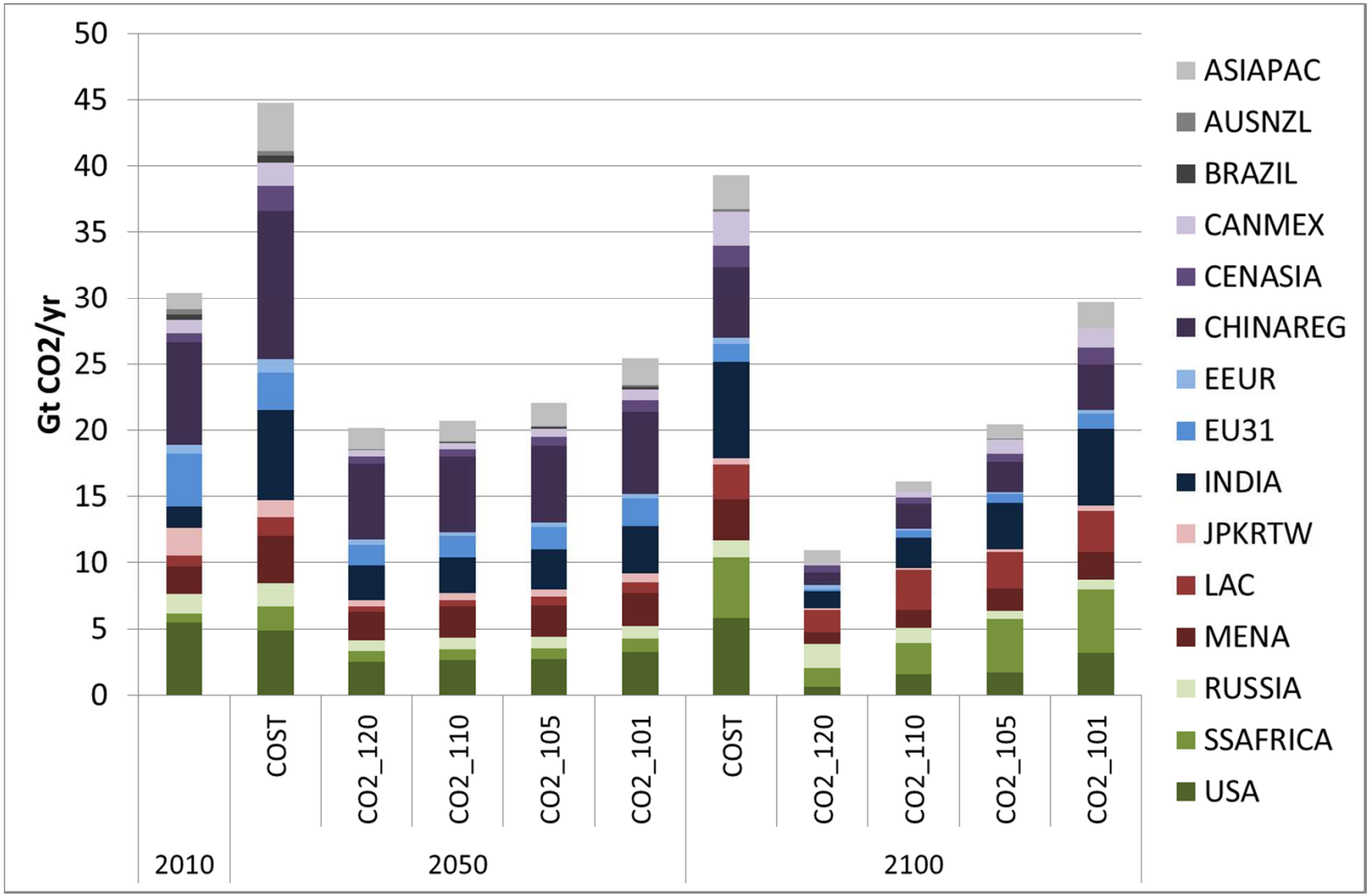
Preliminary results

Direct CO_2 emissions



Preliminary results

Direct CO_2 emissions for different system cost caps



Conclusions on the preliminary results

- Strong decrease of the CO_2 emissions in the non-cost optimisation cases towards 2100
  As expected

- The lower the total system cost cap the higher the CO_2 emissions of the energy system
  But even with a stringent system cost cap, it is possible to maintain today's CO_2 emission level!

- In the non-cost optimisation cases the CO_2 emissions do not go to zero
  This needs to be further analysed!

Next steps / Outlook

1) **Non-cost optimisation**
   - Change of the objective function of the large-scale MARKAL model

2) **Life-cycle impacts in GMM**
   - Life-cycle indicators are calculated for the energy technologies (e.g. coal power plant)
   - *ex-post* analysis of the total environmental burden of the energy system

3) **External cost in GMM**
   - External cost factors are attached to the life-cycle indicators
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4) **Multi-objective optimisation in GMM**
   - Various indicators (environment, risk, society, …) are defined for the energy technologies
   - Analysis including different weights for the indicators

Thank you for the attention

Are there any questions?