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EMPA Materials Science & Technology

Grantham Institute for Climate Change

Environmental and Economical Impact of PV Energy Production

22 October 2013

The carbon emissions mitigation potential of emerging solar photovoltaic technologies

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Support: Grantham Institute, EPSRC, Royal Society

Why we are interested in energy payback time

Imperial College London

Grantham Institute for Climate Change

- Research into energy generating and saving technologies, e.g.
  - **Solar PV**
  - Solar fuels
  - Solar thermal
  - CCS
  - Fuel cells
  - Electric vehicles
  - Smart grids
  - Lighting
  - Cooling
  - Etc…

collaboration

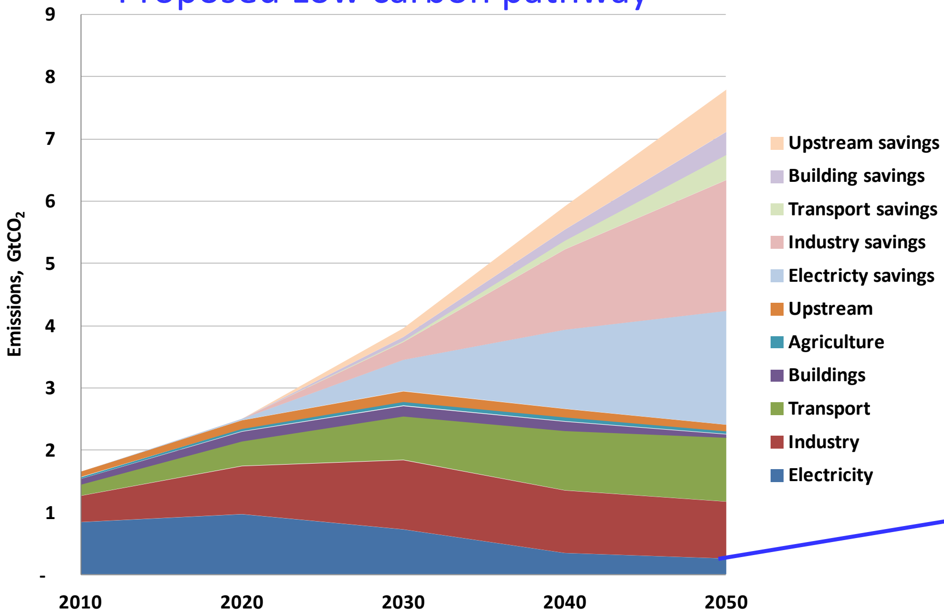
- Research into carbon emissions mitigation potential of technologies
- Low carbon pathways modelling
- Negative emissions
- Renewable energies
- Policy interface
- **Role of emerging technologies?**

Example: Low carbon pathways modelling

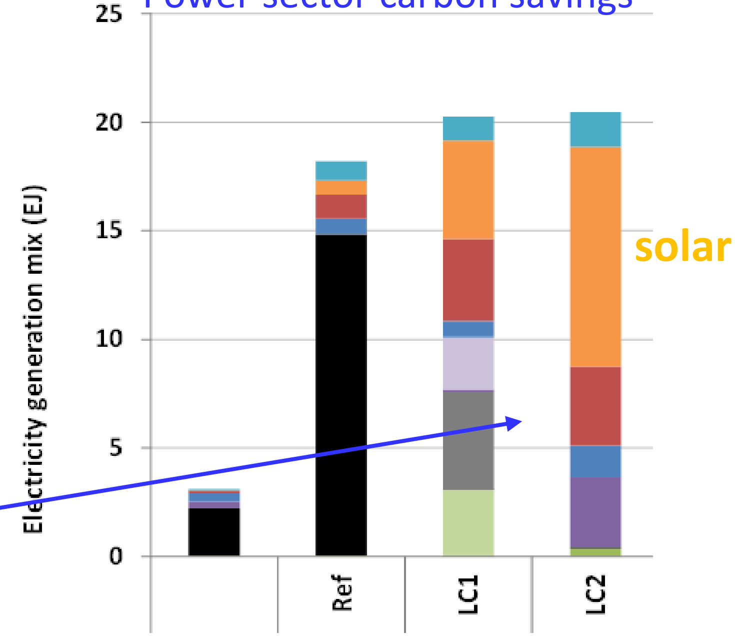
UK govt Dept Energy & Climate Change supported study of low carbon pathways in India to 2050

Grantham Institute report, Gambhir et al., 2012

Proposed Low carbon pathway



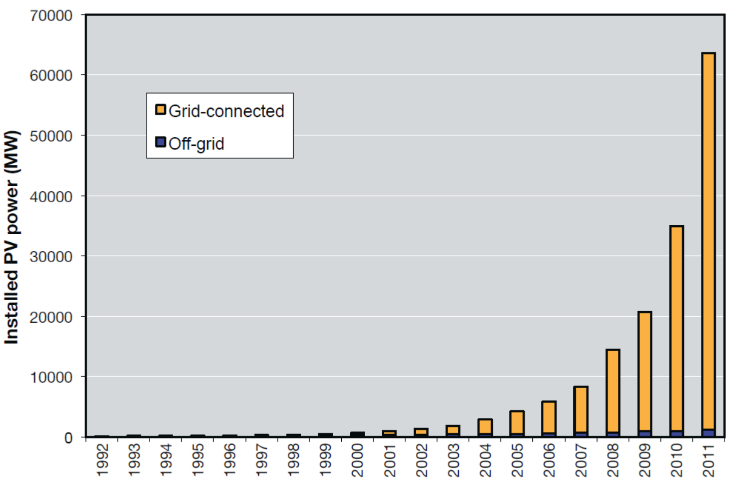
Power sector carbon savings

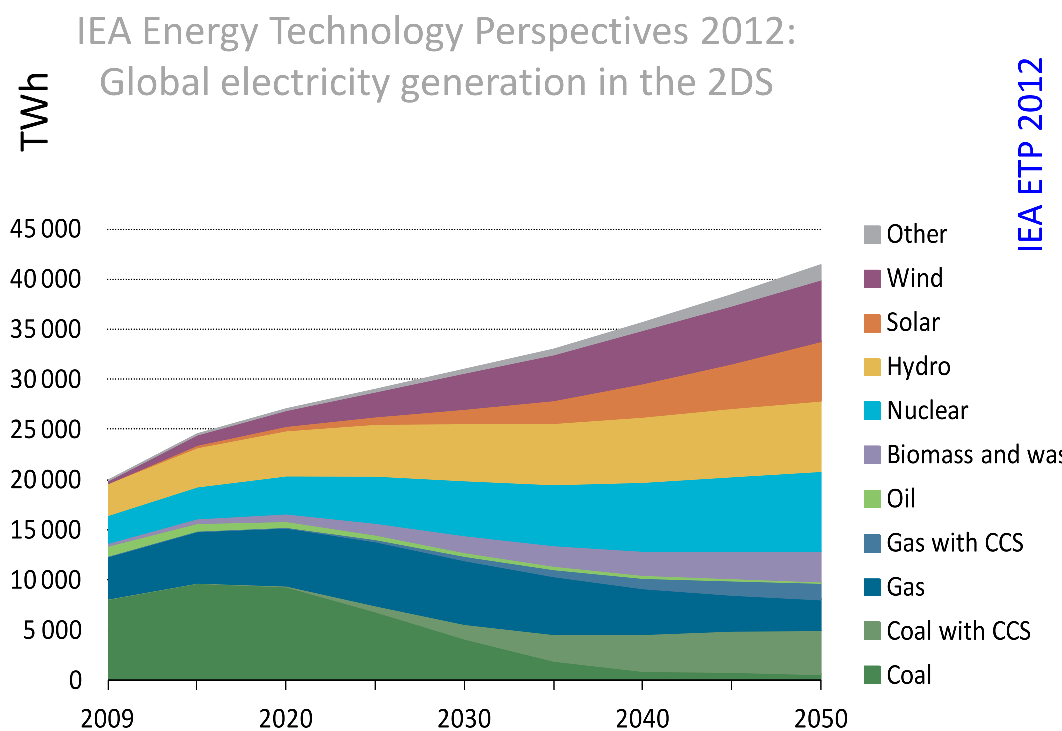


- Possible emissions reductions depend on technology development and related carbon intensity

Role of solar in decarbonising the power sector

IEA PVPS ‘Trends in photovoltaic appliocatopns 2012’





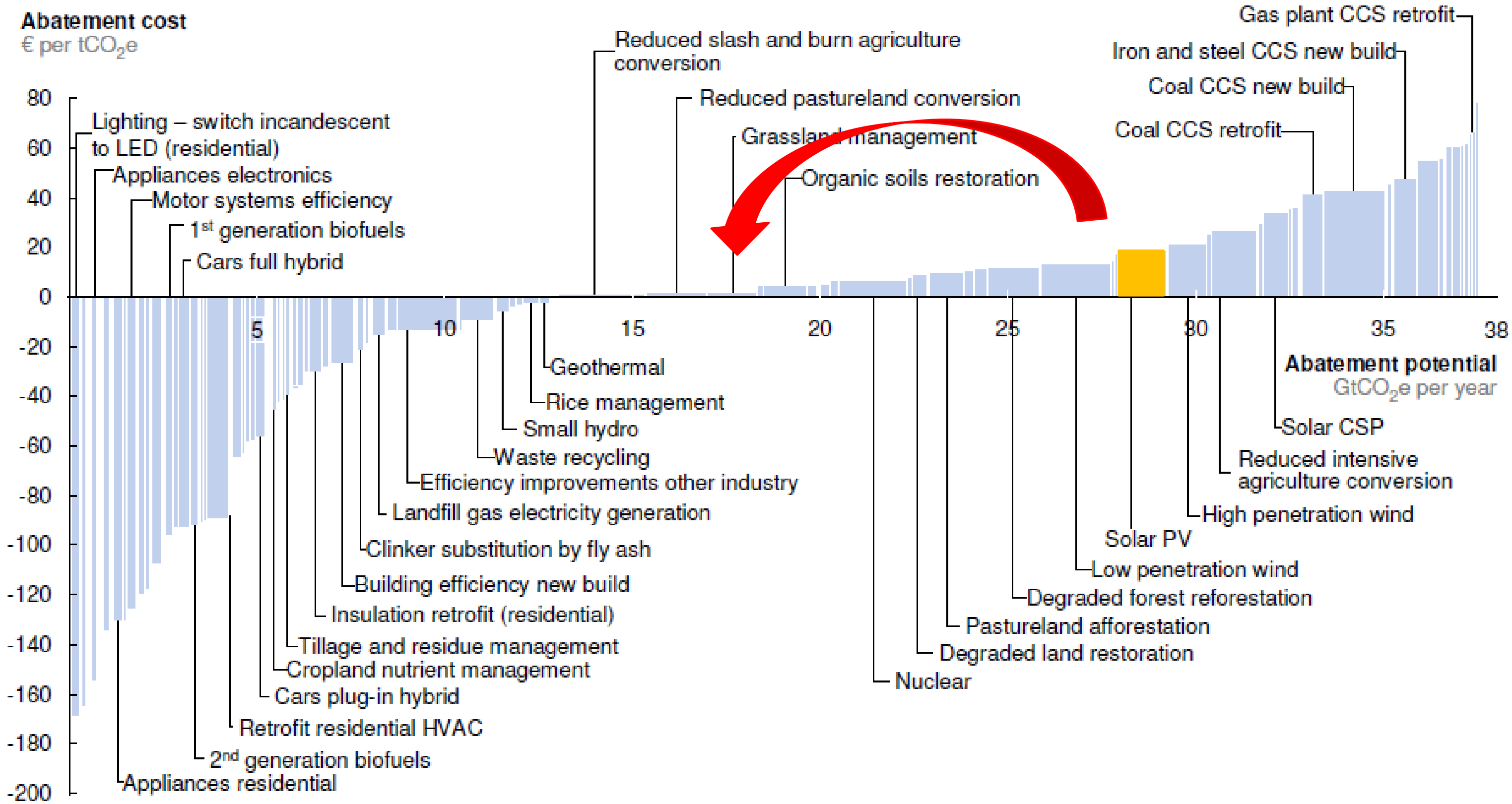
IEA ETP 2012

- Solar power due to provide over 10% of electricity by 2050, (much more in some forecasts)
- Solar power required to grow faster than any other technology

Abatement cost of Solar Power

Implement immediately

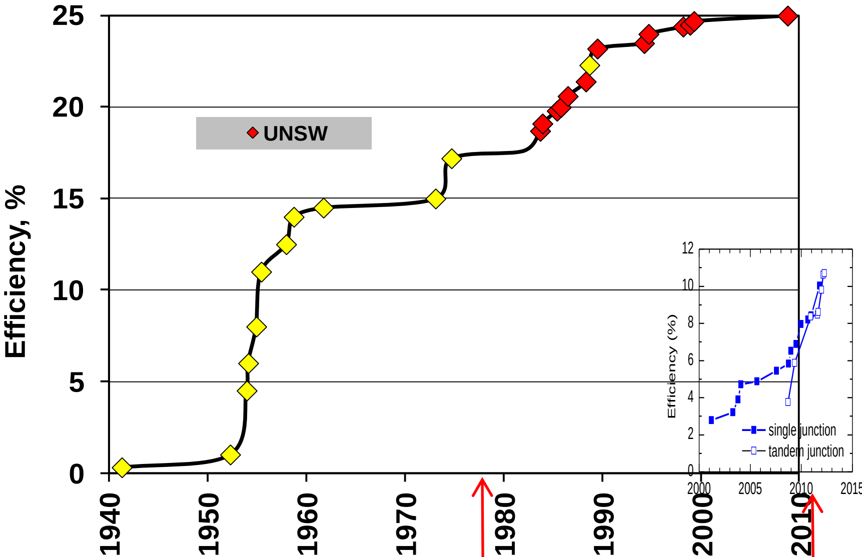
R&D to bring down costs

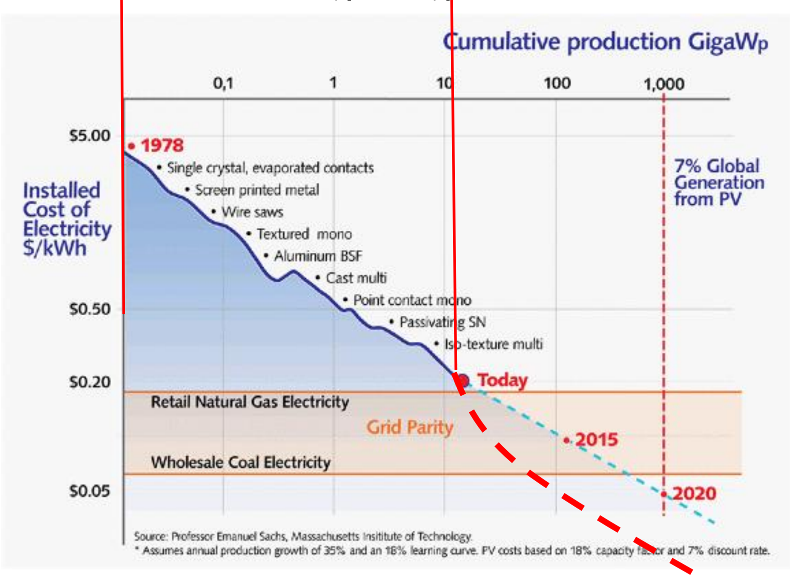


Global GHG Abatement cost curve v 2.1 McKinsey (2010)

- Research and development needed to reduce the abatement cost of solar
- Understand how cost depends on
  - Technology
  - Application context
  - Location

Technological innovation and the cost of solar PV





Courtesy: Martin Green

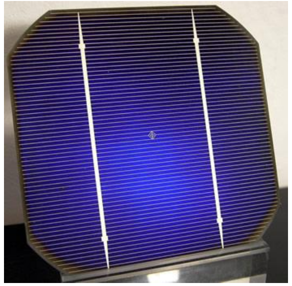
Cost reductions follow maturing of the technology through innovations in manufacturing and design

New PV technologies are still improving.

Further cost reductions will follow through innovations in:

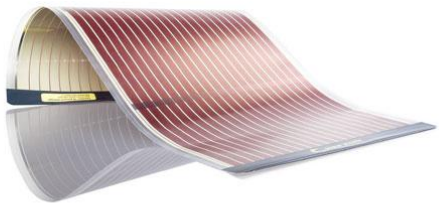
- Materials
- Manufacturing
- Application
- System design.

Status of solar PV: mature and emerging technologies

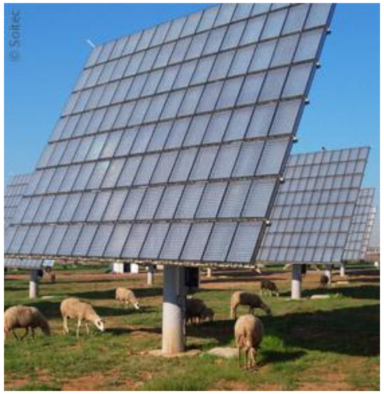


Dominant: **Crystalline Si**
$1 / W_p
2.5kg CO_2 / W_p

Developing thin film: **CdTe**
$0.75 / W_p
0.53kg CO_2 / W_p



Emerging: **Printable PV**
$2.8 / W_p → $ 0.4 / Wp
0.73kg CO_2 / W_p → ?



Developing: **Concentrator (CPV)**
$1.4 / W_p → $ 0.55 / Wp
0.57kg CO_2 / W_p

\+

Balance of Systems
$0.5 – 1/ W_p
0.2 – 0.8kg CO_2 / W_p

\+

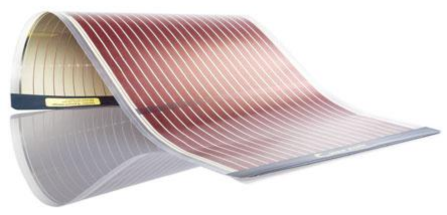
Storage

OR

Distribution grid

Status of solar PV: Focus of research

- Research can bring down the abatement cost of implementing solar power, through:
  - improved performance
  - lower cost production
  - optimised system configuration



Emerging: e.g. **Printable PV**
Lower cost and C intensity

Developing: **Concentrator (CPV)**
Higher energy yield

Fuel cells, solar fuels

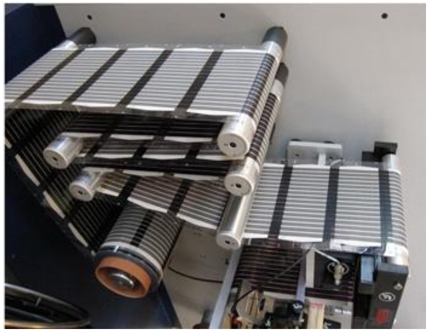
Storage

Smart grids

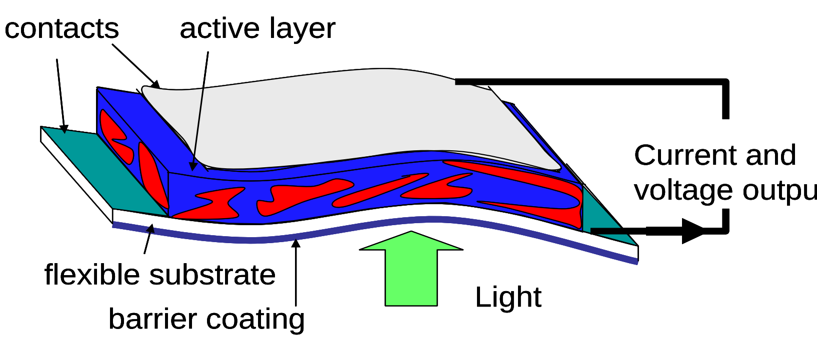
Distribution grid

Research Focus: Printable photovoltaic materials

Solution processable organic, inorganic or hybrid semiconductors



Manufacture by printing or coating



Lightweight, flexible solar cell device

- Advantages of printable PV
  - Light weight, colour and flexibility
  - Low capital investment
  - Rapid growth in production possible
- Dramatic performance improvement
  - Organic: 2% → 11% efficiency since 2001
  - Dye/perovskite: 7% →15% since 1990
- Potentially disruptive technology
- Strong science base in UK printed electronics

Scientific research:

New materials
Process / manufacture routes
Novel device concepts
Modelling and design

Cost modelling and life cycle analysis

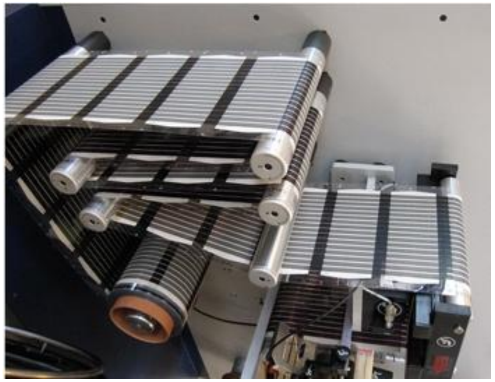
Modelling costs and emissions mitigation potential

- Manufacture:
  - Life cycle analysis of new technologies as projected in production
  - Identify key process and materials factors limiting cost and carbon intensity
- System :
  - Comparison of different solar PV technologies in given application contexts or locations
- Deployment:
  - Analysis of the cumulative emission savings available through PV rollout scenarios

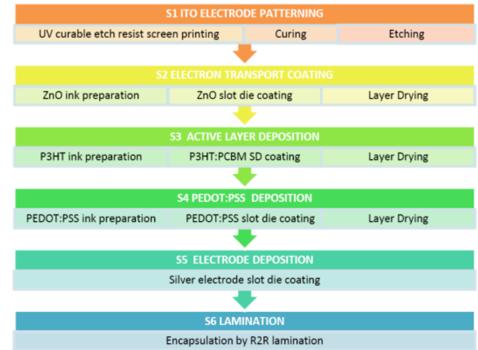
Scale of modelling

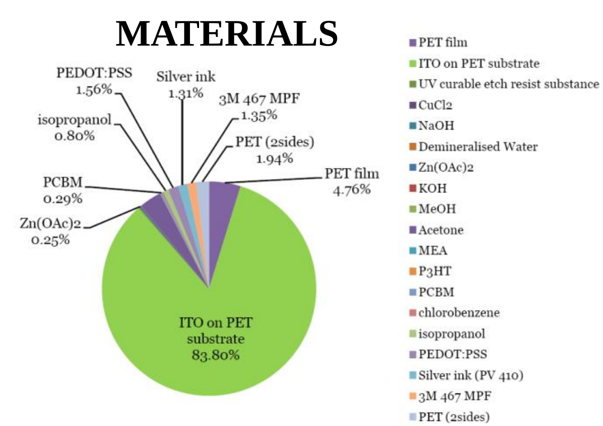
Case Study 1: Cost and life cycle analysis of OPV

N. Espinosa, A. Urbina et al., Sol. Energy Mater. Sol. Cells, (2010)
C. J. M. Emmott, Sol. Energy. Mater. Sol. Cells. (2012)

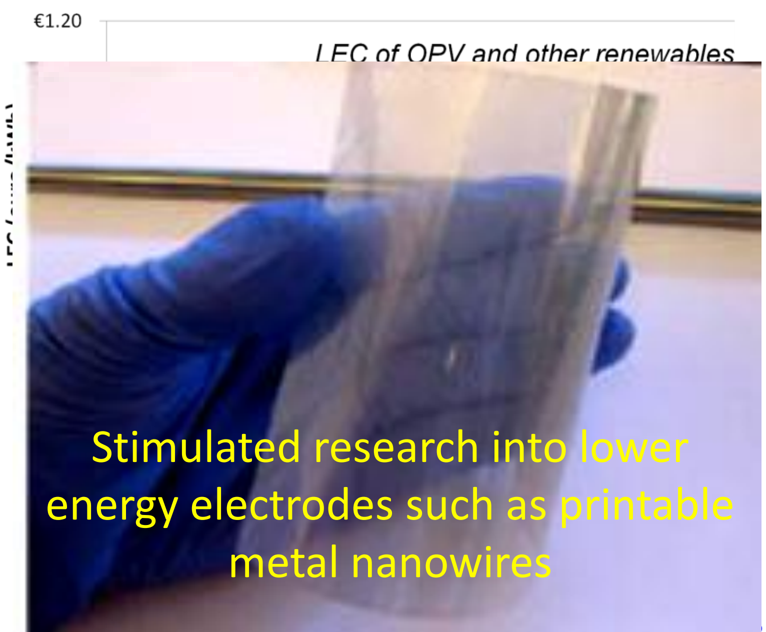


Life cycle analysis and cost modelling of printed OPV



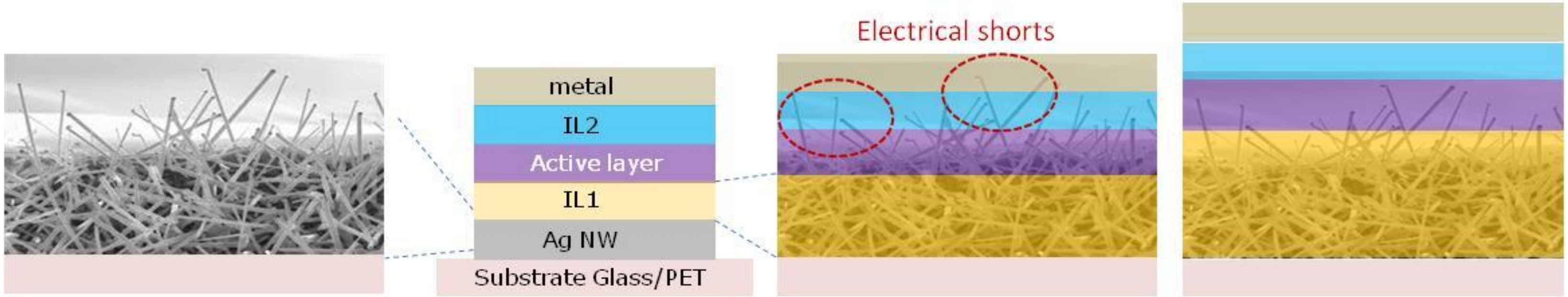


Identify the factors dominating cost and embedded energy

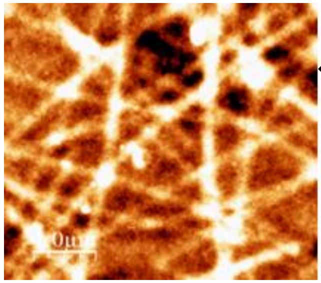


Stimulated research into lower energy electrodes such as printable metal nanowires

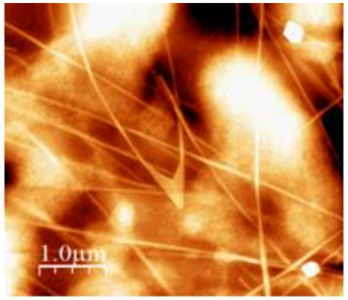
Research example: Replacement of ITO



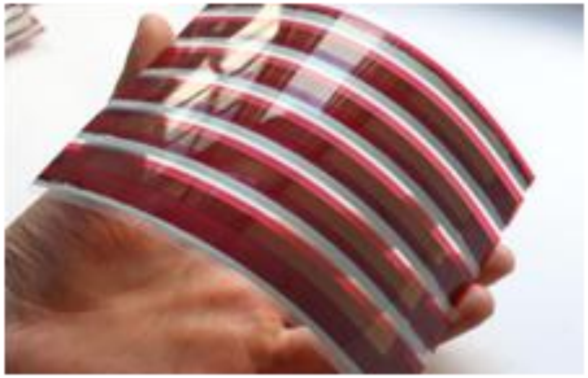
(a) Ag-NW+PH1000 | (b) | (c) Ag-NW+(TiO_2+TiOX) | (d) Ag-NW+(TiO_2+TiOX)



- **Problem**: rough surface causes short circuits
- **Solution**: "planarise" with double layer of TiO_2



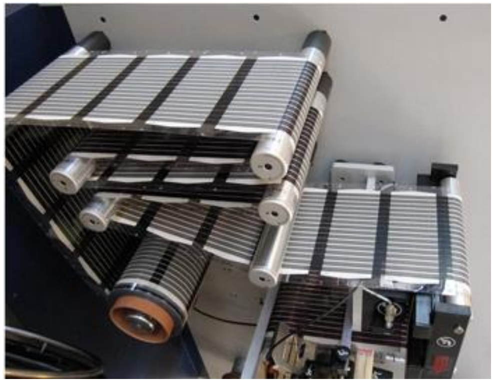
Result: fully solution processed 2.3% efficient ITO free device. ⇨4% devices in a roll-to-roll process.



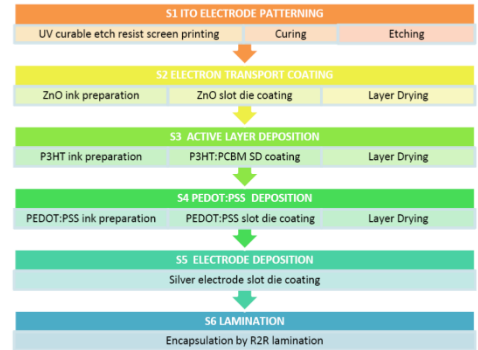
Dr Sachetan Tuladhar: KTS placement at Solar Press

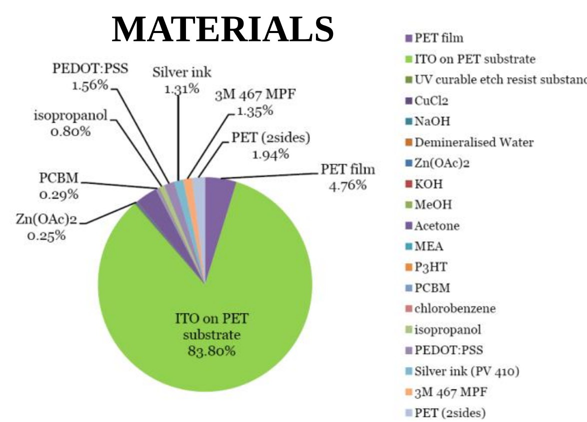
Case Study 1: Cost and life cycle analysis of OPV

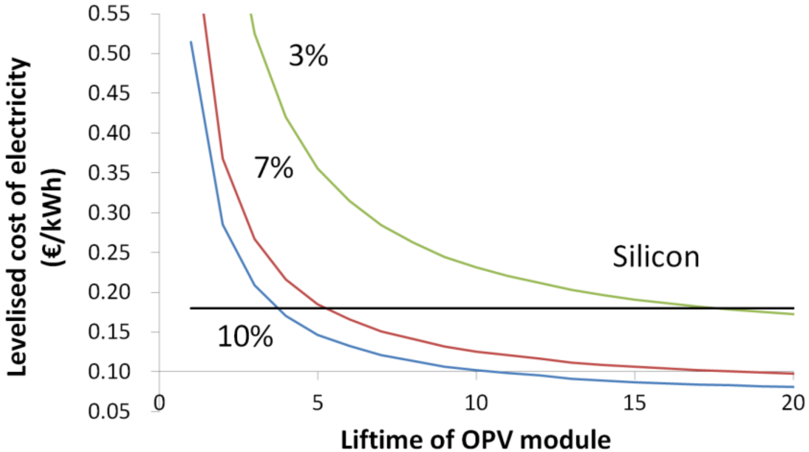
B. Azzopardi *et al. Energy Env. Science* (2011)



Life cycle analysis and cost modelling of printed OPV







Cost: Lifetime dominates the cost effectiveness

Identify the factors dominating cost and embedded energy

Modelling costs and emissions mitigation potential

- Manufacture:
  - Life cycle analysis of new technologies as projected in production
  - Identify key process and materials factors limiting cost and carbon intensity
- System :
  - Comparison of different solar PV technologies in given application contexts or locations
- Deployment:
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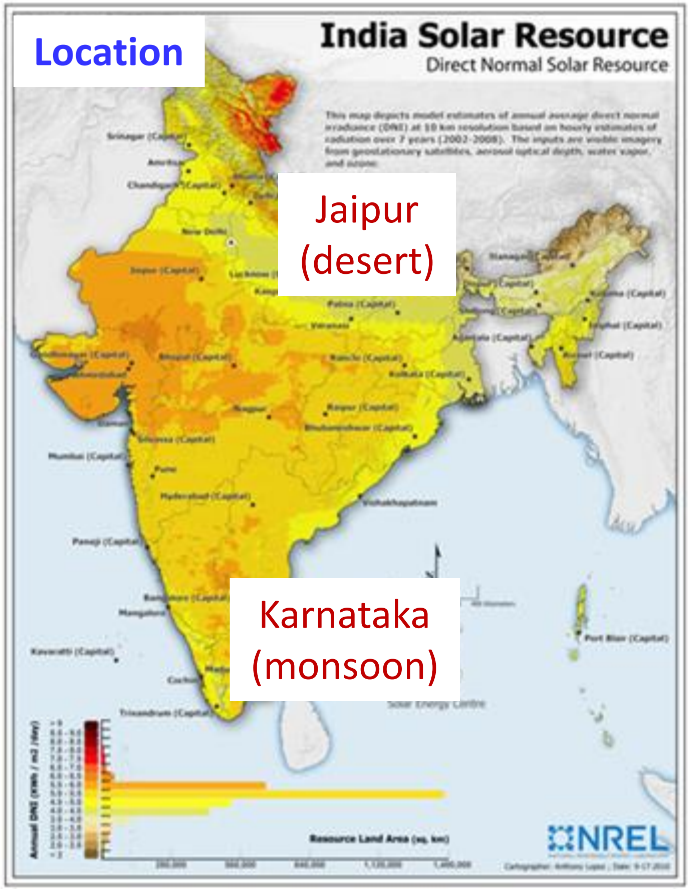
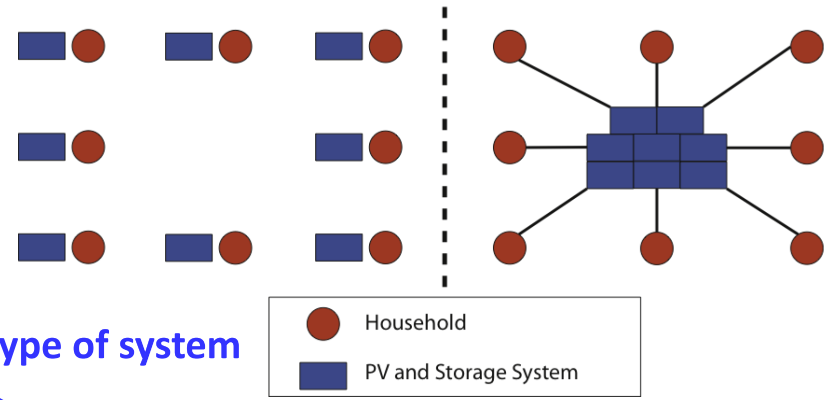
Scale of modelling

Case Study 2: Evaluation of PV for rural power in India

Alvin Chan, Sam Foster, Ajay Gambhir, Chiara Candelise, NED & JN





- Calculate energy output, specific emissions, cost of system, cost of electricity, abatement cost for each configuration
- Design tool to evaluate potential of new technologies

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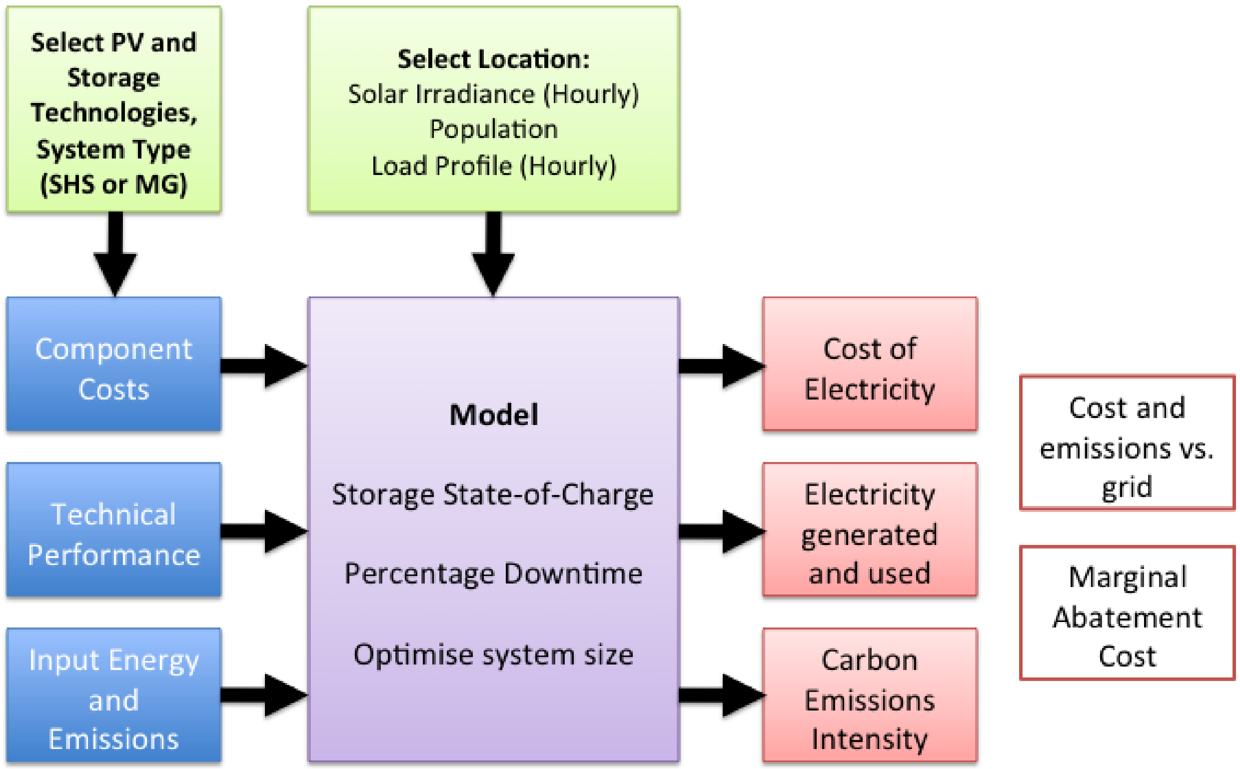

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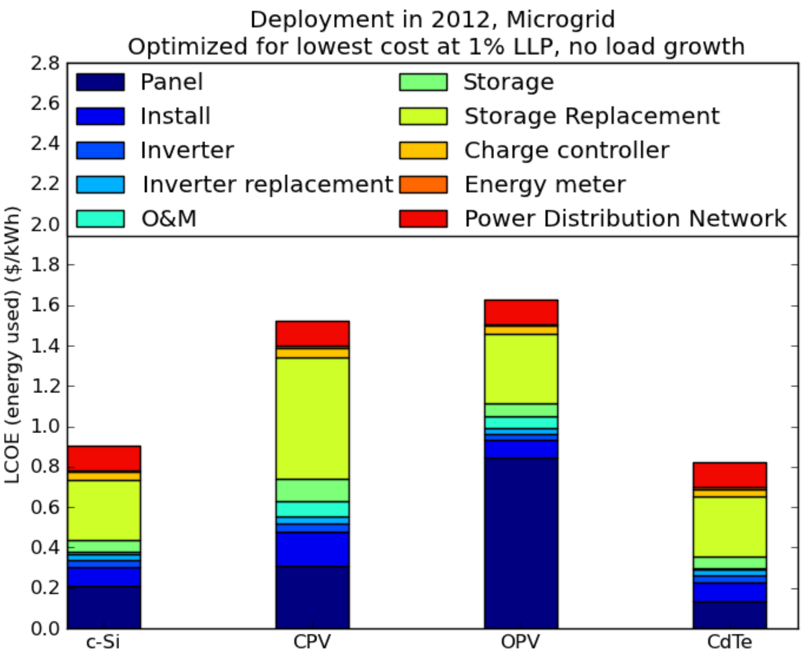

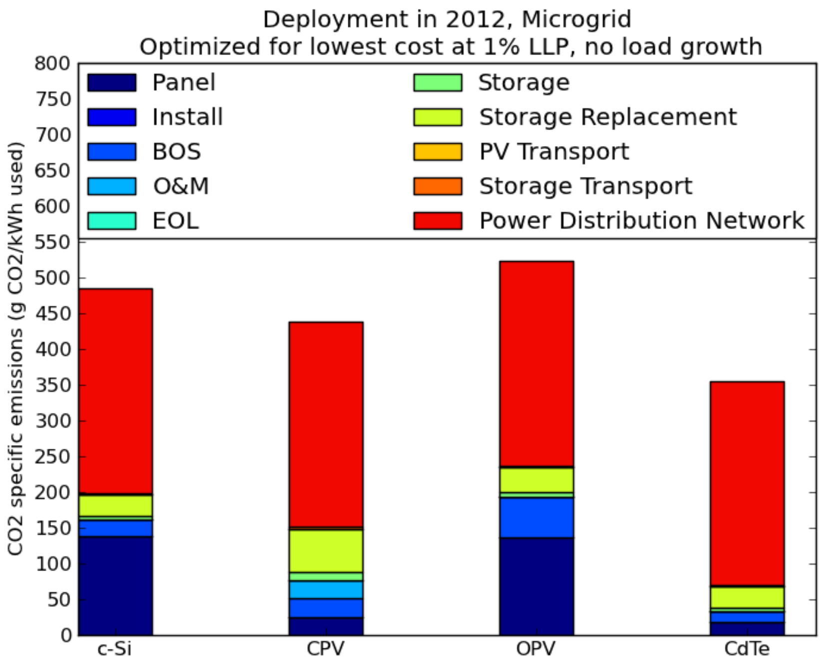

- High storage costs dominate system sizing and push up costs
- CPV more sensitive to intermittency so requires more storage
- Specific emissions dominated by distribution network but always lower than grid extension

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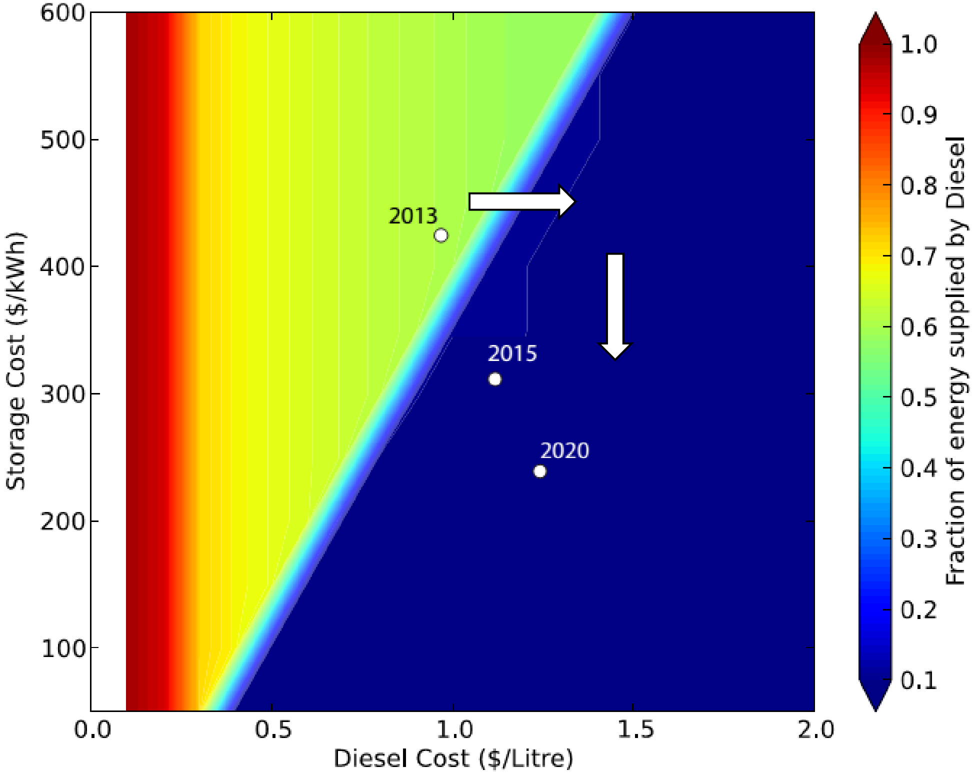
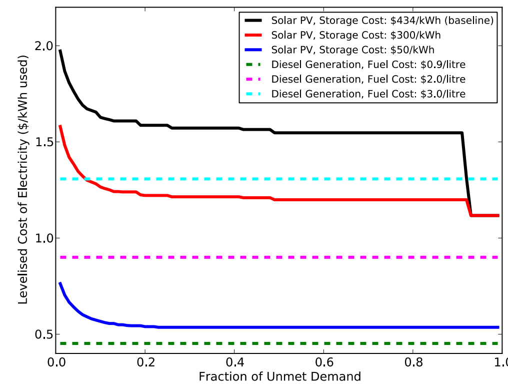
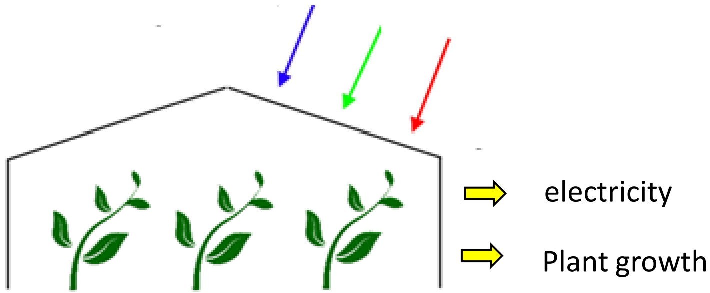




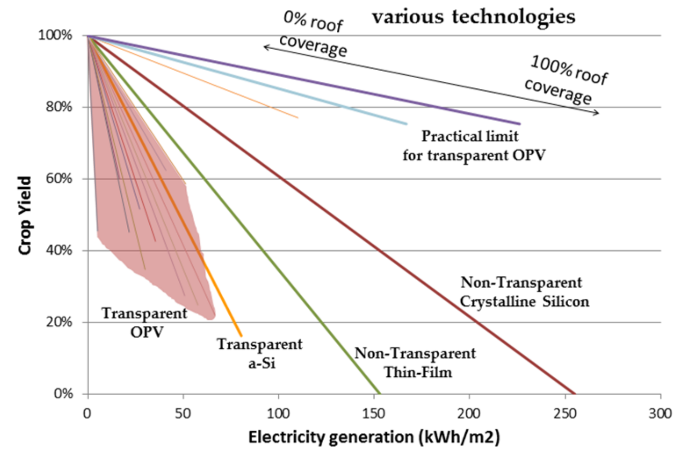
- Use projections of fuel price and technical development to project future cost effectiveness of PV.

Case Study 3 : Photovoltaic greenhouses

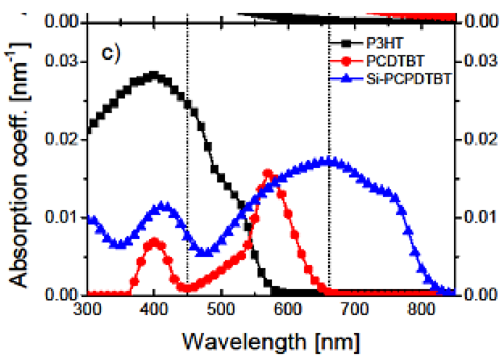
Chris Emmott, Jason Rohr & JN (2013)



Is it economic?



Optimise materials



Evaluate PV performance as function of material absorbance

Variable	Best Case Scenario	Baseline Scenario
Discount rate	2%	6%
Lifetime	10 years	5 years
Module Cost	30 €/m^2	40 €/m^2
Performance ratio	85%	80%
Insolation	2200 W/m^2	2200 W/m^2
Value of electricity	0.159 €/kWh	0.095 €/kWh
Annual increase in electricity value (above inflation)	0%	3%
Minimum cell (Module) efficiency	2.6% (1.75%)	12.9% (8.63%)

Economic analysis

Modelling costs and emissions mitigation potential

- Manufacture:
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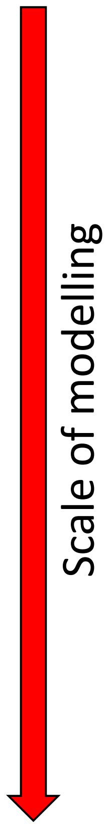
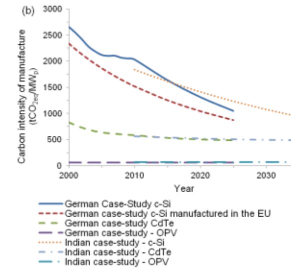
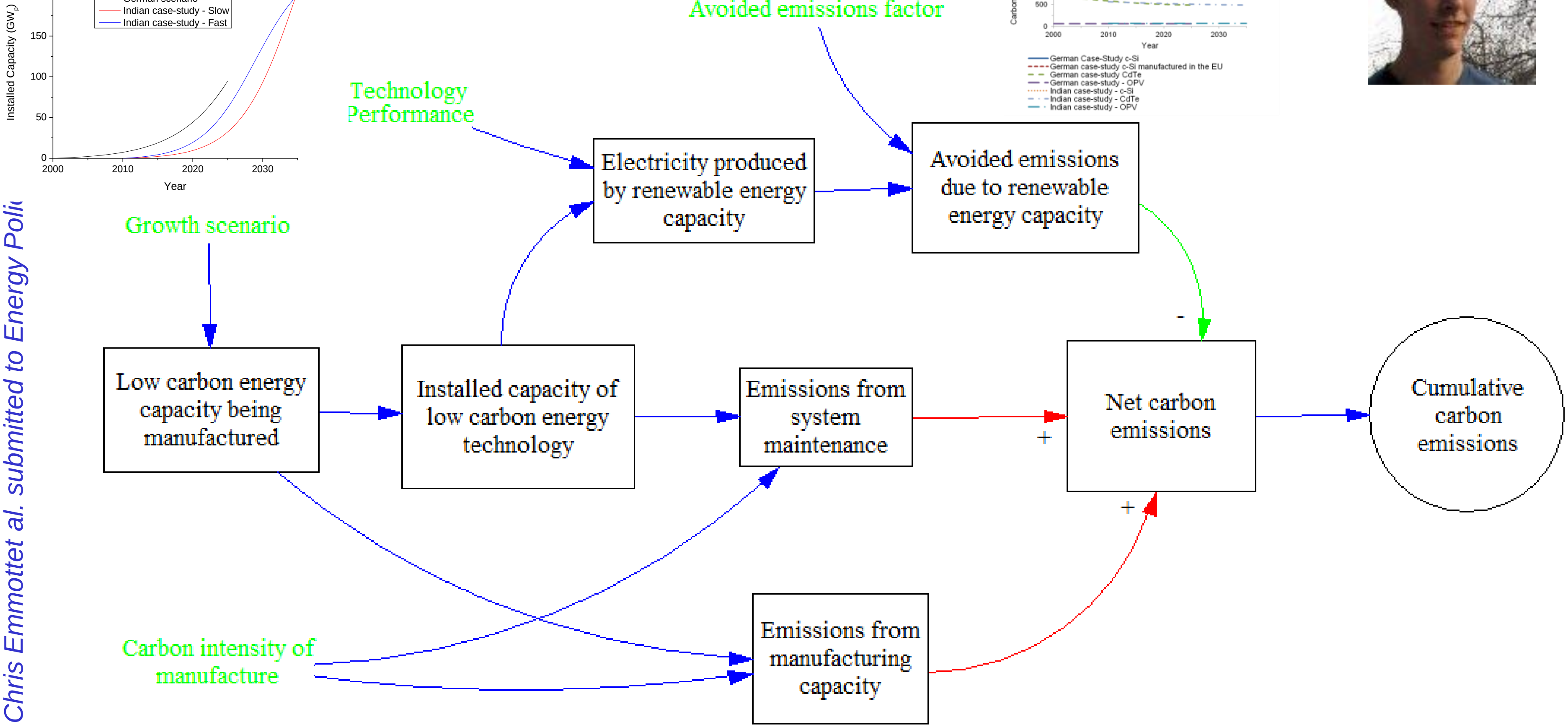


Case Study 4: Projection of emissions savings





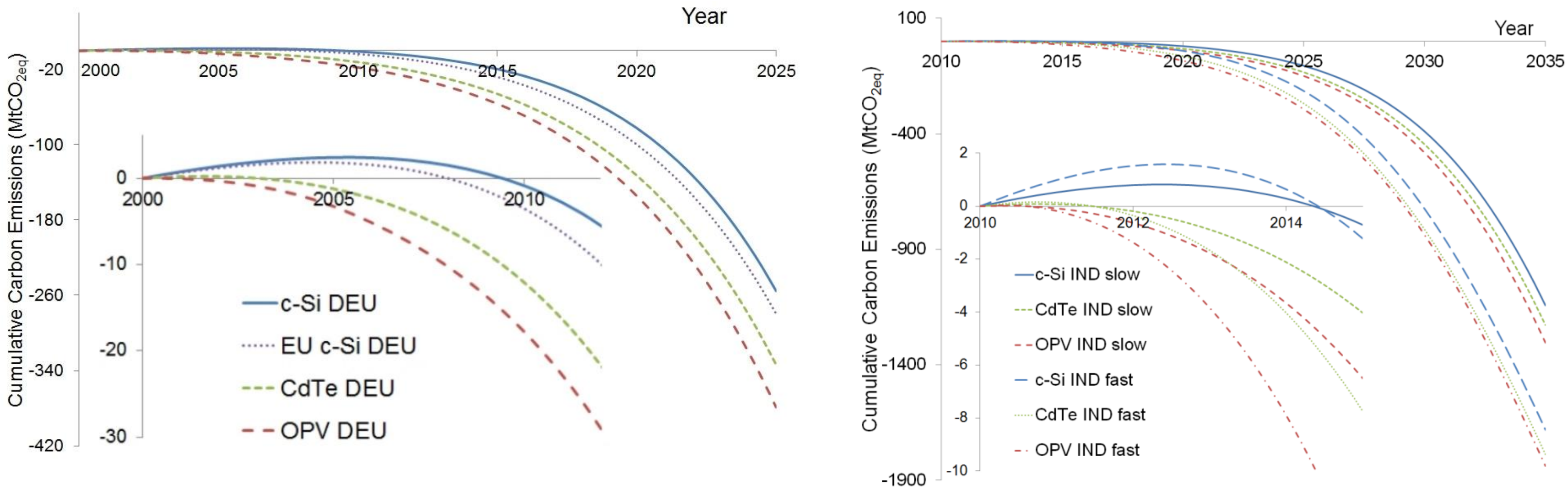
Chris Emmottet al. submitted to Energy Poli

OPV: Espinosa et al., En.Env.Sci 2012
CdTe: Fthenakis et al.,IEA PVPS task 12 (2011)
C-Si: EcoInvent data

Model of technology deployment:
For different PV technologies

Case Study 4: Projection of emissions savings

Chris Emmottet al. submitted to Energy Policy

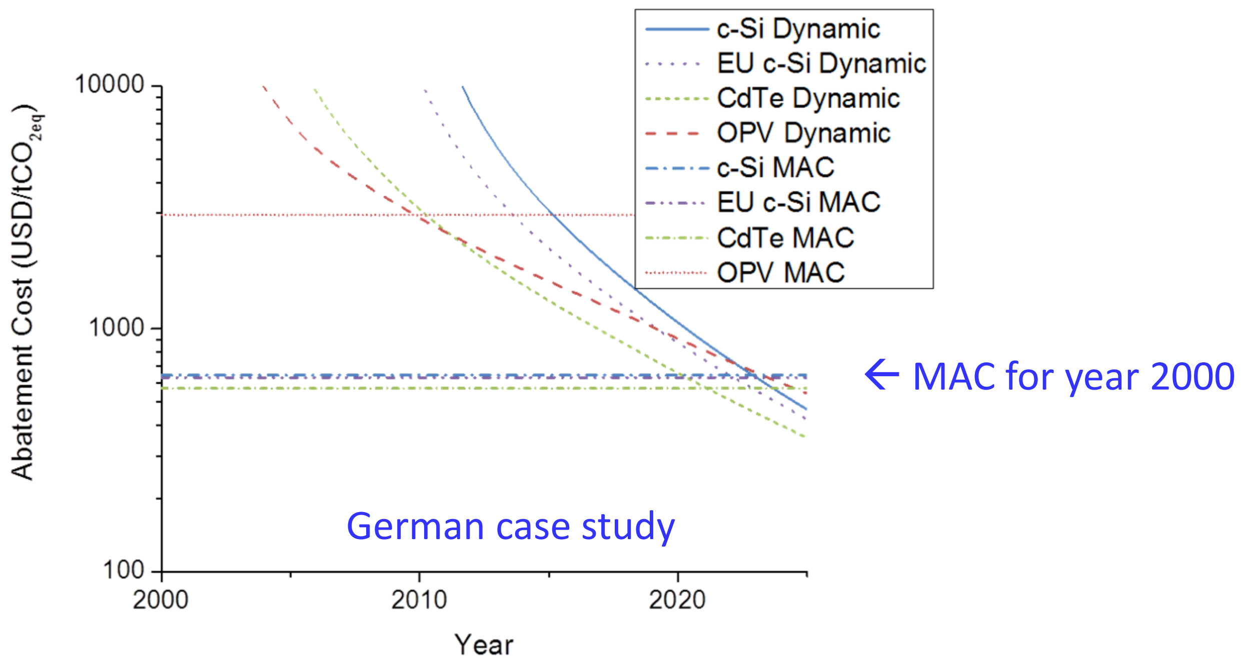


- Faster deployment costs more carbon in short term and saves more in long term
- Low embedded energy technologies more effective at mitigation (within area and availability constraints)

Case Study 4: Projection of emissions savings

Define a **dynamic** abatement cost:

$$= \frac{\text{Cost of all capacity deployed until time}, t - \text{cost of reference solution}}{\text{Total cumulative emissions balance at time}, t}$$

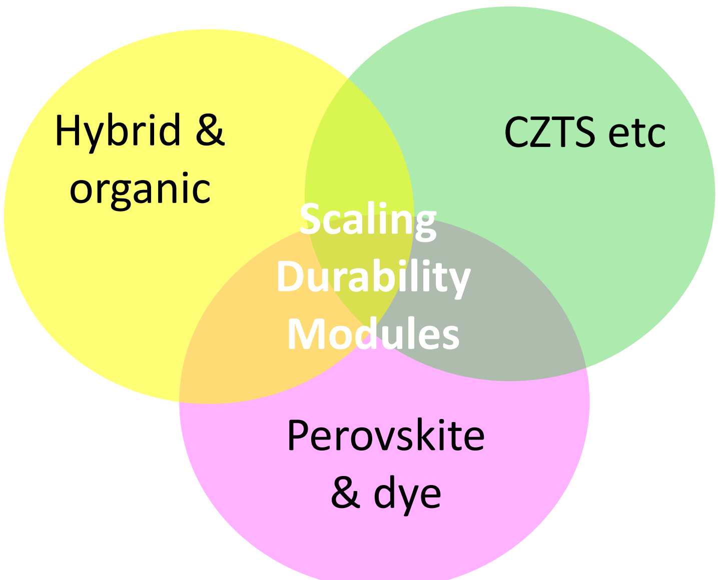


Short term cost of emissions savings can differ substantially from static marginal abatement cost

Chris Emmottet al. submitted to Energy Policy

Work in Progress: Analysis of Technological Innovation

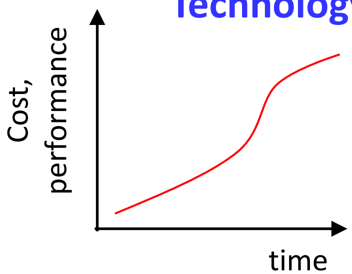
- SPECIFIC Innovation and Knowledge Centre @ Swansea University, co-located with new solar energy research institute Ser Solar. Linked to Imperial.
  - Research into printable photovoltaics
  - Scale-up facilities
  - Technology transfer



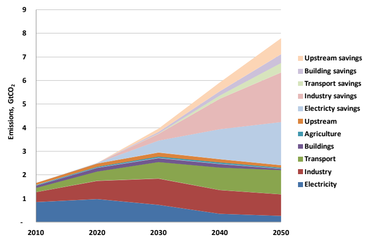
- Opportunity to study the potential impact of innovation in modules design, materials or processes on life cycle costs and energy

Work in progress: Energy systems models

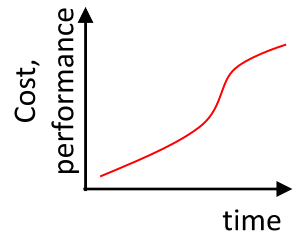
Technology



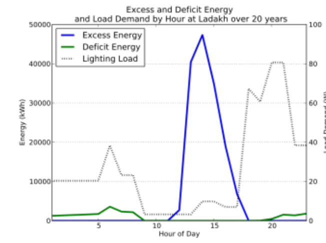
Minimise life cycle cost



Technology

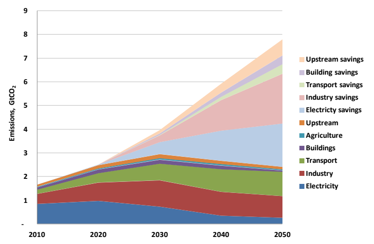


Temporal data



Spatial data

Minimise life cycle cost
Minimise energy flows
Include stochastic effects



Stefan Pfenninger and James Keirstead

- Improved energy systems models allow to model and distinguish new PV (and other) technologies

Conclusions

- Solar PV will be required to deliver large fraction of the future power supply and is capable of delivering, but hindered by high abatement costs

- Potential to reduce cost and abatement cost through research and development of emerging technologies

- Life cycle analysis and system modelling help to
  - Identify and change key factors that limit mitigation potential
  - Choose the right technology and system configuration for a given context
  - Project cumulative emissions savings for different scenarios and technologies
  - Focus on mitigation and not only electricity cost, when developing technologies

- We welcome collaborations with others addressing high throughput PV technologies, manufacture, LCA, innovation modelling, economic analysis