BASQUE CENTRE
FOR CLIMATE CHANGE
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The Potential Land-use Impacts from Solar Energy

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TRANSrisk
TRANSITION PATHWAYS AND RISK ANALYSIS FOR CLIMATE CHANGE POLICIES

Introduction

- Renewable energy more land-intensive than fossil energy
  - Land impacts of bio-energy well known
  - Land impacts of other renewable energies often assumed to be negligble

- Solar energy often installed in agricultural land
  - Rooftop space limited
  - Non-productive land (deserts, dry scrublands) often far from consumption points
  - Agricultural land flat and often well-connected (roads, grids)

- Like bio-energy, solar energy in agricultural space has carbon footprint
  - Direct: conversion of high vegetated land to “solarland” (not very common)
  - Indirect: conversion of agricultural land to “solarland” and high vegetated land to agricultural land else in the world to meet agricultural demand (common)

Solar power installed in croplands, United Kingdom

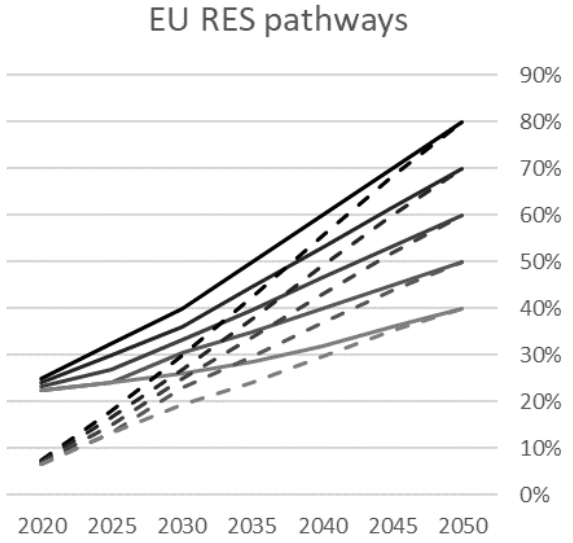
Structure: overall

- Model: Global Change Assessment Model (GCAM)
  - Able to assess trade-offs between energy and land systems
  - Flexible in projecting a variety of energy and climate policies
  - Representing variety of solar power technologies

- Geography: Analysis limited to three regions:
  - European Union: High solar penetration and RE targets, negligible wastelands
  - India: Dense, Low solar penetration, high potential, some wastelands
  - Japan + S Korea: Dense, high solar penetration, no wastelands

- Background assumptions:
  - Global SSP2
  - Global Nationally Determined Contribution emission targets (Fawcett 2015)
  - Fixed electricity output for each of three regions (required for comparison)
  - Fixed international bio-energy demand (to avoid leakage effects)

Structure: study design

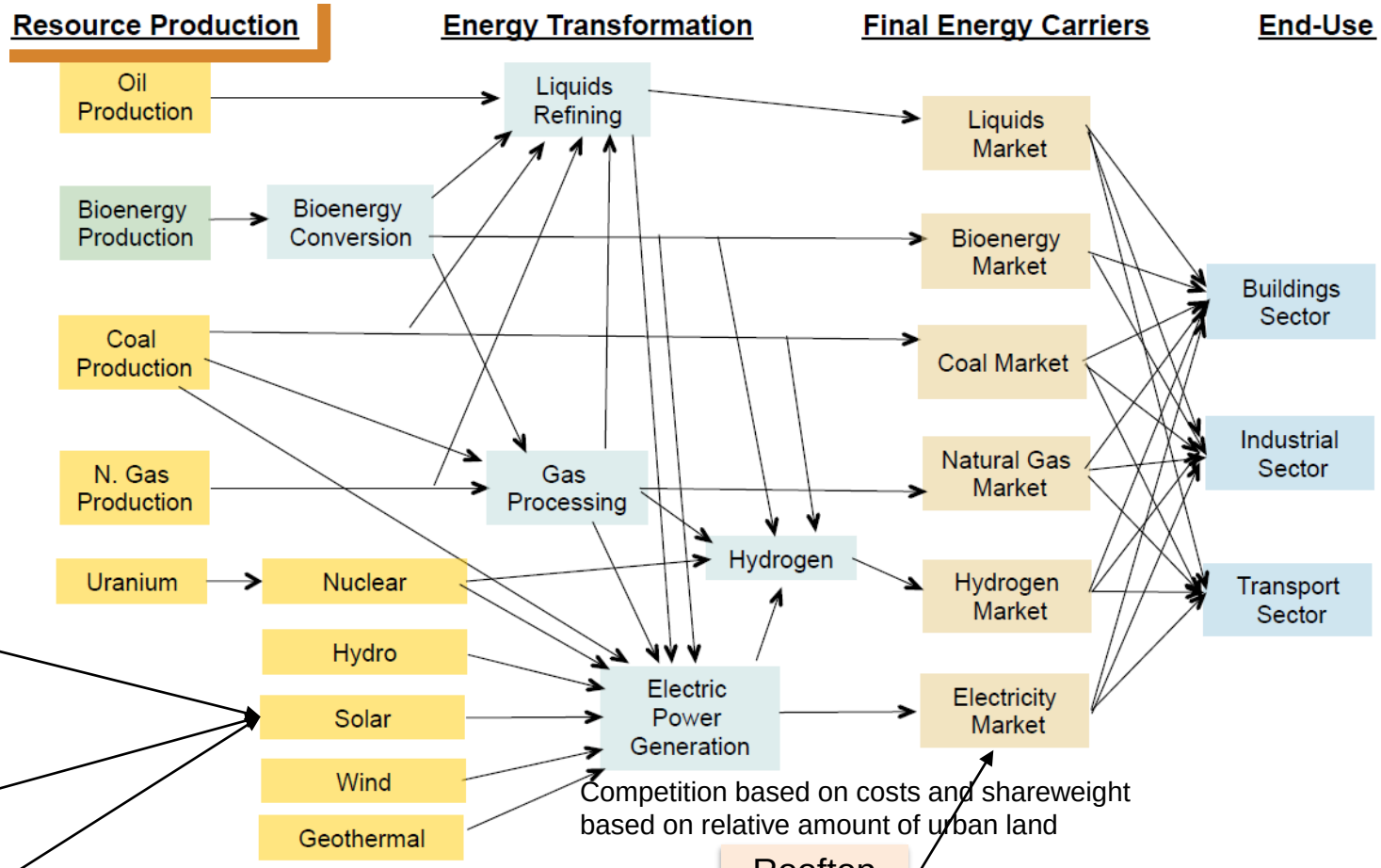


- Renewable electricity (RES) targets
  - Ranging from 40% to 80% by 2050 (solid lines)
  - Increasing part of these targets to be reached by dominant technology (dashed lines)

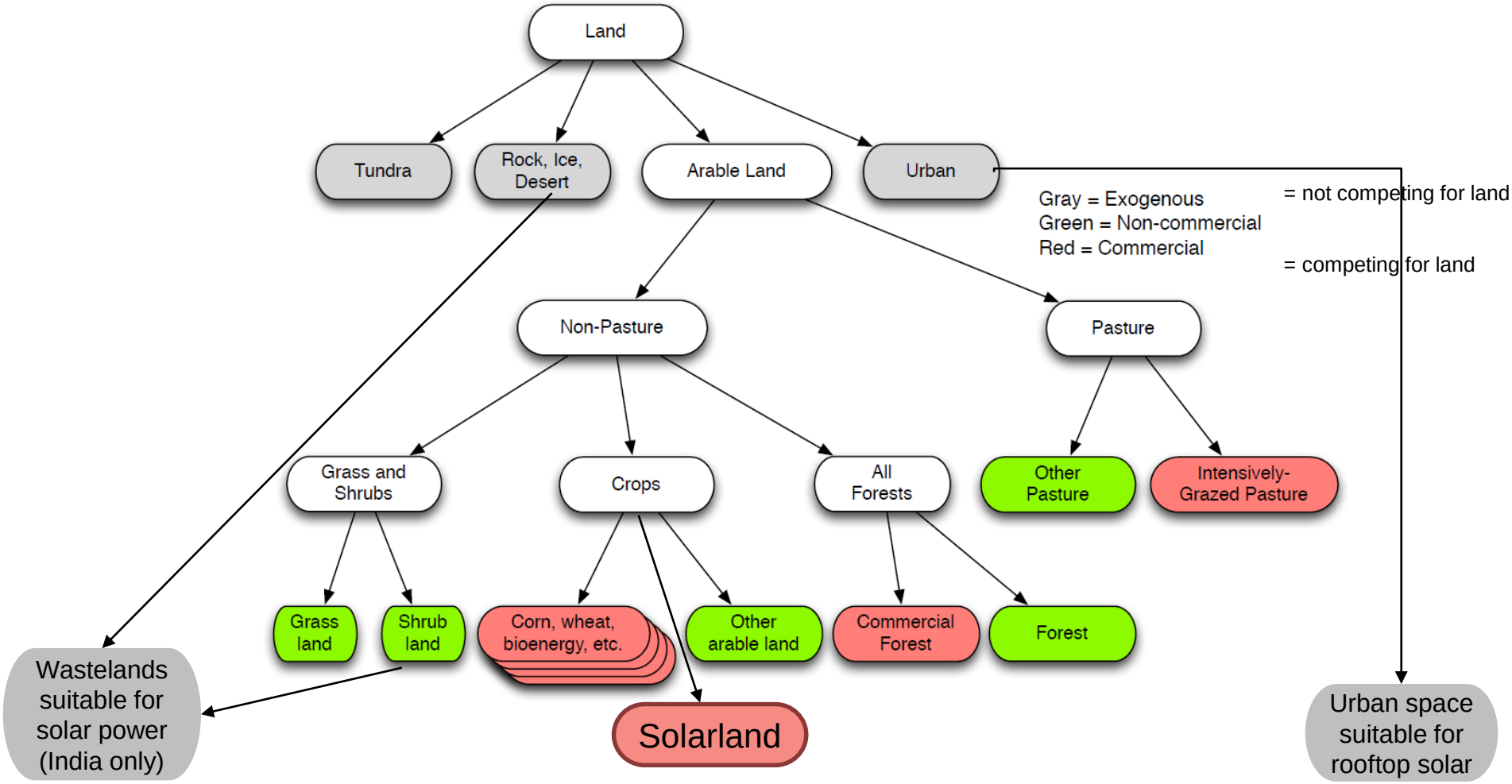
- Dominant technologies:
  - Non land-occupying: wind, geothermal, hydro, rooftop-PV, (nuclear for India)
  - Solar energy: PV, CSP, based on land and on rooftops
  - Bio-energy: Conventional, biomass gasification, CCS, CHP

- Relevant output
  - Compared to non land occupying technology pathway at each RES target level, we measure global land use change emissions per additional GJ of:
    - Solar energy to measure kg per GJ of solar
    - Bio-energy to measure kg per GJ of bio-energy (for comparison)

Method: GCAM energy system + "solarland" module



Method: GCAM land system + “solarland” module

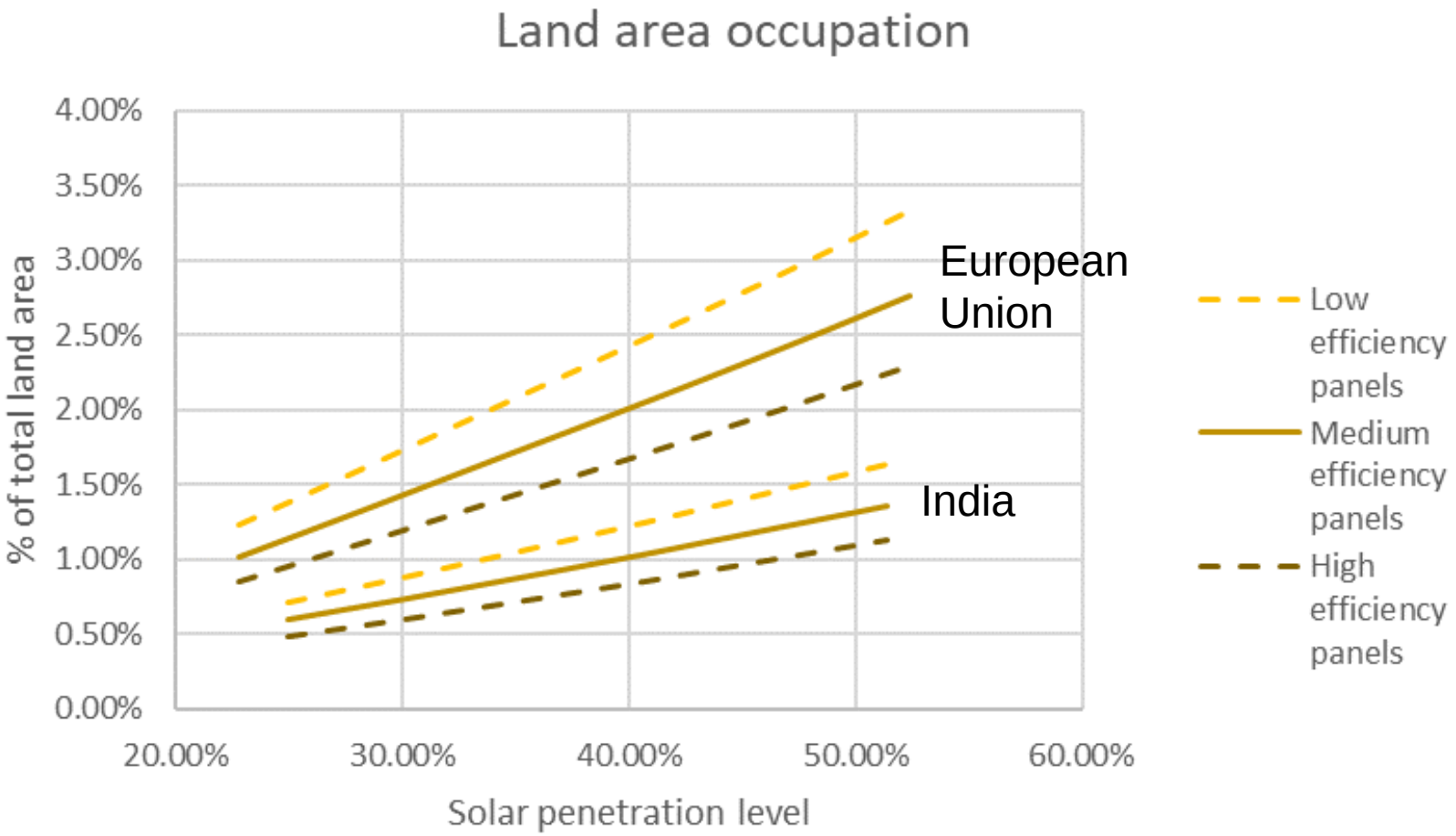


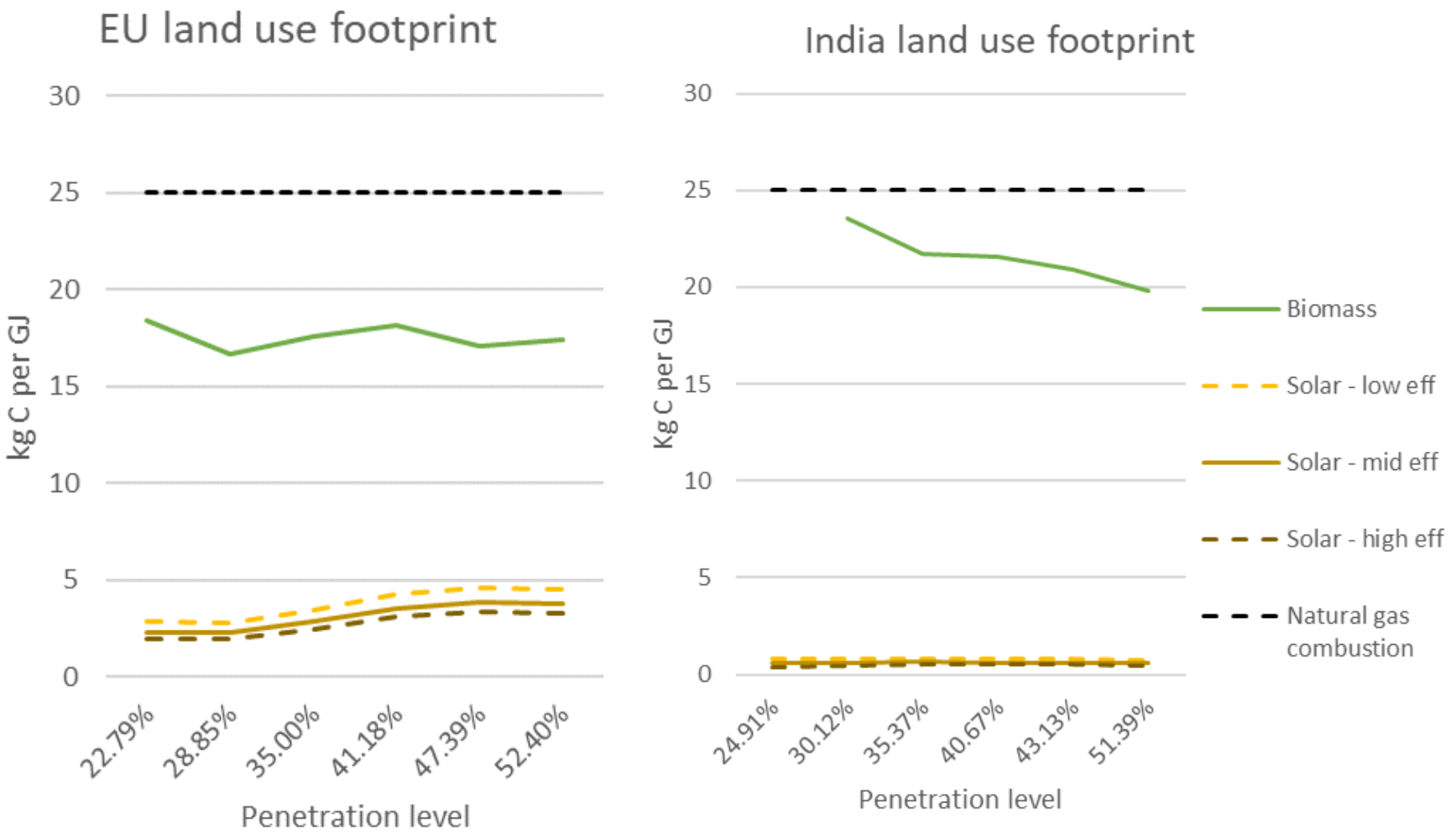
Method: "Solarland" module

- $\rho_e{}^{AEZ} = I^{AEZ} \cdot f^{t}{}_{1} \cdot f_2 \cdot f_3{}^{AEZ}$, where:
  - $\rho_e{}^{AEZ}$ = Solar energy yield per AEZ
  - I^{AEZ} = Average solar irradiance per AEZ
  - f_1 = Solar cell conversion efficiency (increasing with time)
  - f_2 = Averaged performance ratio over the life cycle of the PV power plant
  - $f_3{}^{AEZ}$ = Land-occupation ratio = $GSR \cdot PF^{AEZ}$
    - GSR = Generator-to-system area, set on 0.7
    - PF^{AEZ} = Packing factor per AEZ: Total ground area required for PV array installation in order to avoid self-shading of solar panels =
    - $PF^{AEZ}(sc1) = cos\ \beta^{AEZ} + \frac{sin\ \beta^{AEZ}}{\tan(66.55° - \emptyset^{AEZ})}$

- For more details, see Castro et al (2013), Martín-Chivelet (2016)

Results


Land area occupation
% of total land area
4.00%
3.50%
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
20.00%
30.00%
40.00%
50.00%
60.00%
Solar penetration level
European Union
India
Low efficiency panels
Medium efficiency panels
High efficiency panels


EU land use footprint
30
25
20
15
10
5
0
kg C per GJ
22.79%
28.85%
35.00%
41.18%
47.39%
52.40%
Penetration level
India land use footprint
30
25
20
15
10
5
0
Kg C per GJ
24.91%
30.12%
35.37%
40.67%
43.13%
51.39%
Penetration level
Biomass
Solar - low eff
Solar - mid eff
Solar - high eff
Natural gas combustion

Conclusions

- Land occupation solar power significant at high latitude regions
  - Up to 3.30% of total land at 50% penetration in the EU
  - Significantly lower in India due to higher irradiance and lower latitude (more dense installation)
  - For penetration levels of 20% and 50%, rooftops make up for 18% and 7% of solar energy in EU, while only for 3.8% to 9% in India

- Land-based carbon footprint of solar power
  - Not to be ignored for high latitudes: up to 18% of natural gas emissions and 25% of biomass land use impact
  - Very insignificant in India due to high irradiance, dense packing and low agricultural productivity