HS PF

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Assessing residential PV-systems: Combining economic and ecological assessment to ease decision making

Introduction

- Shift to renewable energy sources to stop climate change.
- Growing interest of **society** in climate and **environmental protection**.
- Photovoltaic (PV) for single-family houses:
  - Efficient use of already sealed area (space for systems is limited).
  - Different module types available.
- Magic triangle of energy policy: **system costs, environmental protection** and security of supply
- Environmental aspects go further than Carbon Dioxide Emissions: e.g. land use, minerals and metals extraction, human toxicity.

⇒ Multi-Dimensional Problem: The decision making process is complex; possible trade-offs must be weighted.

Research Question

- From a perspective of a house owner: Is it interesting at all to install rooftop PV systems?
  - Is the installation of photovoltaic profitable in terms of economic and ecologic aspects?
- Bringing economic and ecological aspects together - how to solve the multi criteria decision problem?
- Can the integration of an environmental assessment be helpful for the decision making process? Does it introduce new aspects and can possible drive the expansion of renewables?

System Parameters

- Electricity consumption: 4000 kWh
- Installed photovoltaic capacity 3 kWp
- Average yield 817 kWh/kWp (Bundesnetzagentur 2019)
- Module degradation of 2% in the first year; afterwards 0,5% per year
- Self consumption of 35% of generated PV electricity (Quaschning et al. 2013)

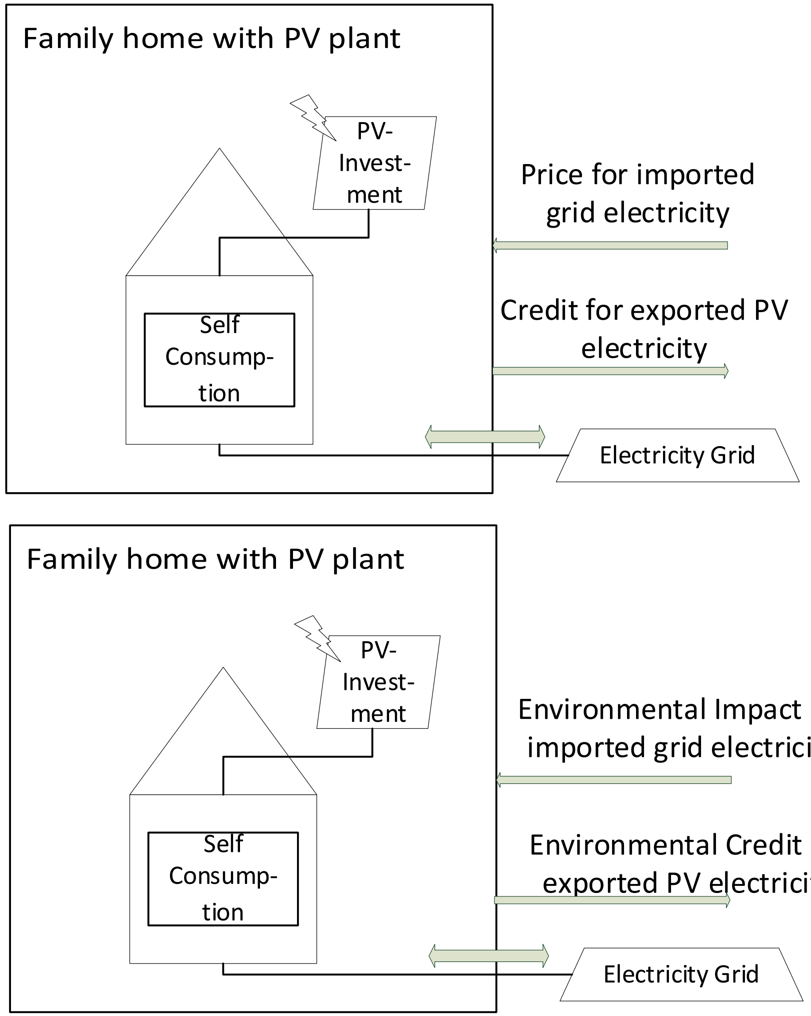

Fig 1: System Boundaries and Credits

PV Modules

- Mainstream: state of the art modules with 275-325Wp, white back film)
- Low Cost Modules (Second hand modules, lower quality)
- All Black (modules with black back film with 290-390Wp)
- High Efficiency Crystalline (crystalline modules from 330Wp (e.g. PERC, HJT, N-Typ)
- Thin Film (e.g. CIS, CdTe)

(www.pvxchange.com)

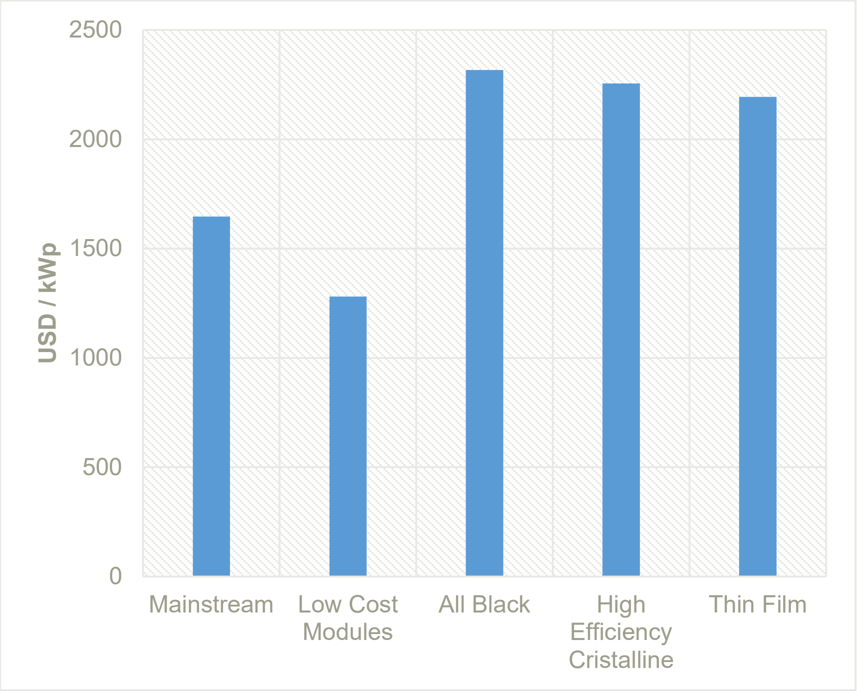

Fig 2: Total System Costs for different PV modules (Acc. IRENA 2019)

Method I: Levelized Cost of Electricity (LCOE)

Parameter:

- Discount rate $r = 2{,}7\%$
- Lifetime $n = 30\ a$ (Wernet et al. 2016)
- Replacement investment for inverter after 15 a
- Credit of 0,09 USD/kWh for fed in electricity (Bundesnetzagentur 2021)
- Operation & Maintenance $5\ \frac{USD}{kW_p * a}$ (Steffen et al. 2020)

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

LCOE = the average lifetime levelised cost of electricity generation

I_t = investment expenditures in the year t

M_t = operations and maintenance expenditures in the year t

F_t = fuel expenditures in the year t

E_t = electricity generation in the year t

r = discount rate

n = life of the system.

(IRENA, 2019)

Method II: Life Cycle Assessment (LCA)

- Assessment of the full Life Cycle of a technology (ISO 14040/44)
  - All stages from raw material extraction, production, use and disposal are considered.
  - Different environmental impacts are assessed (Greenhouse Gases, Air Pollutants Land Use, Minerals & Metals etc.)
- To evaluate these impacts the Ecological Scarcity Method is applied (Frischknecht and Büsser-Knöpfel 2013, Lambrecht et al. 2020)
  - Special version of a weighted sum.
  - External normalisation and weighting is applied, which is based on politically legitimised targets

$u_i(x) = \sum_{j=1}^{n} w_j r_{ij}(x),$

i = scenarios and j criteria (Tzeng and Huang 2011)

$w_j = (\frac{A_j}{T_j})^2$ … weight

$r_{ij}(x) = \frac{x_{i,j}}{N_j}$

A = current environmental pressure
N = reference value
T = target value

Method III: Weighted Sum Approach

- The criteria are **total costs** and the **total environmental impact per year.**
- Normalisation is performed with Vector Normalisation (Vafaei et al. 2018):

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} {x_{ij}}^2}}$$

i = scenarios and j = criteria (Tzeng and Huang 2011)

x = criteria results

- Weighting (w_j): **Economy and Ecology 1:1**
- Result: $u_i(x) = \sum_{j=1}^{n} w_j r_{ij}(x),$

Results I: LCOE

- Low Cost Modules reach lowest LCOE followed by Mainstream Modules
- LCOE is higher for All Black, High Efficiency Crystalline and Thin Film

⇒ Only the cheapest and with probably lowest efficiency are viable compared to the German electricity mix.

⇒ Yearly savings are 100 USD/a for Low Cost Modules (10 USD/a for Mainstream)

⇒ Why doing the effort of installing PV at all?

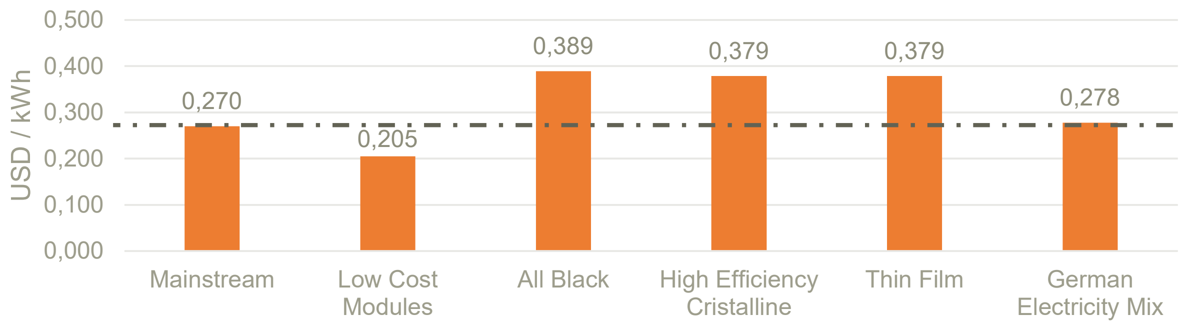

Fig. 3: LCOE Residential PV and average price for German electricity

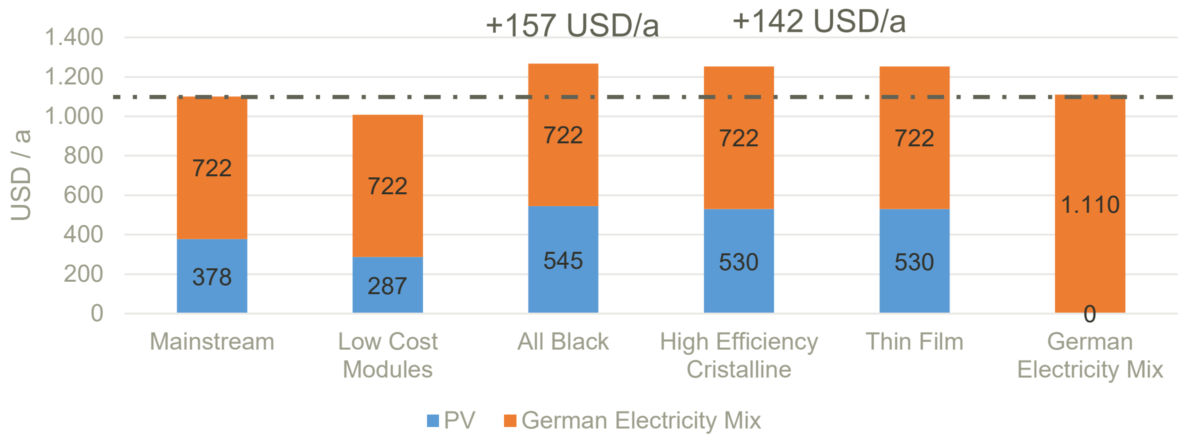

Fig. 4: Yearly total electricity costs for a household

Results: LCA

- High general reduction potential of environmental impacts
- In contrast to LCOE all alternatives have lower impacts.
- Especially global warming (grey)
- Increase of heavy metals emissions into water

⇒ In contrast to the cost assessment thin film PV is the best option

⇒ All PV technologies have a lower environmental impact than the German electricity mix.

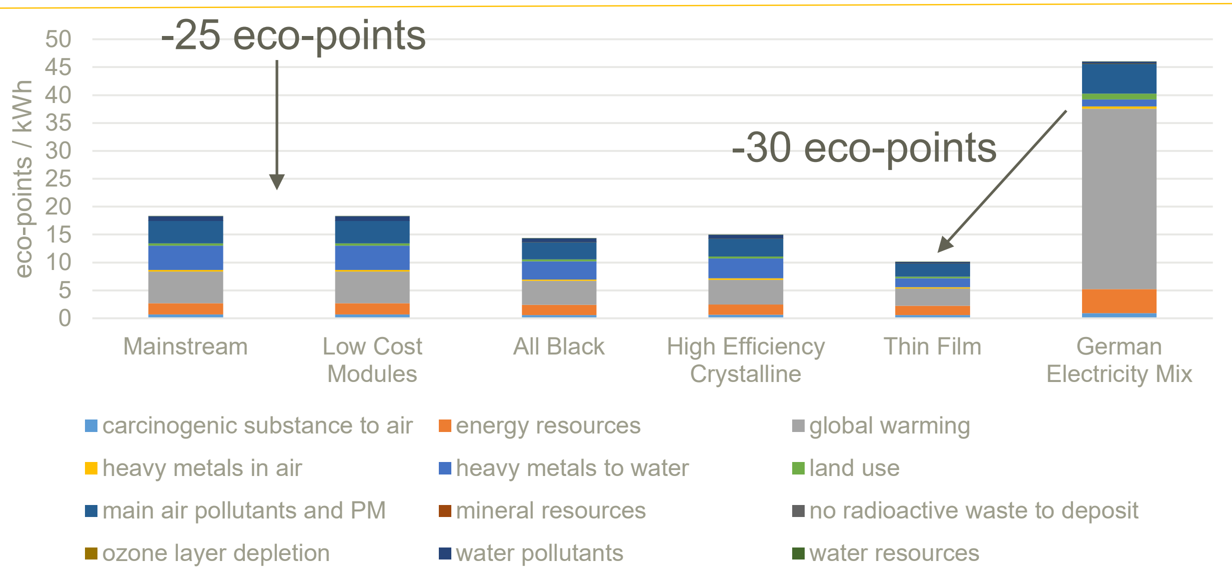

Fig. 5: Potential environmental impact of different photovoltaic technologies

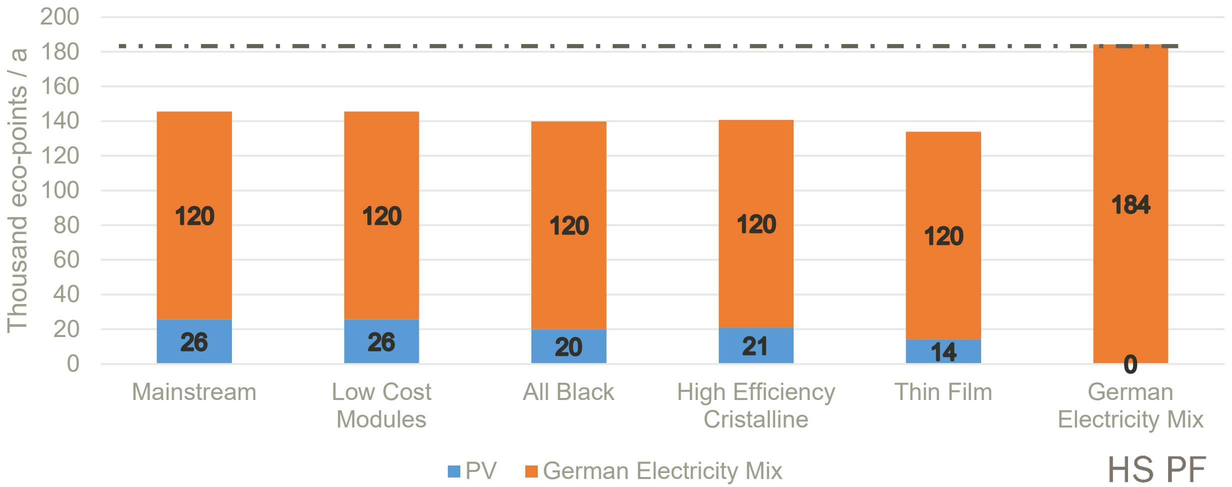

Fig. 6: Total yearly environmental impact of a single house family

Results: Weighted Sum

- Low Costs modules results in being the best option.
  - Lifetime can be discussed.
- Mainstream modules are following with a total score of 0,877.
- Electricity mix is the worst option.

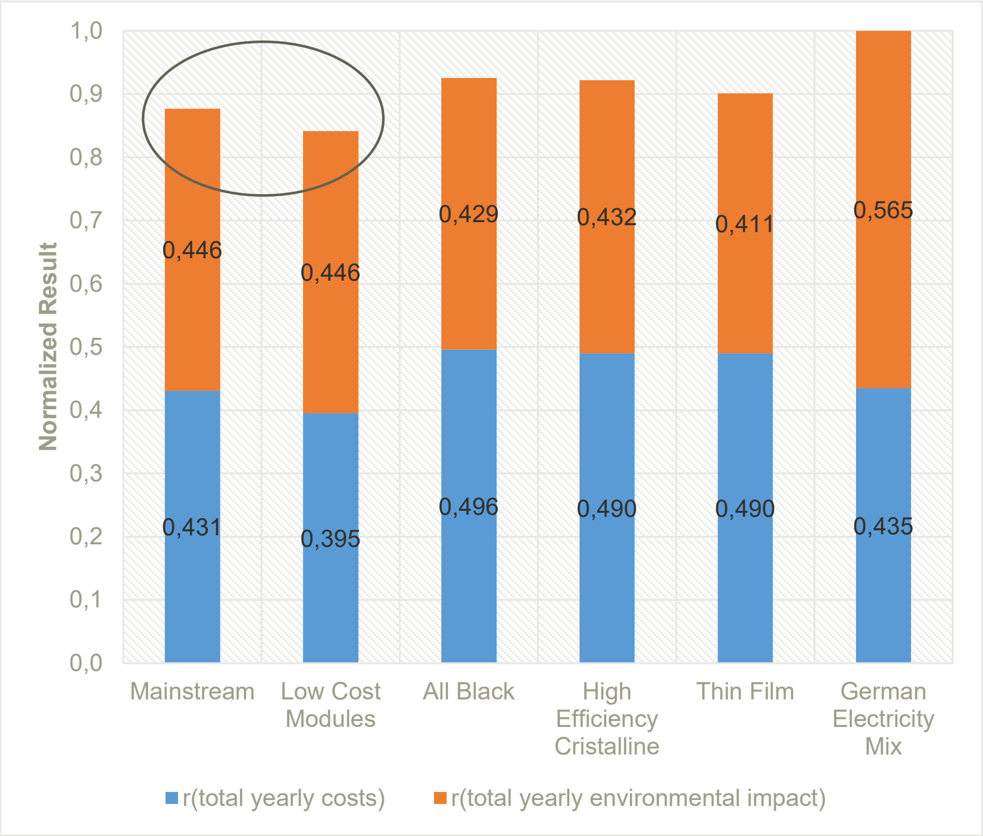

Fig. 7: Total normalized results (weighting 1:1)

Sensitivity Analysis: Weighting

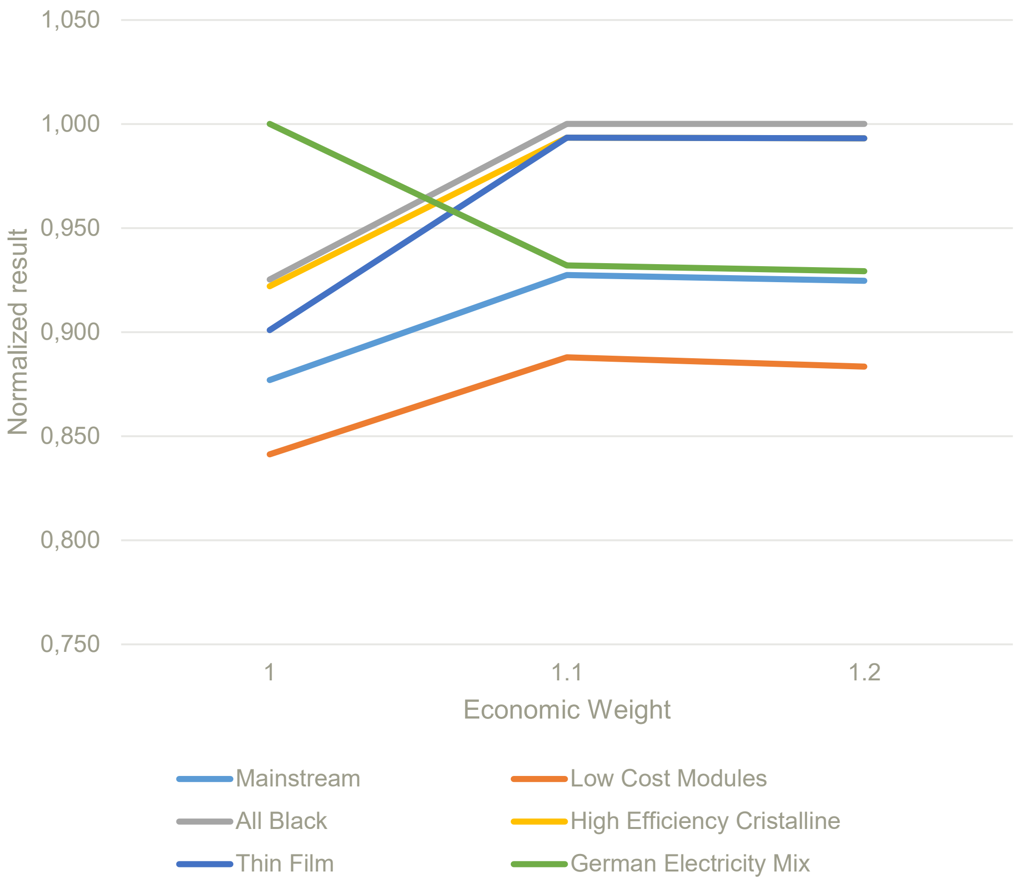

Fig. 8: Increasing the economic weight (ecologic weight = 1)

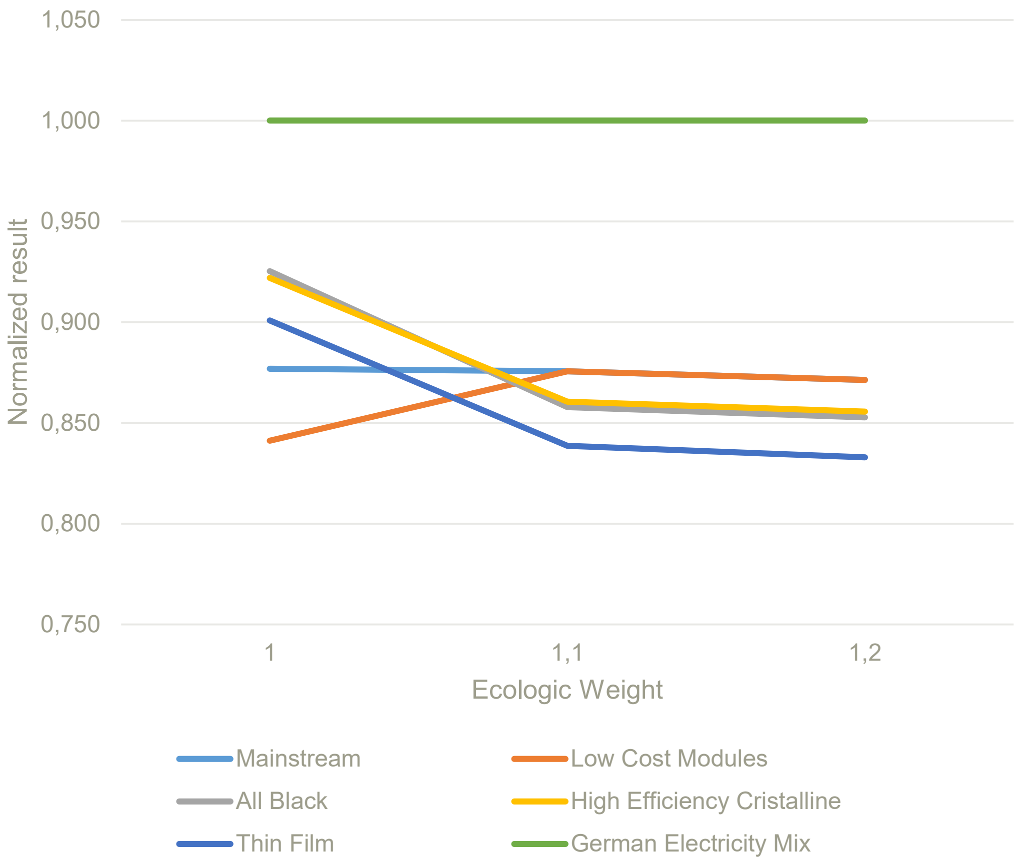

Fig. 9: Increasing the ecologic weight (economic weight = 1)

Conclusion

- The utilization of PV plants is environmentally beneficial but only for low-priced modules economically viable.
- There are PV modules with better environmental performance available.
- Attractiveness for the installation of PV plants for homeowners could be higher.

⇒ Updated incentive system is needed to differentiate between module types…

⇒ …or ways to increase self-consumption (integration of electricity storage systems?)

- Performing an assessment for environmental impacts next the economic increases insights and moreover provides more arguments for or against different energy scenarios.
- It is adventurous to include more environmental impacts than carbon dioxide emissions as there are counteracting impacts.
- Method is applicable to assess every energy system to weigh up economic and environmental impacts.

Outlook

- Method to define weights
- Extending the assessment by implementing electricity storage systems
- Analysing industrial or commercial buildings
- Integration of security of supply

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