Can large-scale solar panels and wind-mills farms create a significant climate change?

Yan Li, Eugenia Kalnay, Safa Motesharrei, Jorge Rivas,

Eviatar Bach, Fred Kucharski, Daniel Kirk-Davidoff, Ning Zeng

***Science*, out on September 7 2018**

Can large-scale solar panels and wind-mills farms create a significant climate change?

Yes! And it would be very beneficial!

Yan Li, Eugenia Kalnay, Safa Motesharrei, Jorge Rivas,

Eviatar Bach, Fred Kucharski, Daniel Kirk-Davidoff, Ning Zeng

***Science*, out on September 7 2018!**

Introduction

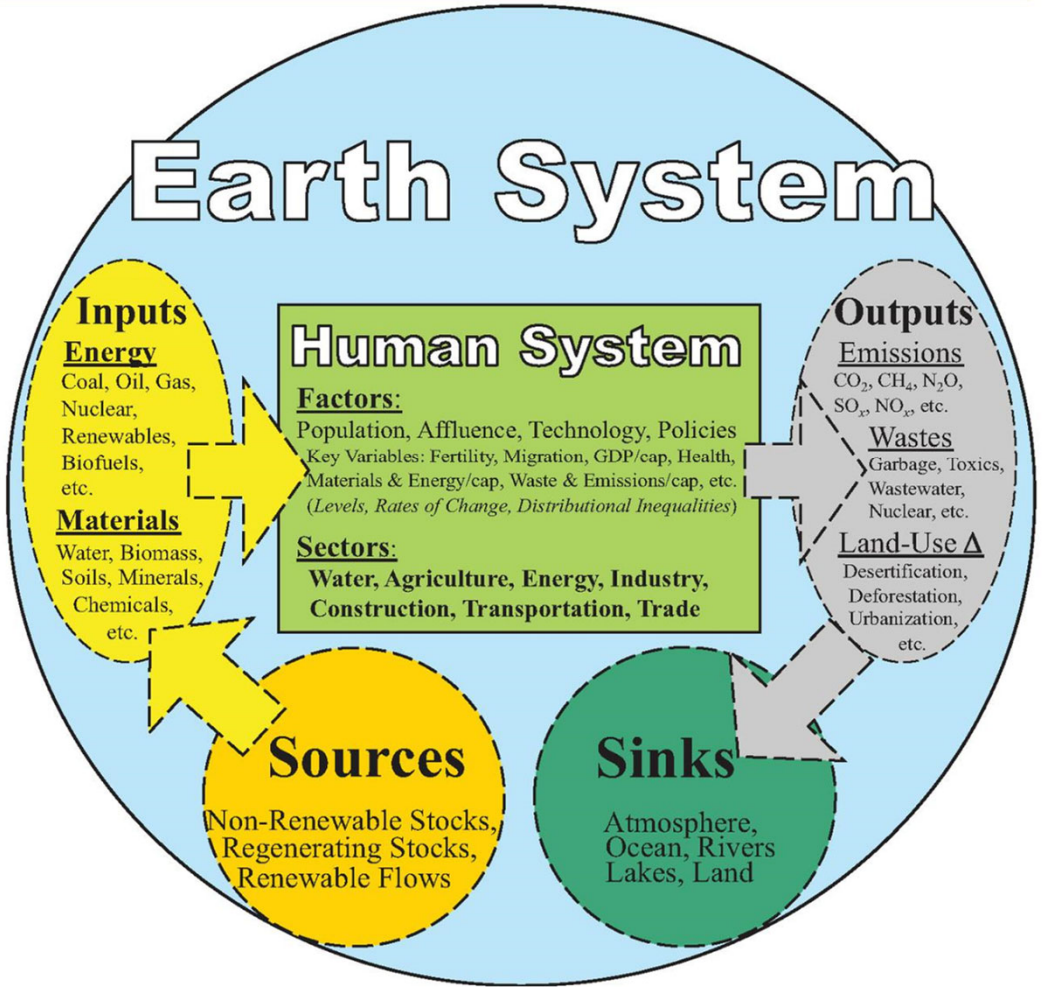
- The human and the natural systems are coupled, with positive, negative and delayed feedbacks
- However, the models of the Earth System and the Human system ARE NOT bidirectionally coupled.
- This results in a major underestimation of the probability of societal collapse

The Human System is **within** the Earth System:

- ES *sources* provide the inputs to the HS.
- HS outputs must be absorbed by the ES *sinks*.

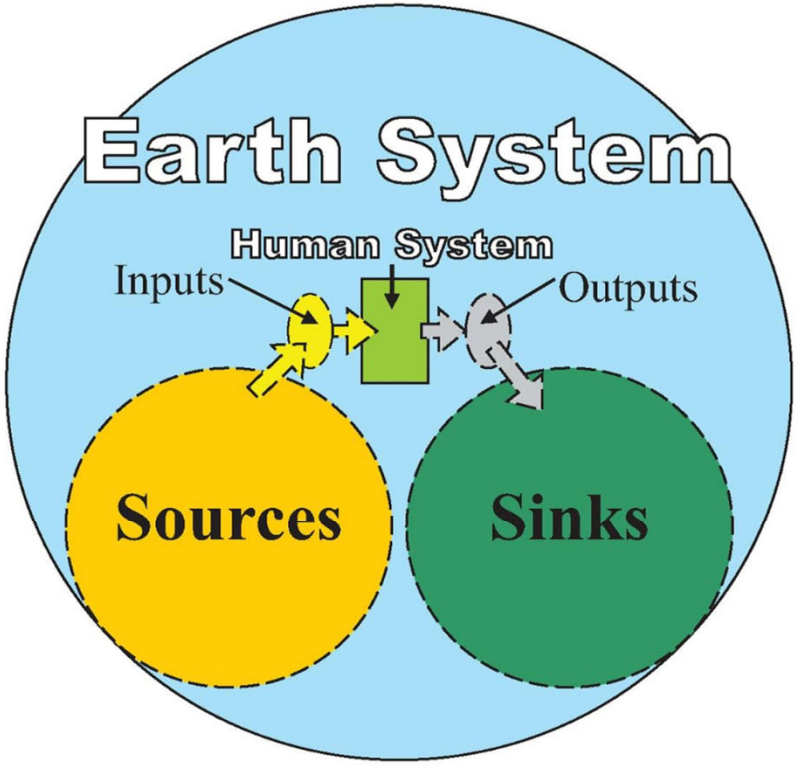
However, **current Earth System models** are **not** bidirectionally coupled. Is this important?

Human System-Earth System Relationship



The Past: "Empty World"

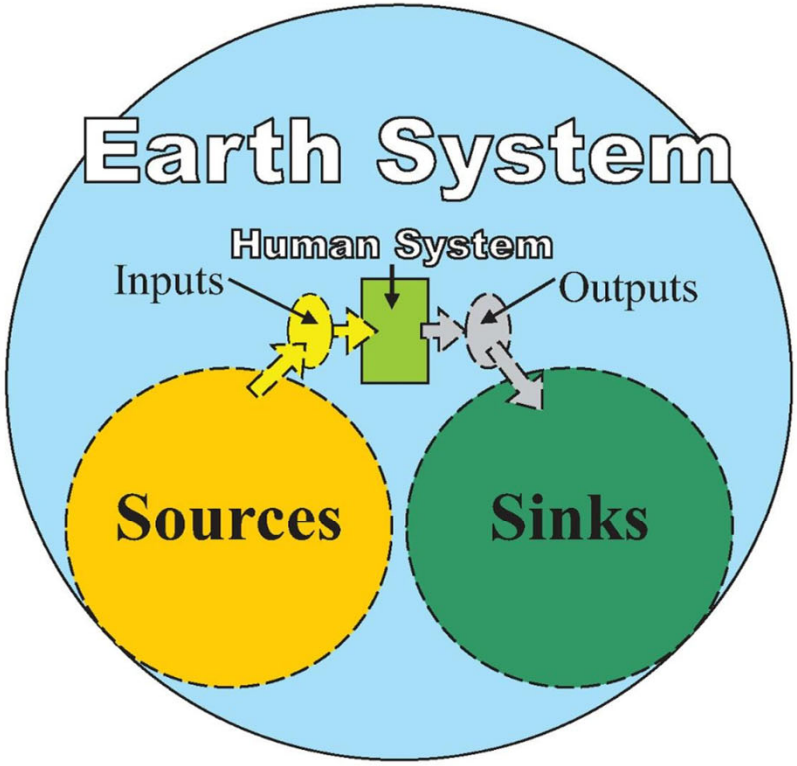
When the Human System was small relative to the Earth System, the two could be modeled separately.



Capacity of ES sources was large relative to HS inputs.
HS outputs were small relative to absorption of ES sinks.

The Past: "Empty World"

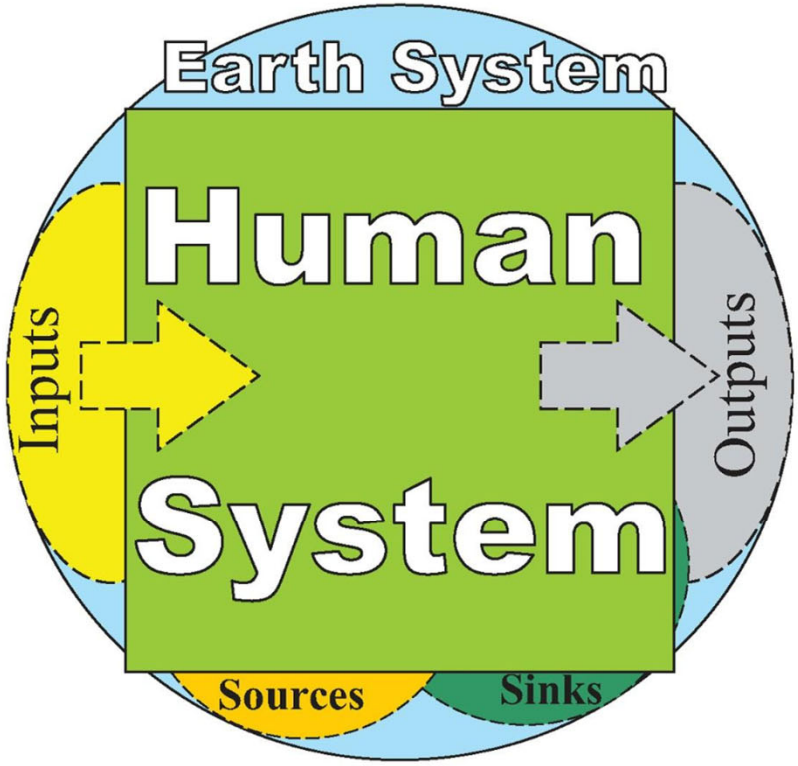
When the Human System was small relative to the Earth System, the two could be modeled separately.



Capacity of ES sources was large relative to HS inputs.
HS outputs were small relative to absorption of ES sinks.

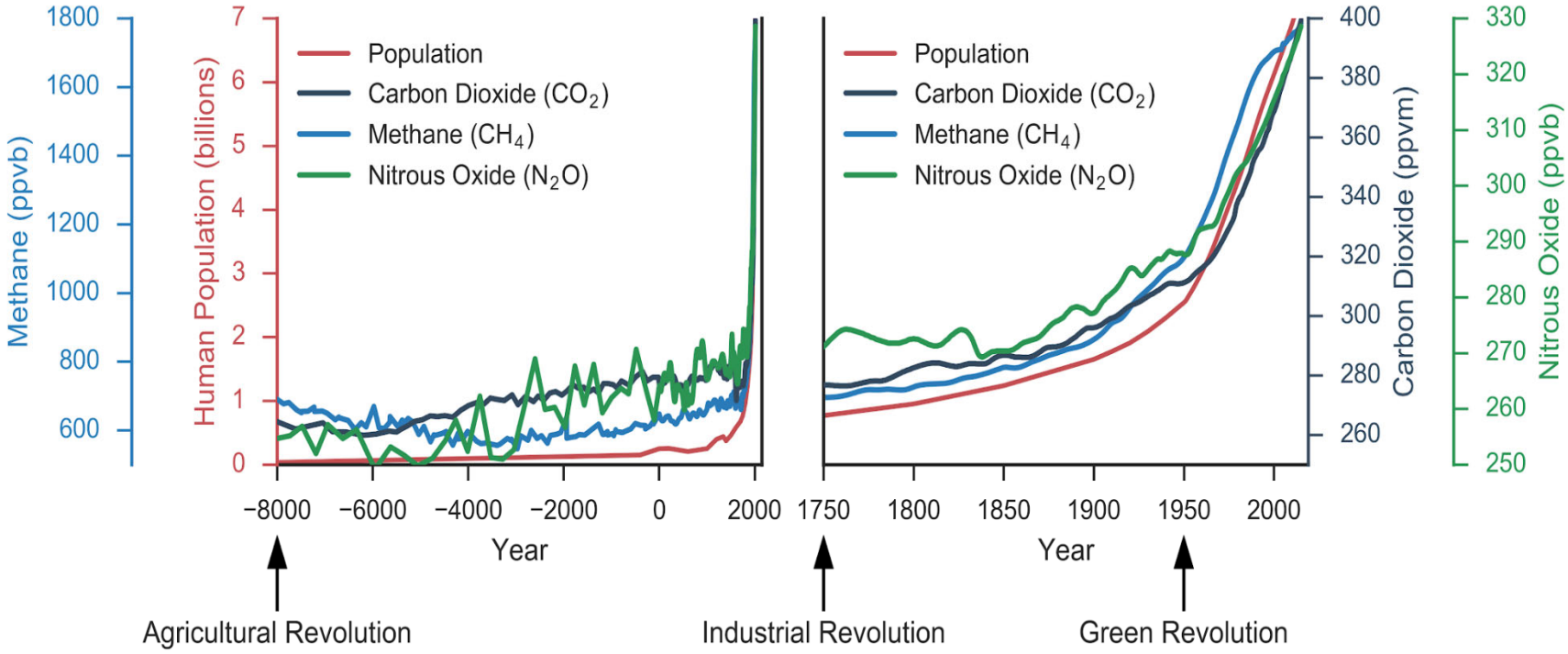
The Present: "Full World"

The Human System has grown so large that both must now be modeled coupled to each other.



Now, HS inputs and outputs are so large relative to the ES, they threaten to deplete its sources and overwhelm its sinks.

Population has grown rapidly since 1750, and explosively after 1950. Population has become the dominant driver of changes in the natural environment.



The similar evolution of human population and the atmospheric concentrations of the greenhouse gases strongly suggests that population is the driver. Note the abrupt acceleration around mid-20th century, especially with the Green Revolution and the massive use of fossil fuels.

Top downloaded paper of the Journal 4.5 years after publication; Citations = 222 (Google Scholar)

ELSEVIER

Ecological Economics

Volume 101, May 2014, Pages 90-102

Methodological and Ideological Options

Human and nature dynamics (HANDY): Modeling inequality and use of resources in the collapse or sustainability of societies

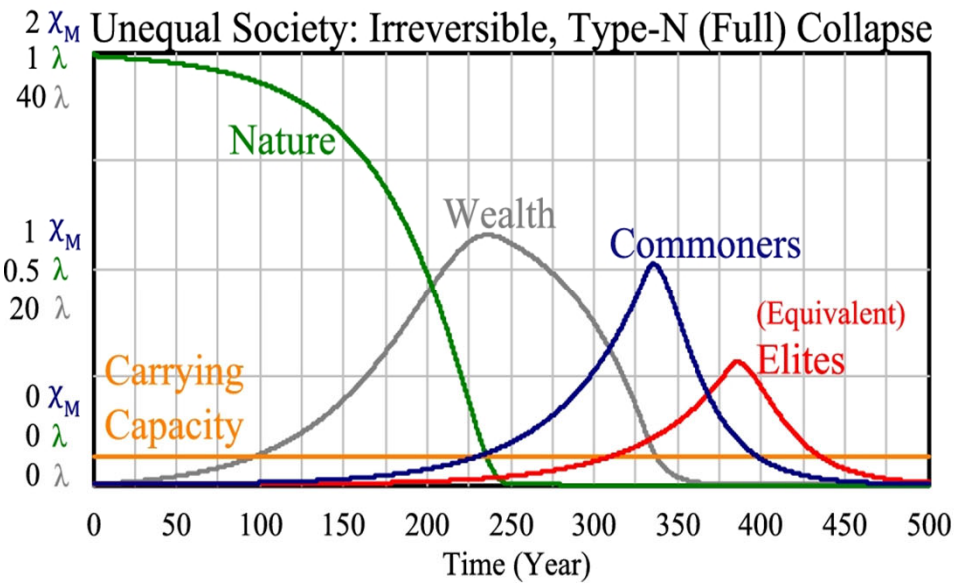
Safa Motesharrei [a], Jorge Rivas [b], Eugenia Kalnay [c]

Show more

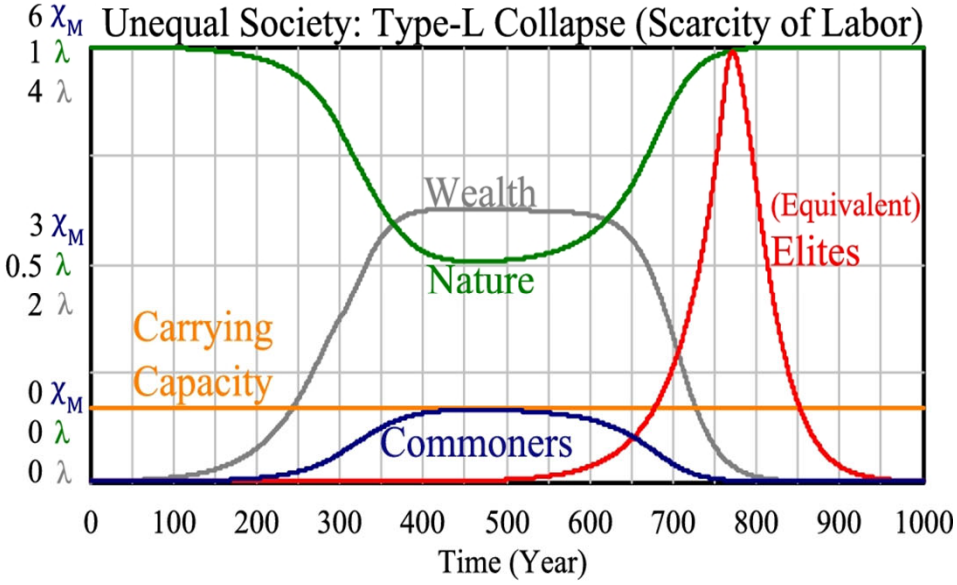
https://doi.org/10.1016/j.ecolecon.2014.02.014

Our Human and Nature Dynamics (HANDY) model included bidirectional feedbacks in a minimal model.

Over depletion and inequality



Inequality



Heights of Commoners and Elites Population curves reflect their consumption.

Most read paper of the Journal to date, total downloads and views > 21,000

OXFORD ACADEMIC

NSR National Science Review

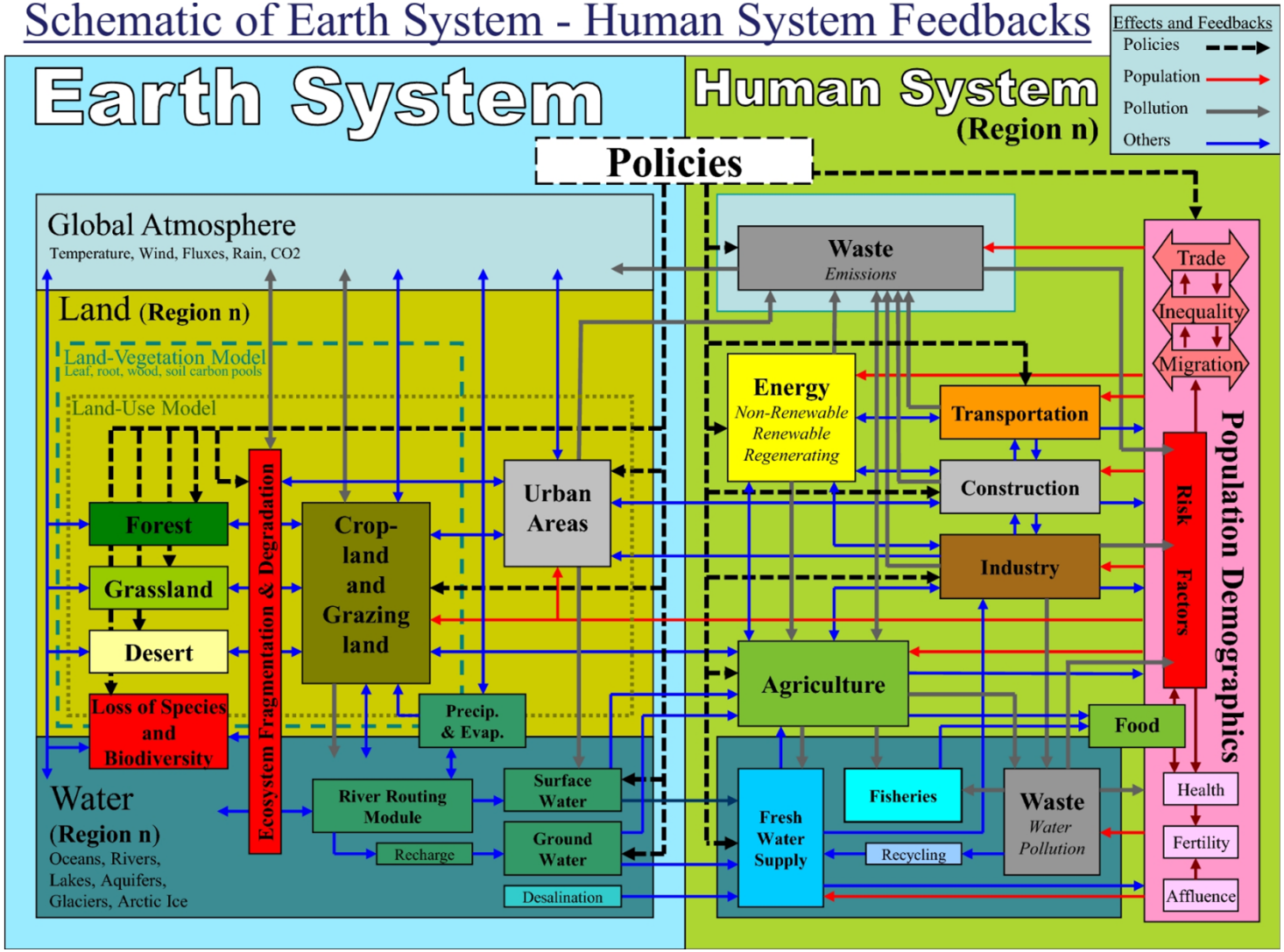
Issues | More Content ▾ | Publish ▾ | Purchase | Alerts | About ▾ | All National

Volume 3, Issue 4
December 2016

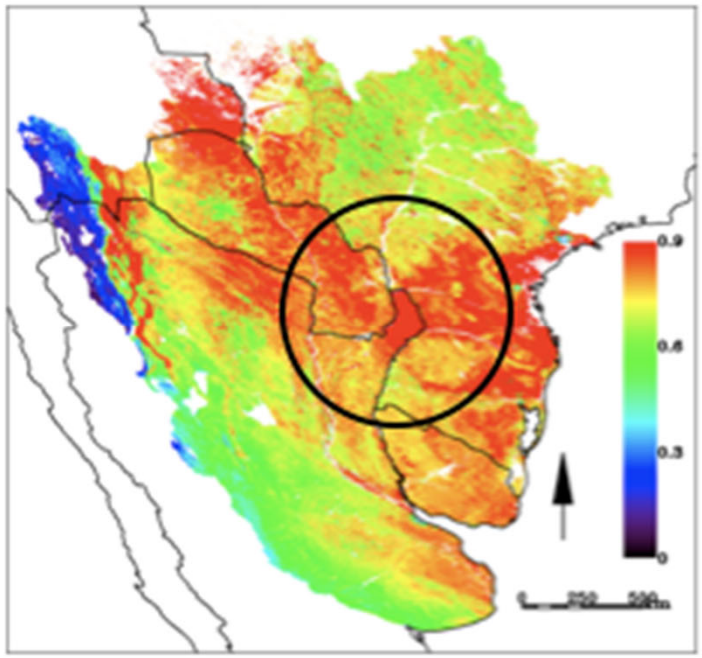
Modeling sustainability: population, inequality, consumption, and bidirectional coupling of the Earth and Human Systems

Safa Motesharrei ✉, Jorge Rivas, Eugenia Kalnay, Ghassem R. Asrar, Antonio J. Busalacchi, Robert F. Cahalan, Mark A. Cane, Rita R. Colwell, Kuishuang Feng, Rachel S. Franklin Klaus Hubacek, Fernando Miralles-Wilhelm, Takemasa Miyoshi, Matthias Ruth, Roald Sagdeev, Adel Shirmohammadi, Jagadish Shukla, Jelena Srebric, Victor M. Yakovenko, Ning Zeng

Schematic of Earth System - Human System Feedbacks



Policies: Can we use nature sustainably?



The red (highest NDVI **vegetation index**) is in the province of Misiones, Argentina, that protects the forest.
Compare Misiones with Brazil, Paraguay and the rest of Argentina!

Climate model shows large-scale wind and solar farms in the Sahara increase rain and vegetation

Yan Li*, **Eugenia Kalnay***, **Safa Motesharrei***, **Jorge Rivas**,

Fred Kucharski, Daniel Kirk-Davidoff, Eviatar Bach, Ning Zeng

*Corresponding authors: yanli.geo@gmail.com (Y.L.); ekalnay@umd.edu (E.K.); ssm@umd.edu (S.M.)

Published in Science on 07 September 2018

Within 3 weeks, it was downloaded >100K times.
Altmetric: in the 100 top 2018 scientific papers in the world,
in the 10 top 2018 climate papers.

Wind farms change the land surface friction (roughness)

Solar farms change the surface albedo (reflectivity)

But: **Large-scale wind and solar farms could also affect climate!**

(Like an unintended geo-engineering experiment?)

What impact the large-scale wind farm and solar panels would have on climate, if they were to substitute fossil fuels, e.g., in the Sahara?

We performed a long simulation with the UMD-ICTP Earth System Model (SPEEDY-VEGAS)

What are the impacts of wind and solar farms on the climate?

Global climate impact (good!):

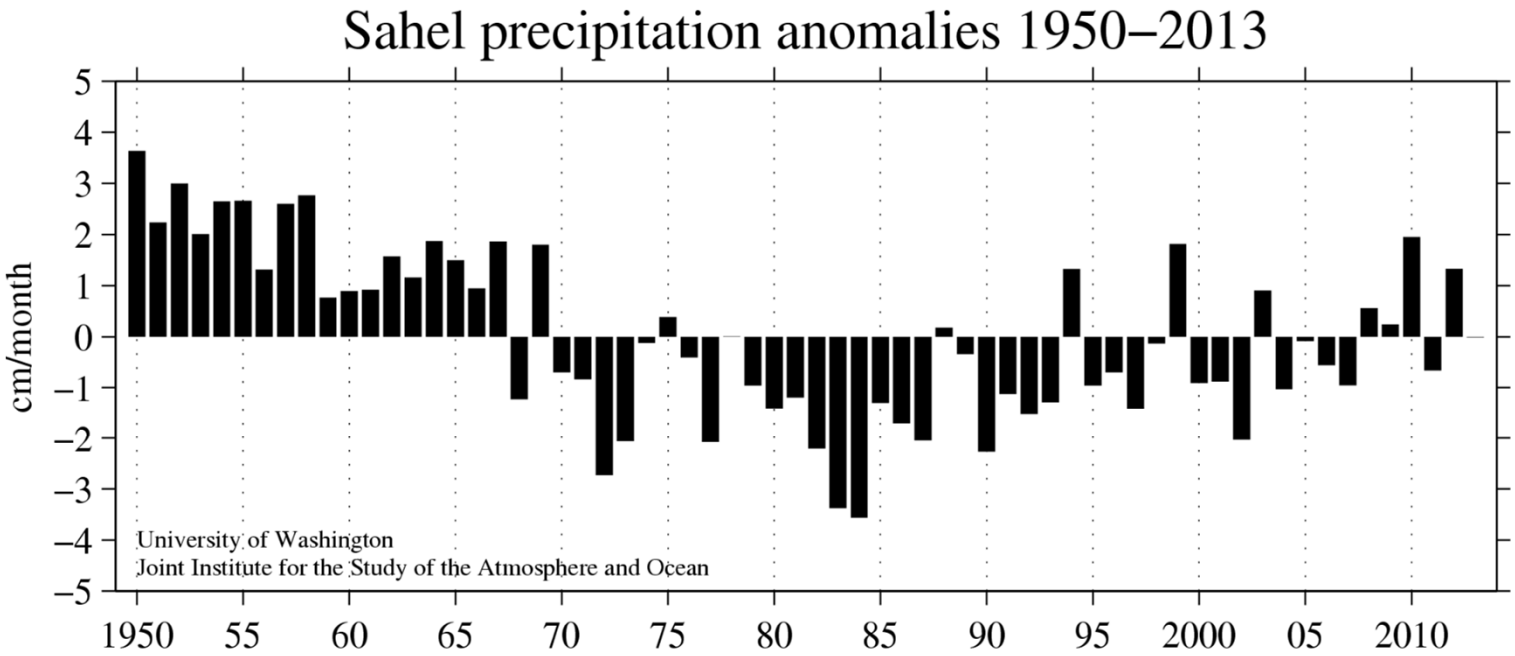
By substituting fossil fuels, renewable energy farms would reduce the emission of greenhouse gases, and thus could reduce or slow anthropogenic climate change.

Local climate impact (good?, bad?):

Changes to surface roughness and albedo could affect climate.

To test whether this is beneficial or detrimental, we conducted simulation experiments with the UMD-ICTP Earth System Model (SPEEDY+VEGAS models).

From the mid 1960s to ~2010, Sahel precipitation decreased substantially



The 2013 value is –0.01 cm/month

June through October averages over 20–10N, 20W–10E. 1950–2013 climatology.
NOAA NCDC Global Historical Climatology Network data

Drought Δpp ~
-1 to -3 cm/month
-0.3 to -1.0 mm/day

Δpp from wind and solar farms:
+1.34 mm/day
1 - 4 times larger!

Charney and Sud Feedback Mechanisms to explain the Sahel Drought

Charney (1975):

Overgrazing=>

Increased albedo=>

Less heating=>

Downward motion=>

Less rain=>

Less vegetation

Sud and Smith (1985):

Overgrazing=>

Reduced friction=>

Less convergence=>

Less rain=>

Less vegetation

J. G. Charney, Dynamics of deserts and drought in the Sahel. *Q. J. R. Meteorol. Soc.* **101**, 193–202 (1975).

Y. C. Sud, W. E. Smith, The influence of surface roughness of deserts on the July circulation - A numerical study. *Boundary-Layer Meteorol.* **33**, 15–49 (1985).

We apply them in the opposite direction to see if we can increase the Sahel precipitation:

Charney (1975):

Solar panel farms=>

Reduced albedo=>

More heating=>

Upward motion=>

More rain=>

More vegetation

Sud and Smith (1985):

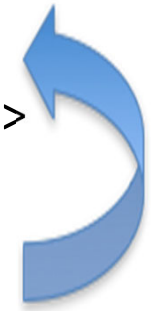
Windmill farms=>

Increased friction=>

More convergence=>

More rain=>

More vegetation



J. G. Charney, Dynamics of deserts and drought in the Sahel. *Q. J. R. Meteorol. Soc.* **101**, 193–202 (1975).

Y. C. Sud, W. E. Smith, The influence of surface roughness of deserts on the July circulation - A numerical study. *Boundary-Layer Meteorol.* **33**, 15–49 (1985).

Apply Charney and Sud mechanisms to the Sahara:

More rain => more vegetation => more rain

Friction-Precipitation-Vegetation (Sud mechanism)

Wind farm

Solar farm

Surface Friction ↑

Low-level convergence

Precipitation ↑↑

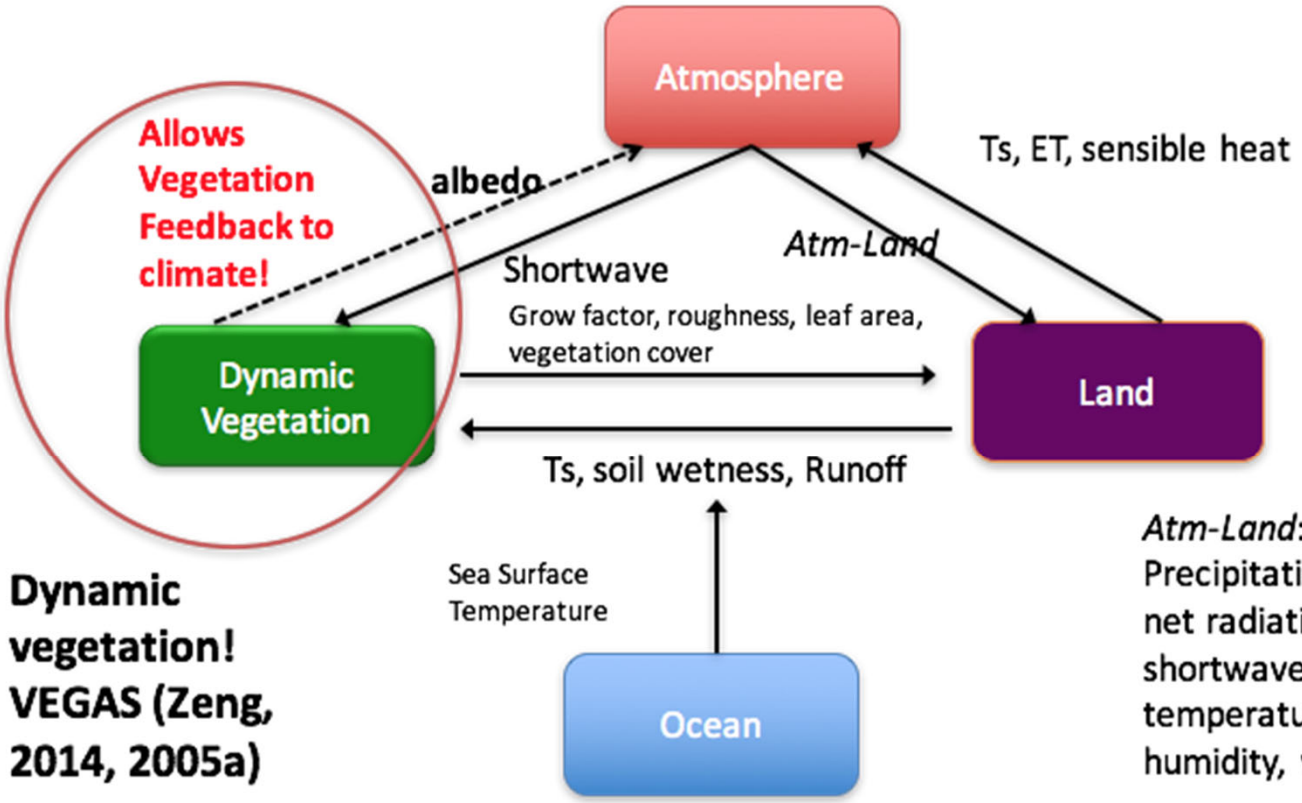
Vegetation ↑↑

Upward motion

Effective Albedo ↓

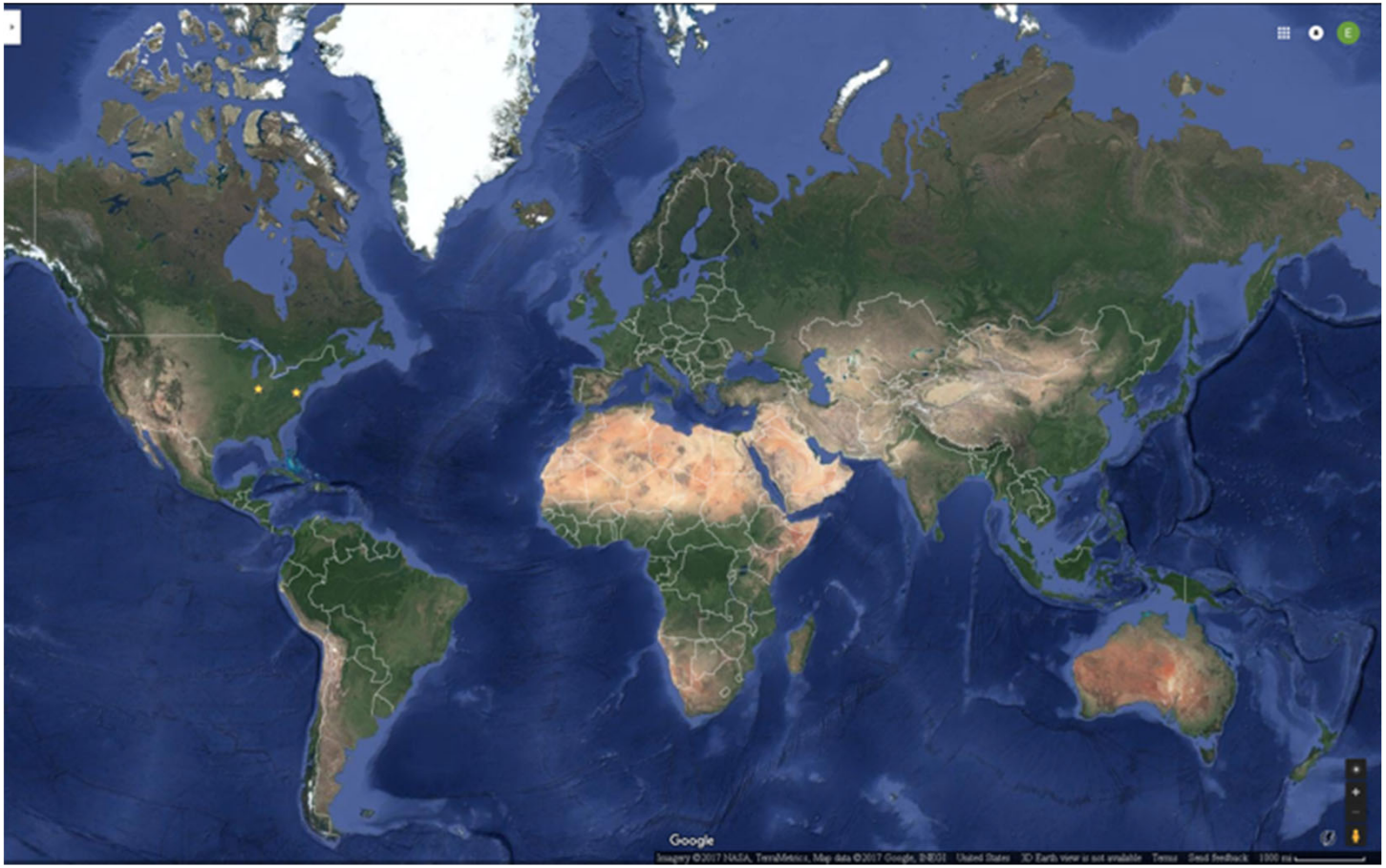
Albedo-Precipitation-Vegetation (Charney mechanism)

The UMD-ICTP Earth System Model (SPEEDY-VEGAS) with *dynamic* vegetation (it changes if climate changes)



Dynamic vegetation! VEGAS (Zeng, 2014, 2005a)

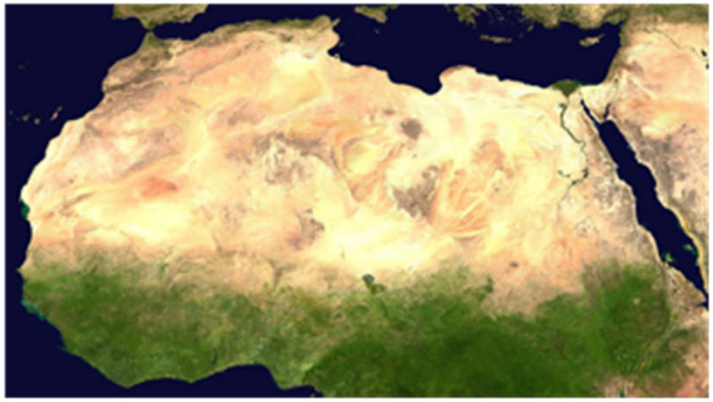
Sahara is not only the largest desert, but also has the highest albedo.

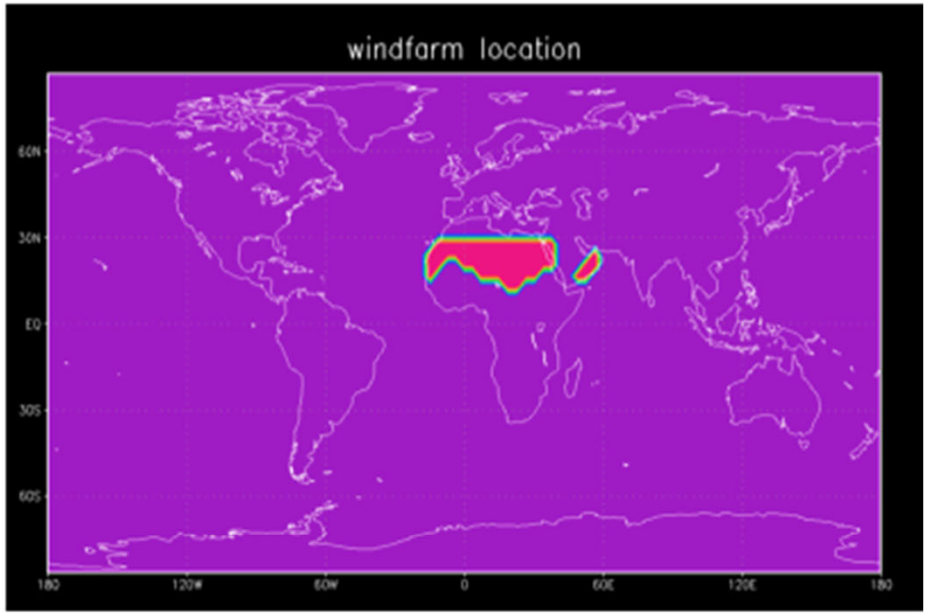


We covered the Sahara in the model with wind and solar farms.

The Sahara desert is ~ 9.2 million km^2 and the Sahel is ~ 3.1 million km^2.

We model wind and solar farms in the Sahara:

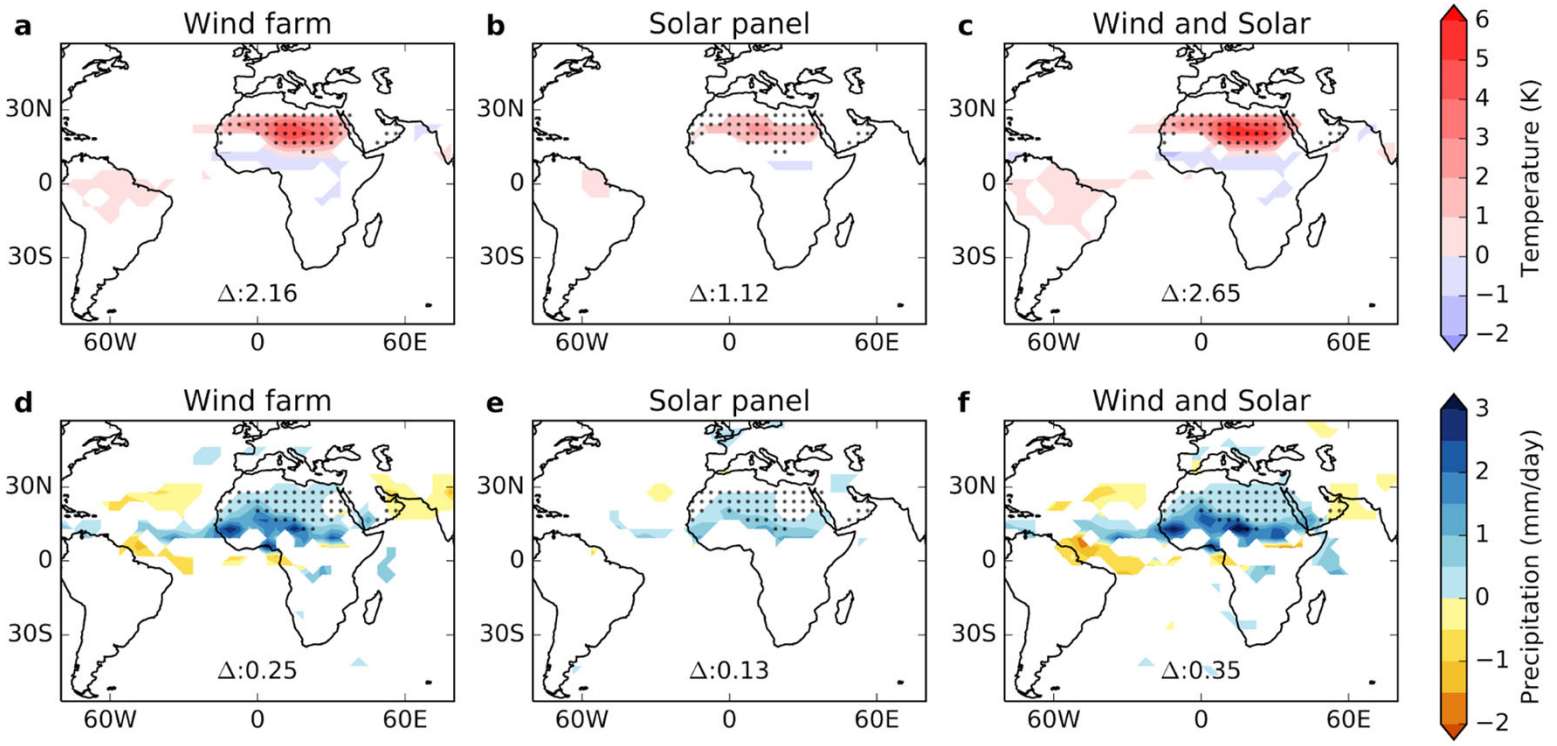




- Atmosphere-land-vegetation coupled
- Prescribed SST
- 1901-2000 (100 yr)
- T32 grid (3.75 degree resolution)

Wind/solar farm location in the model over the Sahara and Arabian Desert

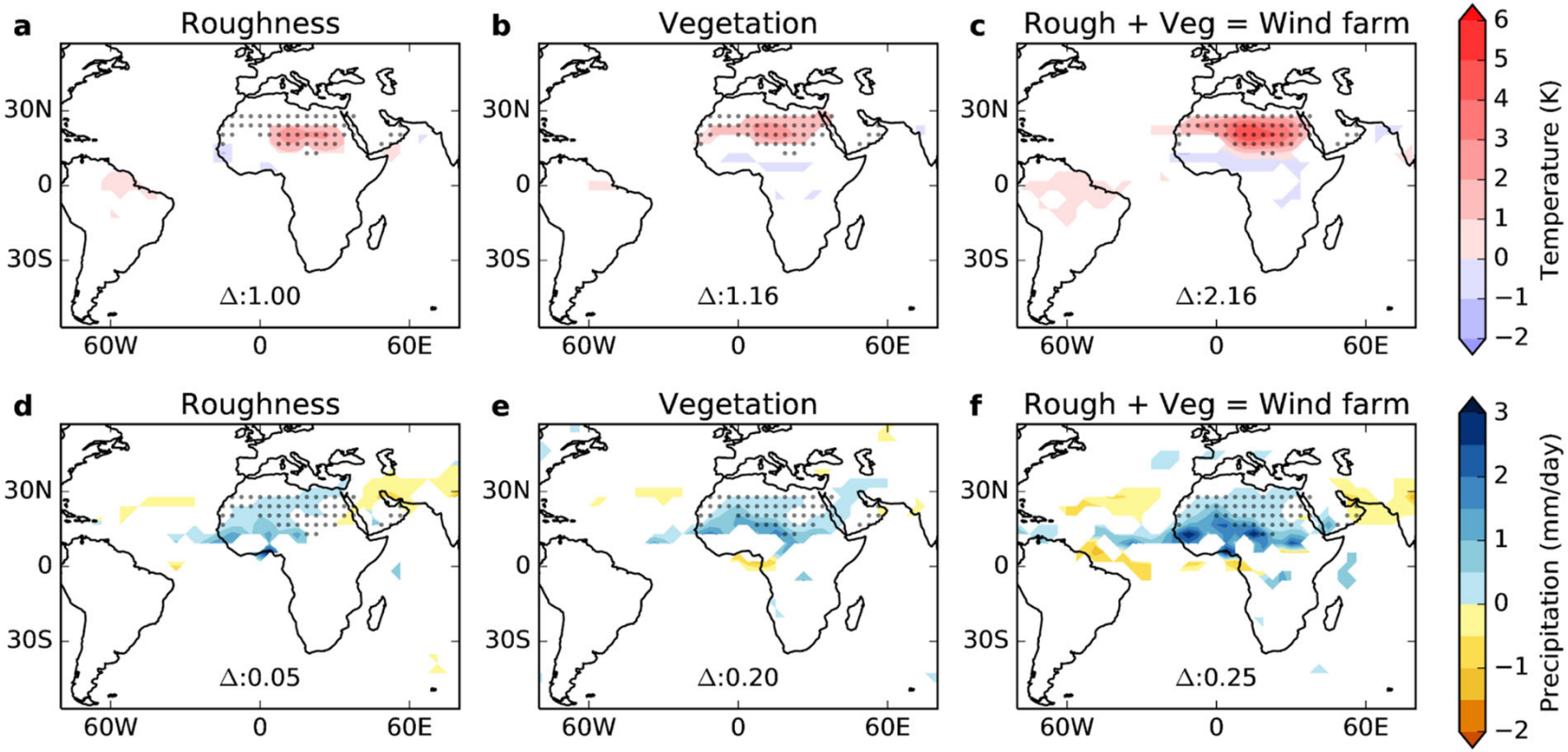
IMPACT OF WIND AND SOLAR FARMS IN THE SAHARA: increased local temperature and **>doubled precipitation**



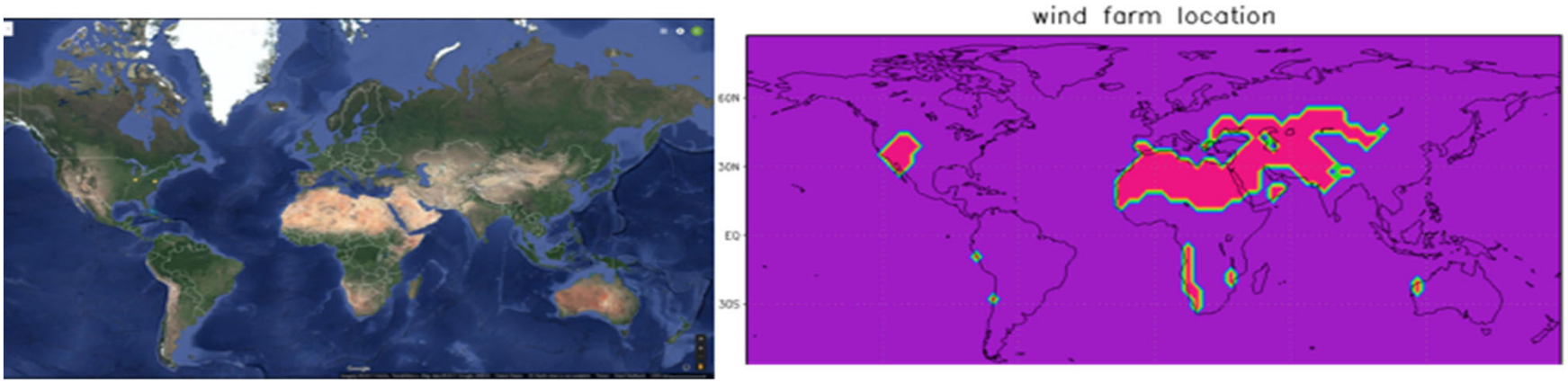
Surface Temperature (K)

Precipitation (mm/day)

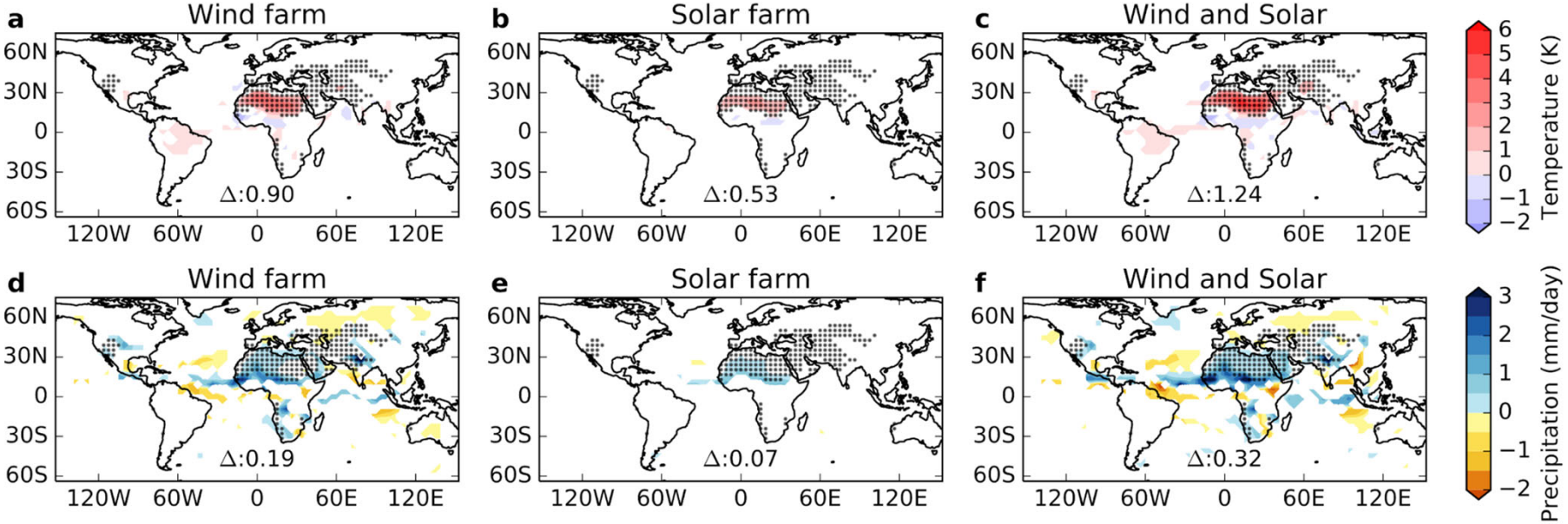
80% of the windmills precipitation impact is due to the dynamic vegetation albedo feedback



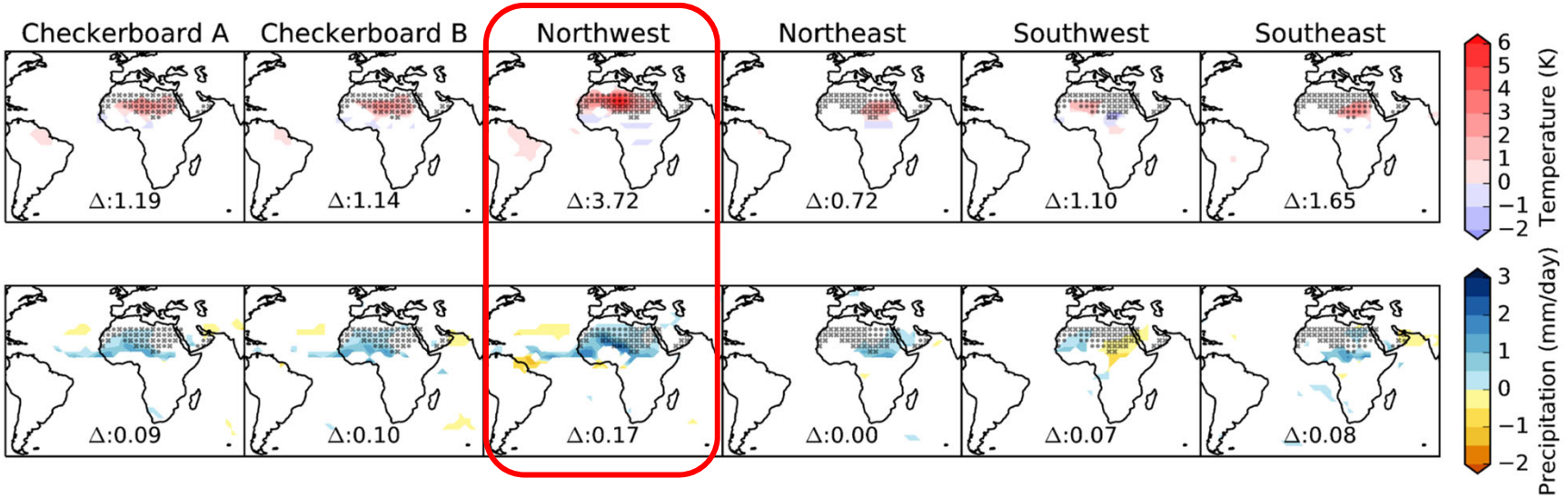
Are there impacts in other deserts of the world?



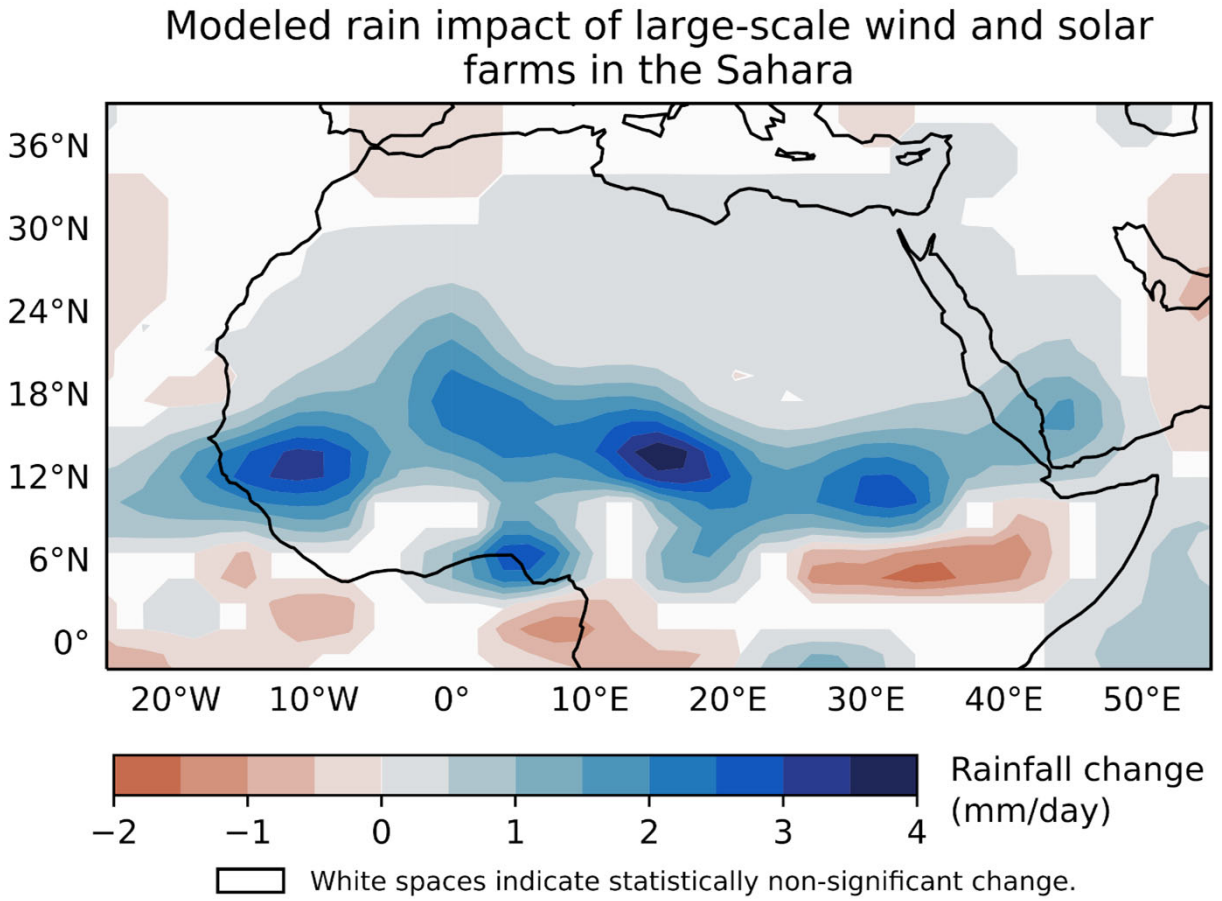
Are there impacts in other deserts of the world? Yes, but much smaller.



Would there be impacts from smaller farms?



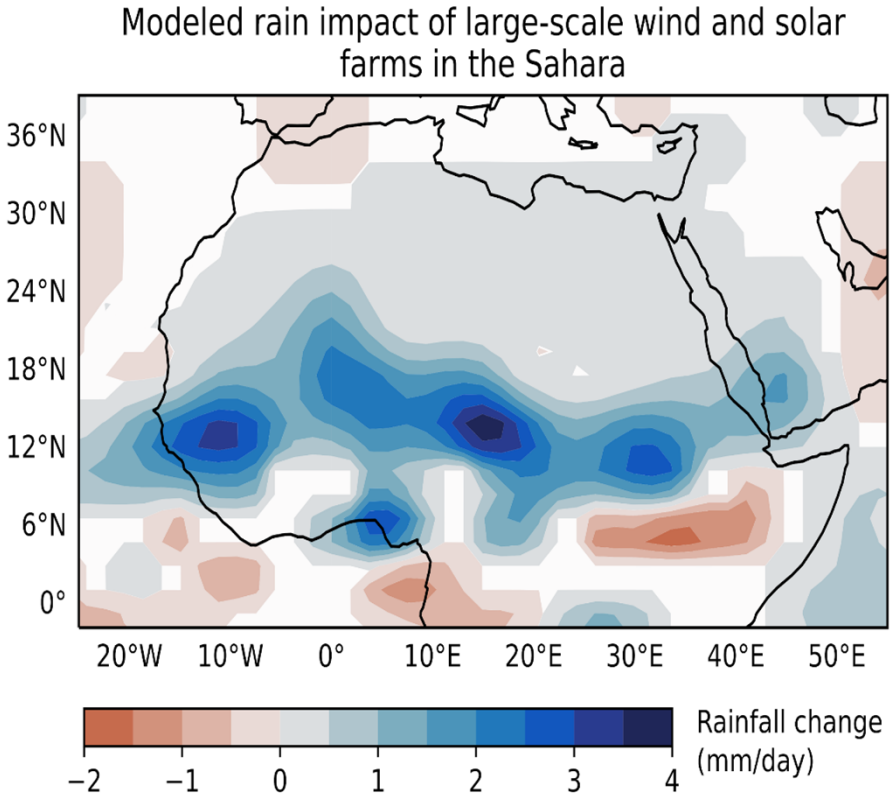
The Northwest quarter alone produces almost as much rain as the whole Sahara!

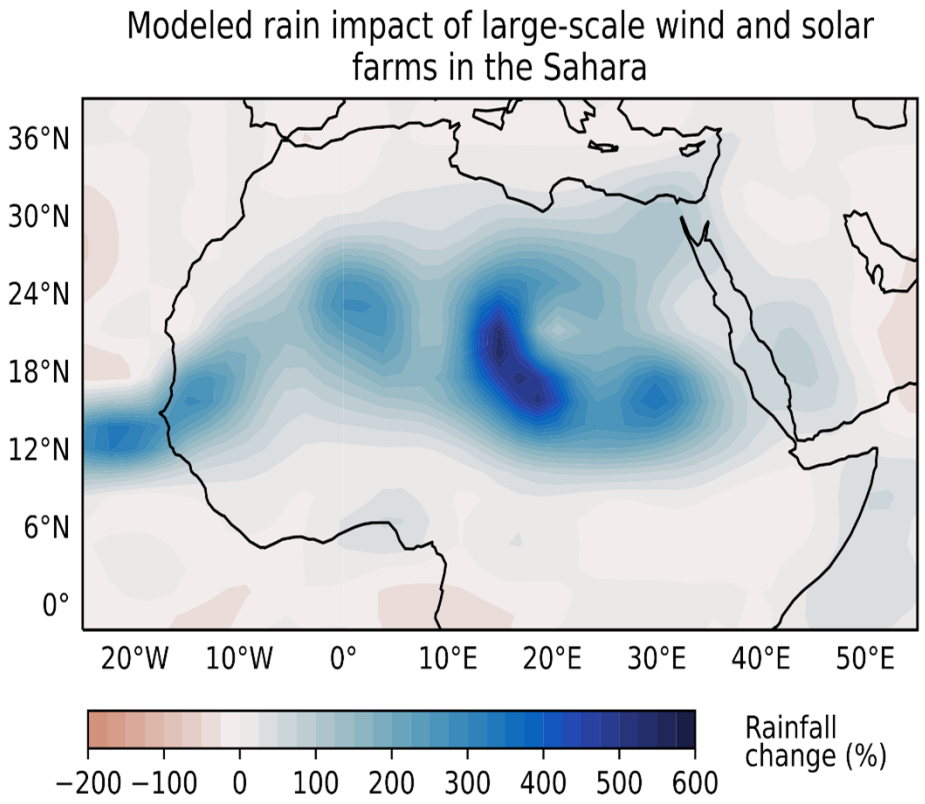


Precipitation in the Sahel increases up to 500 mm/year.

Average precipitation in the Sahara increases from 0.24 to 0.59 mm/day, and in the Sahel increases from 2.23 to 3.57 mm/day.

Absolute vs. Relative rain impact





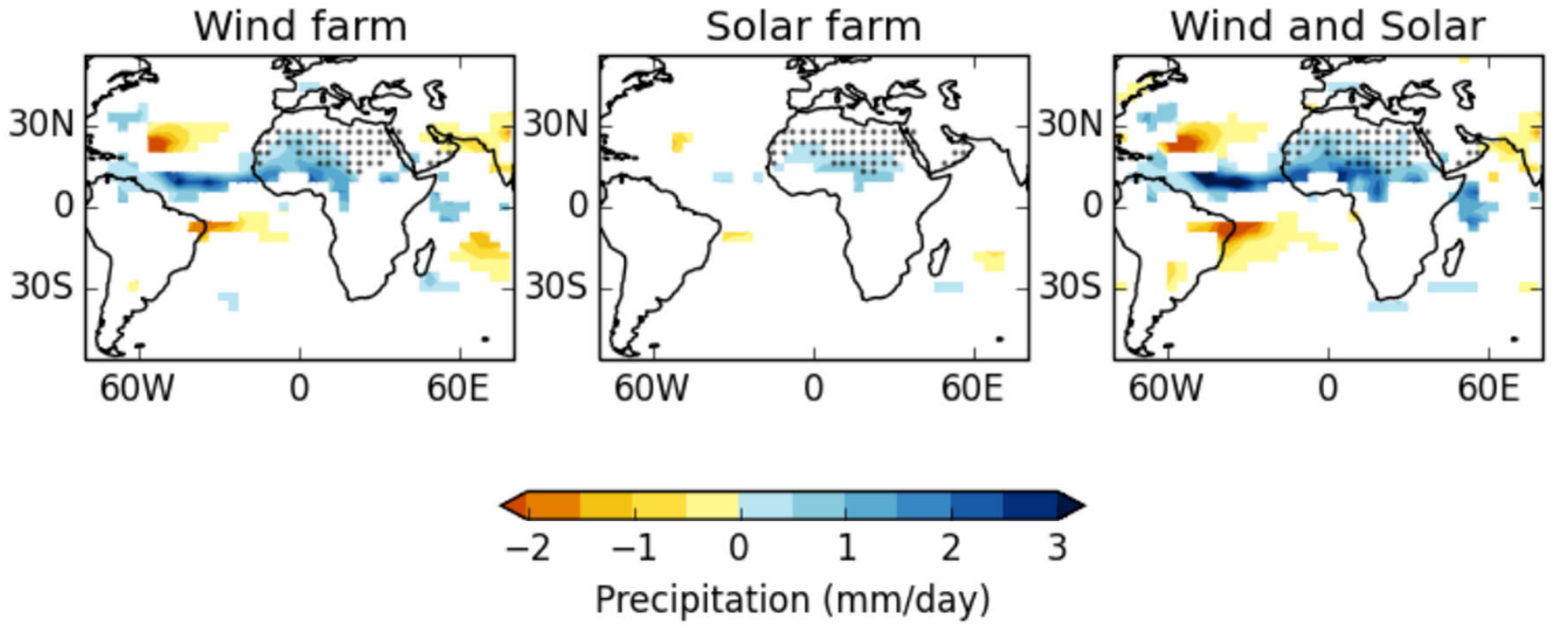


Fig 2. Precipitation changes in the wind and solar farms experiments in the Sahara using the same UMD-ICTP model in *(2)*, but coupled with an interactive ocean model, NEMO *(4)*.

Results are very similar with a coupled ocean model (NEMO) as with prescribed SSTs

Between 6000 to 10,000 years ago, Sahara was green.

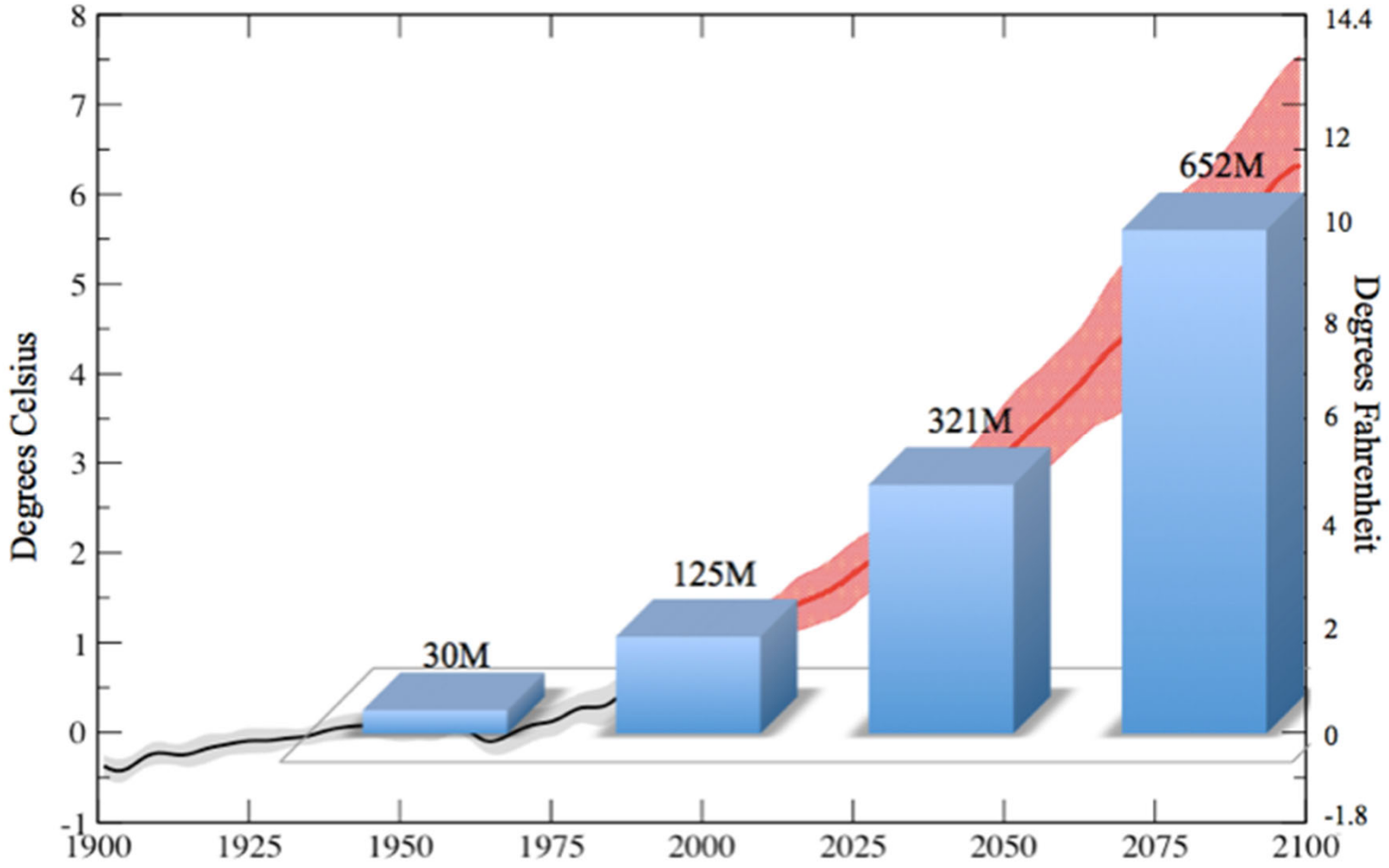
These prehistoric rock paintings are in the Manda Guéli Cave in the Ennedi Mountains, in the Sahara, Chad.

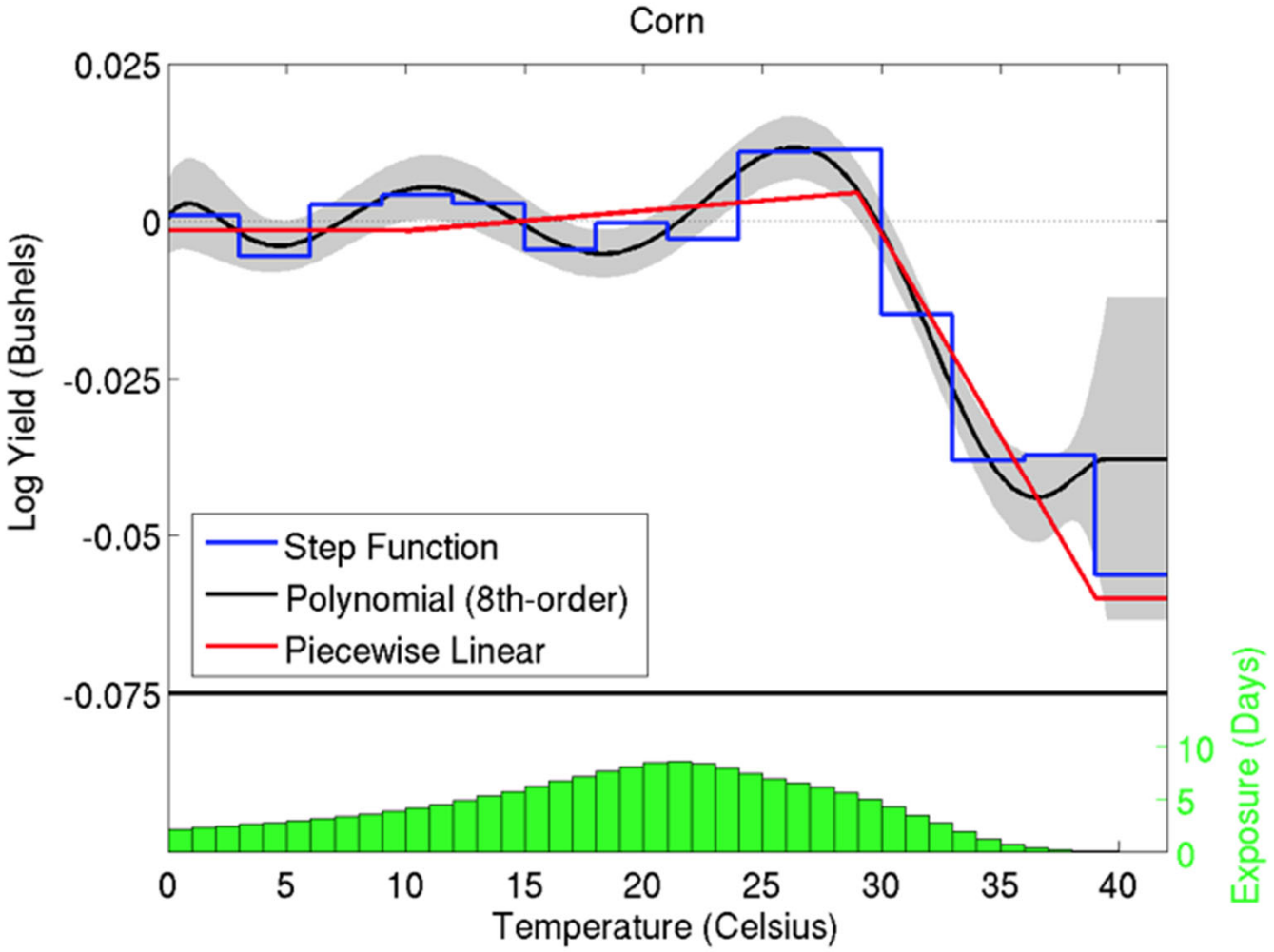
Could wind and solar farms also trigger a return to the **Green Sahara**?

Summary

- Large-scale wind and solar farms could have unintended climate impacts.
- We explored this possibility by performing 100 year experiments with the SPEEDY-VEGAS Earth System Model, with dynamic vegetation.
- **The increase of precipitation in the Sahel in the SPEEDY-VEGAS model (+1.34 mm/day) is larger than the reduction of precipitation during the Sahel drought of 1965-2010 (~ -0.3 to -1.0 mm/day)**
- In the Sahara, **the total precipitation is more than doubled (+150%).**
- **Solar and wind farms in the Sahara would produce 4 x TOTAL ENERGY used in the world.**
- Hence, the Sahara could provide enough renewable energy to cover global energy needs, now and for the foreseeable future, reverting climate change.
- It would not only revert climate change, but also improve life in the Sahel, the poorest region in the world, with the fastest population growth.

Projections of Population and Temperature in the Sahel

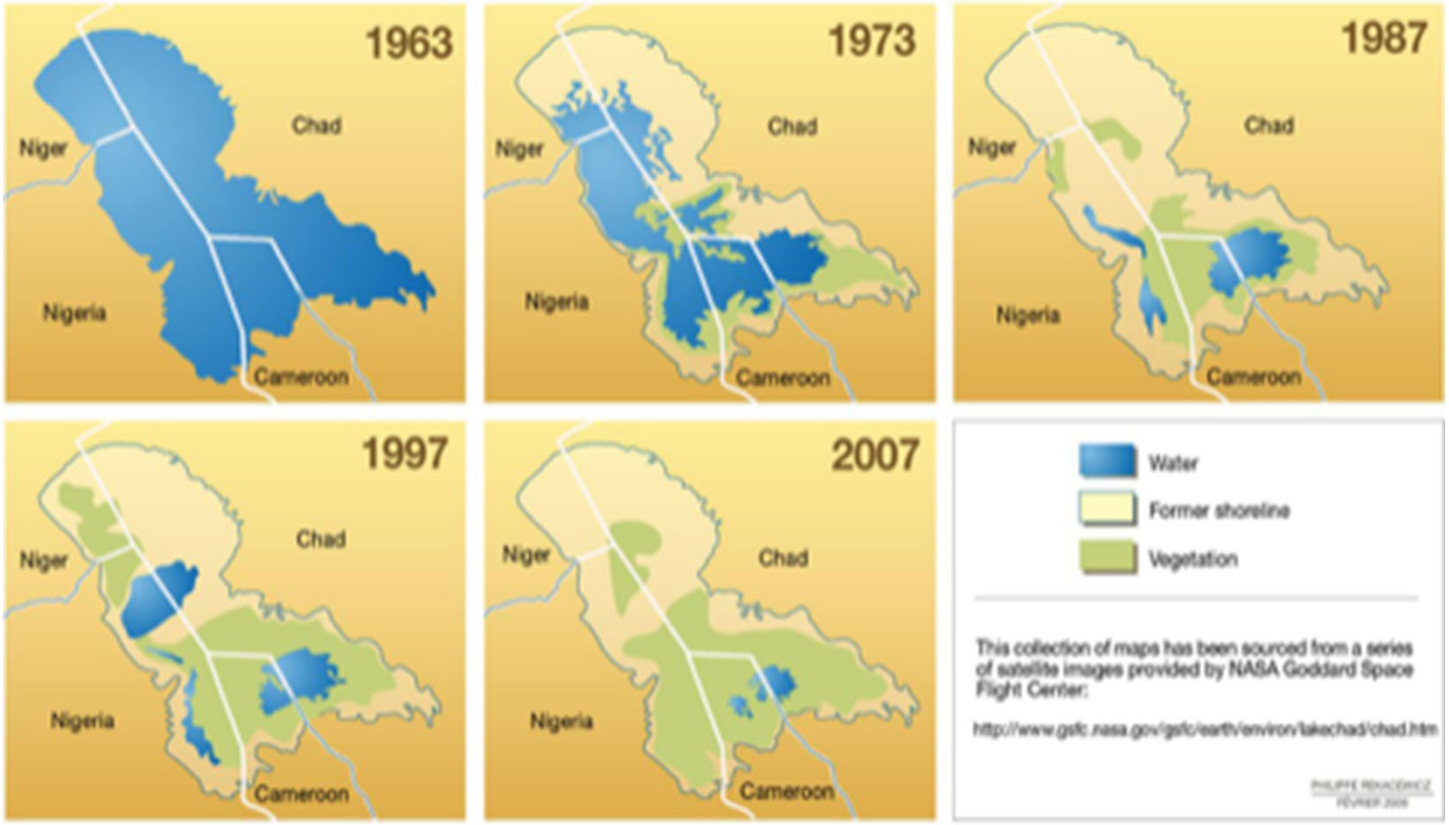




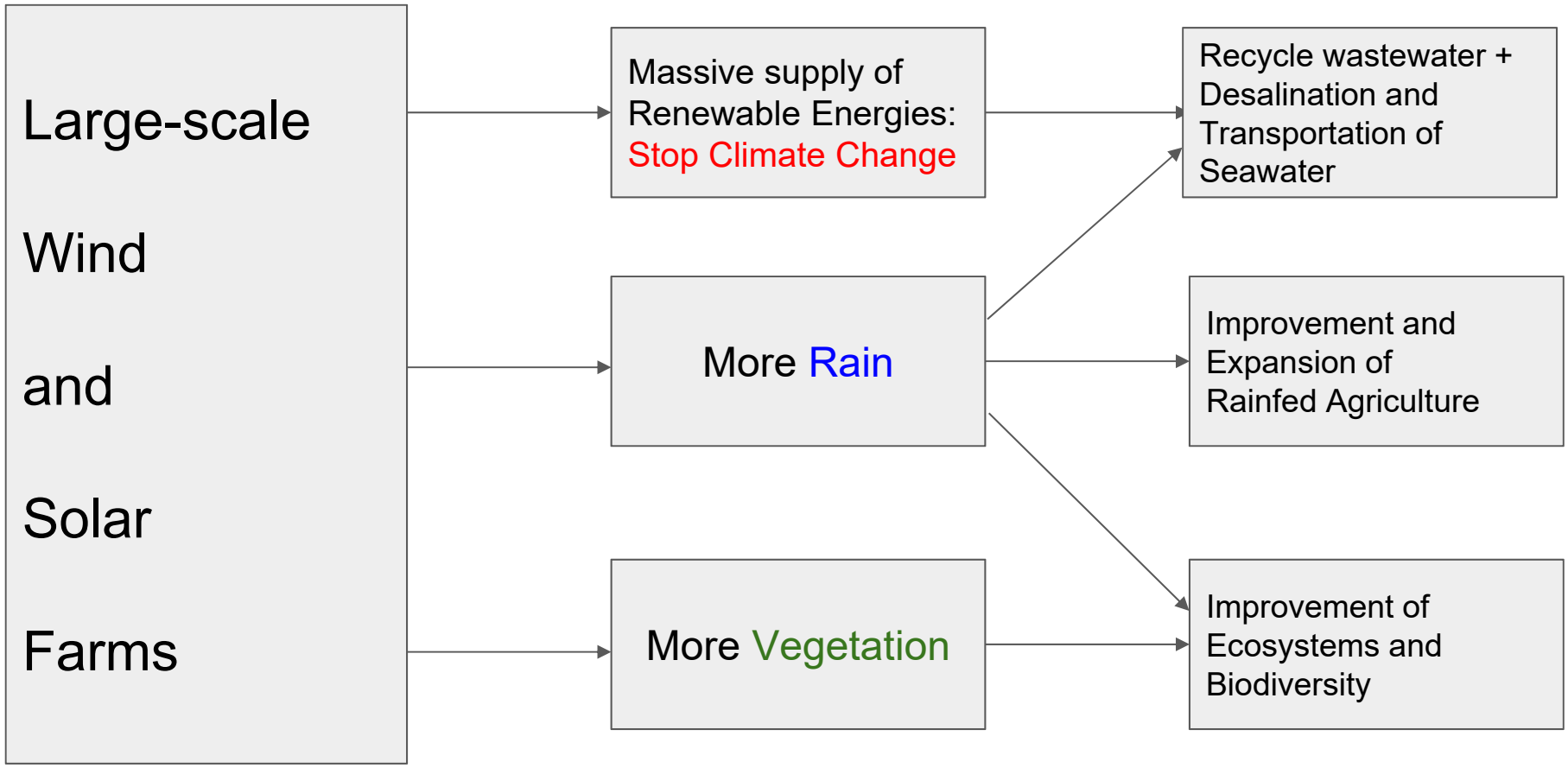
An example of drop in crop yields with the increase in Temperature.

Note that the vertical scale is logarithmic.

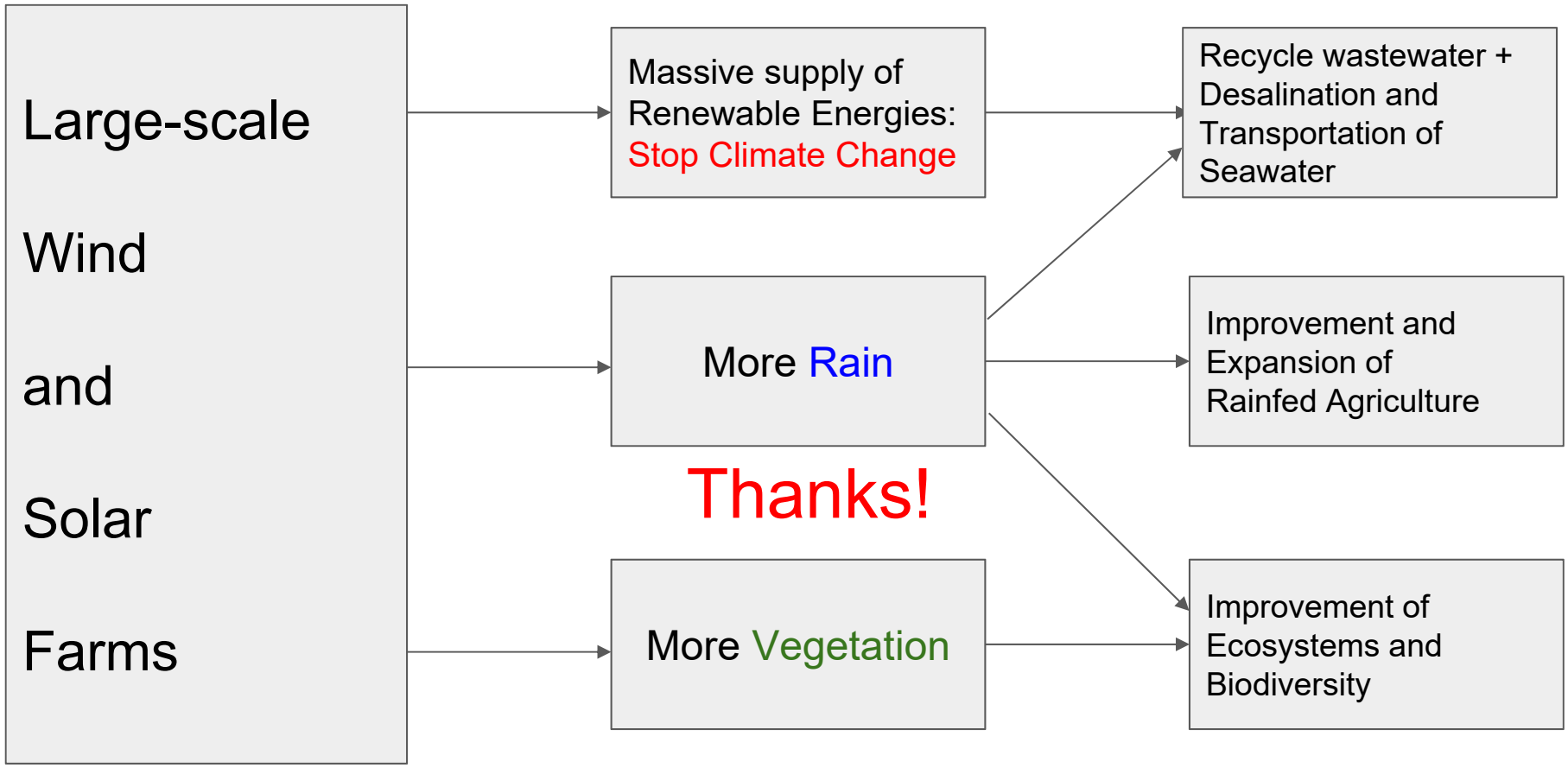
Example of Lake Chad in Africa:



A Win–Win for Environment, Economy, and People



A Win–Win for Environment, Economy, and People



Thanks!