Changes in Solar and Wind Power Generation Potentials over South Korea under Future Global Warming

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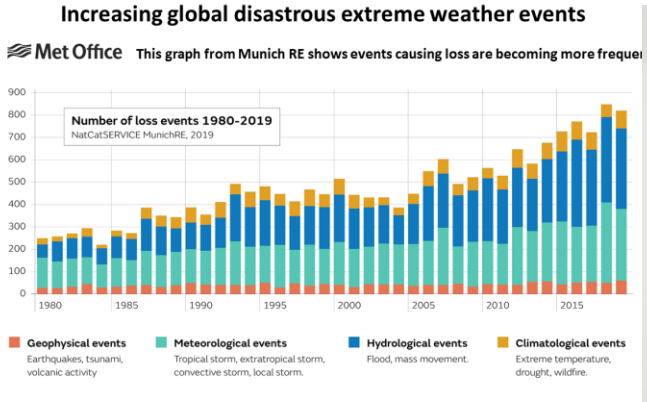
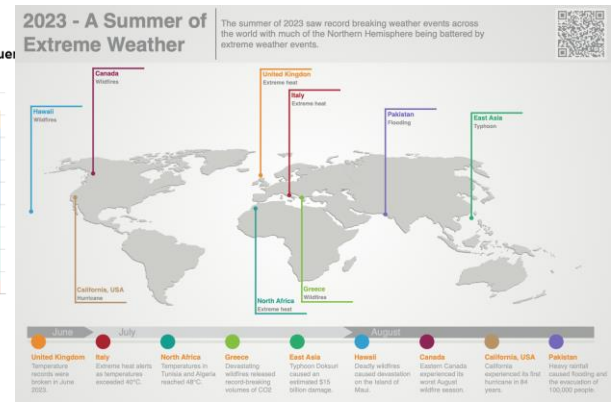
Background

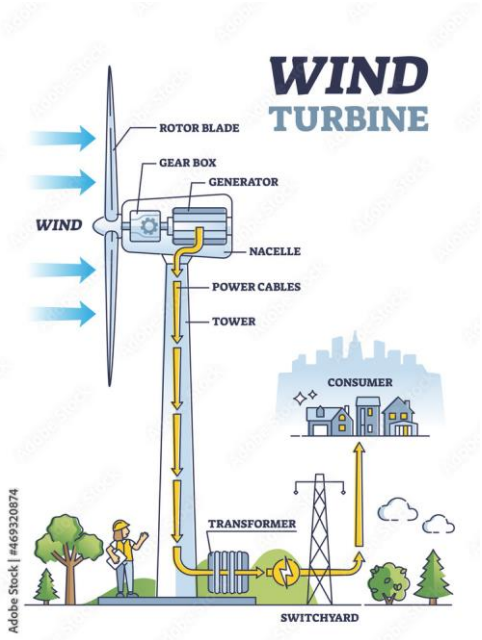
- Due to climate change caused by global warming, extreme climate/weather events have become intense and frequent.
  - ✓ WMO said that there is a 66% likelihood that the annual average near-surface global temperature between 2023 and 2027 will be more than 1.5C .
- The reduction of GHG emissions is a big topic to mitigate climate change implications.
- It is highly desirable to increase the share of electricity generation from renewable energy resources and reduce the production from fossil fuels.

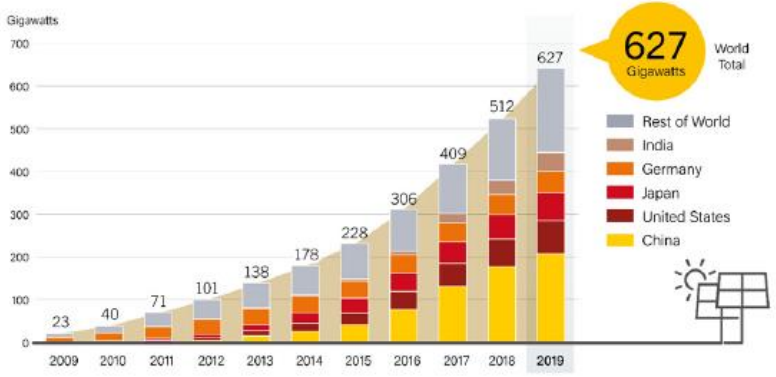




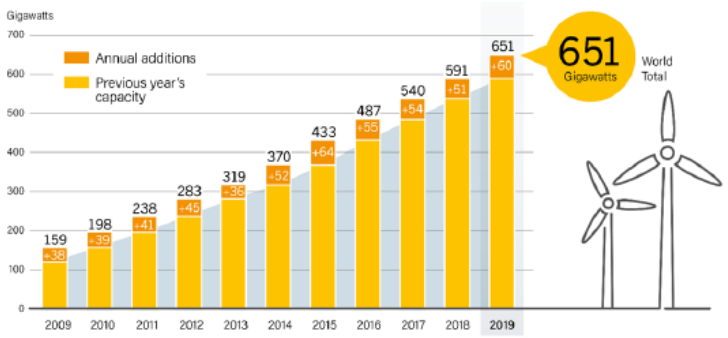
Background

- Many countries are increasing the portion of renewable energy production such as wind and solar powers.
  - ✓ According to the Europe 2030 climate and Energy Strategy plan, the European Commission aims to produce 27% of its energy through renewable resources.
  - ✓ HI, CA in the US aims to supply 100% of their electricity consumption with renewable energy by 2045.
- Renewable energy resources, particularly wind and solar power energy which depends on climate, can be affected by future climate change. The vulnerability could affect the feasibility of future low-carbon energy supply system.
- For regional development plan of the renewable energy system, which regions are more vulnerable to climate change should be analyzed.





자료 : REN21, Renewables 2020 Global Status Report, 2020



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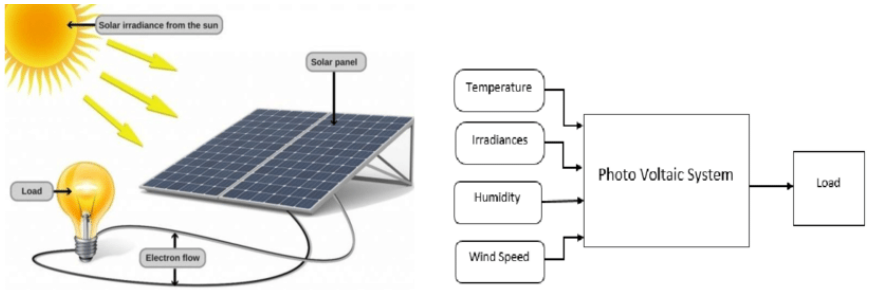
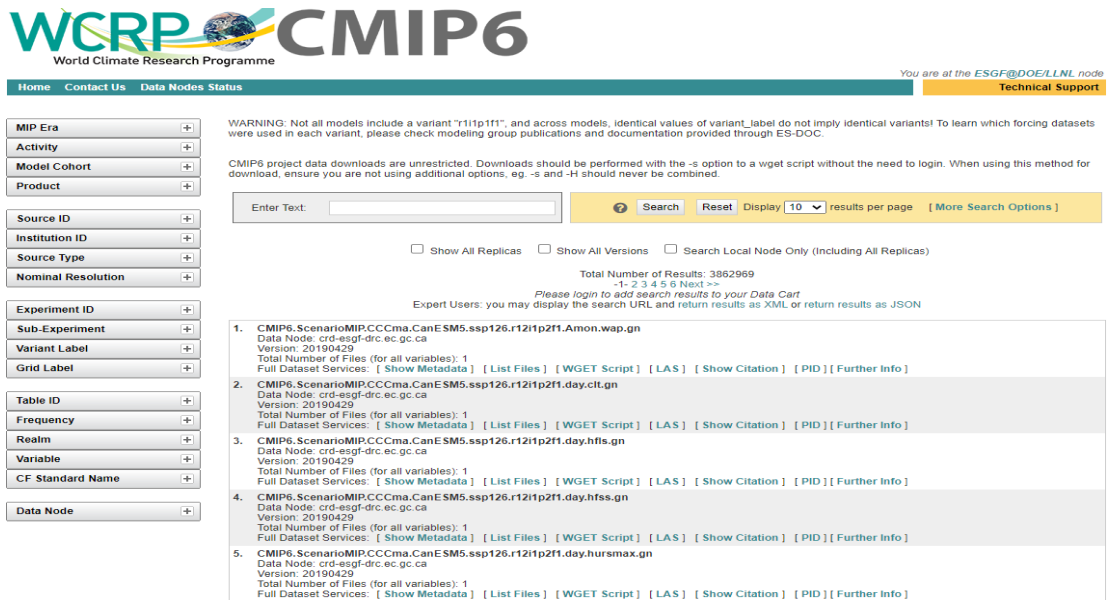


How to project the mean change?

CMIP (Coupled Model Intercomparison Project)

CMIP is a international project of the World Climate Research Programme (WCRP) providing climate projections to understand past, present and future climate change

- Provided by dozens of climate modeling institutions around the world
- **historical run**: Simulations using forcings due to both natural causes (e.g., volcanic eruption and solar) and human factors (CO2 emissions, aerosols, etc) over the period of 1850-2014.
- **Future climate change scenario run (SSP)** : Simulations using forcings associated with climate change scenarios of projected socioeconomic global changes up to 2100.



4AOP-v1-5	ECMWF-IFS-HR	MPI-ESM-1-2-HAM
ACCESS-CM2	ECMWF-IFS-LR	MPI-ESM1-2-HR
ACCESS-ESM1-5	ECMWF-IFS-MR	MPI-ESM1-2-LR
ARTS-2-3	FGOALS-f3-H	MPI-ESM1-2-XR
AWI-CM-1-1-HR	FGOALS-f3-L	MRI-AGCM3-2-H
AWI-CM-1-1-LR	FGOALS-g3	MRI-AGCM3-2-S
AWI-CM-1-1-MR	FIO-ESM-2-0	MRI-ESM2-0
AWI-ESM-1-1-LR	GFDL-AM4	NESM3
BCC-CSM2-HR	GFDL-CM4	NICAM16-7S
BCC-CSM2-MR	GFDL-CM4C192	NICAM16-8S
BCC-ESM1	GFDL-ESM2M	NICAM16-9S
CAMS-CSM1-0	GFDL-ESM4	NorCPM1
CAS-ESM2-0	GFDL-GRTCODE	NorESM1-F
CESM1-1-CAM5-CMIP5	GFDL-OM4p5B	NorESM2-LM
CESM1-CAM5-SE-HR	GFDL-RFM-DISORT	NorESM2-MM
CESM1-CAM5-SE-LR	GISS-E2-1-G	RRTMG-LW-4-91
CESM1-WACCM-SC	GISS-E2-1-G-CC	RRTMG-SW-4-02
CESM2	GISS-E2-1-H	RTE-RRTMGP-181204
CESM2-FV2	GISS-E2-2-G	SAM0-UNICON
CESM2-WACCM	GISS-E3-G	TaiESM1
CESM2-WACCM-FV2	HadGEM3-GC31-HH	TaiESM1-TIMCOM
CIESM	HadGEM3-GC31-HM	UKESM1-0-LL
CMCC-CM2-HR4	HadGEM3-GC31-LL	
CMCC-CM2-SR5	HadGEM3-GC31-LM	
CMCC-CM2-VHR4	HadGEM3-GC31-MH	
CMCC-ESM2	HadGEM3-GC31-MM	
CNRM-CM6-1	HiRAM-SIT-HR	
CNRM-CM6-1-HR	HiRAM-SIT-LR	
CNRM-ESM2-1	IITM-ESM	
CanESM5	INM-CM4-8	
CanESM5-CanOE	INM-CM5-0	
E3SM-1-0	INM-CM5-H	
E3SM-1-1	IPSL-CM6A-ATM-HR	
E3SM-1-1-ECA	IPSL-CM6A-LR	
EC-Earth3	IPSL-CM6A-LR-INCA	
EC-Earth3-AerChem	KACE-1-0-G	
EC-Earth3-CC	KIOST-ESM	
EC-Earth3-LR	LBLRTM-12-8	
EC-Earth3-Veg	MCM-UA-1-0	
EC-Earth3-Veg-LR	MIROC-ES2L	
EC-Earth3P	MIROC6	
EC-Earth3P-HR		
EC-Earth3P-VHR		

How to project the mean change?

SSP(Shared Socioeconomic Pathways)

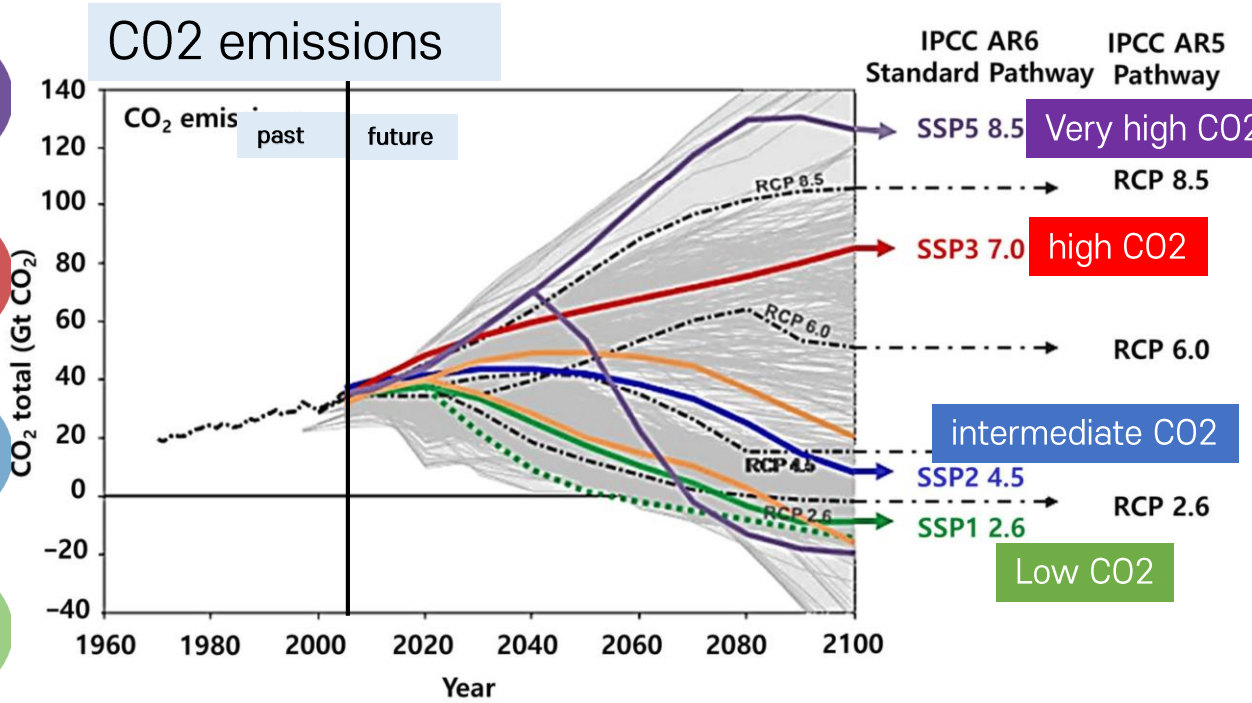
SSP scenarios distinguished according to future mitigation and adaptation efforts to climate change based on the intensity of radiative forcing as of 2100 and future social and economic development

SSP5-8.5 Fossil-fueled development

SSP3-7.0 Passive in climate change Mitigation

SSP2-4.5 Mitigation and Economic development at intermediate level

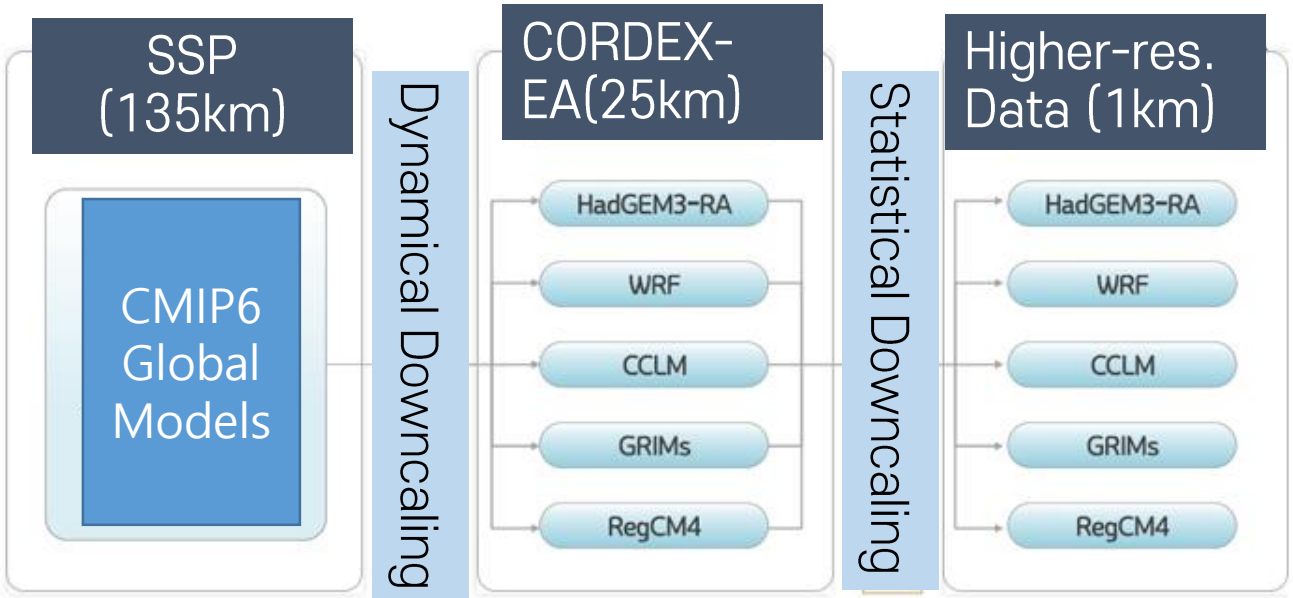
SSP1-2.6 Minimal use of fossil fuels , sustainable economic growth



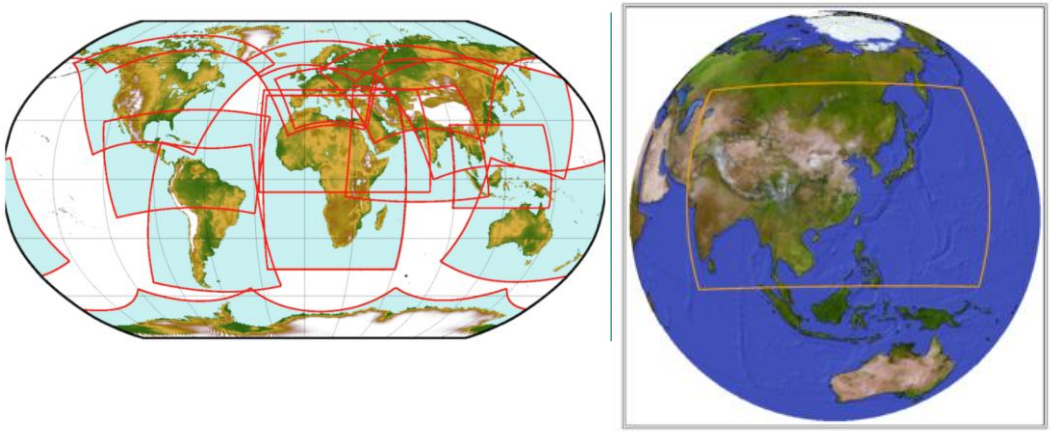
Taken from IPCC

How to project the mean change?

Dynamical (CORDEX) and Statistical Downscaling



CORDEX-EA
(COordinated Regional Downscalling EXperiments-East Asia)
For better understanding relevant regional/local climate phenomena, their variability and changes, through downscaling



* 동아시아 시나리오 산출에 사용된 전지구 기후모델은 UKESM1임

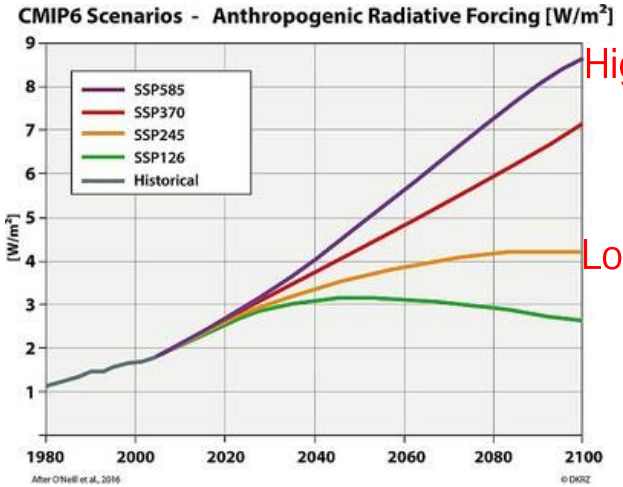
- Spatial resolution of CMIP data: too **coarse** to better understand regional climate phenomena, their variability and future projections
- Dynamical Downscaling: Producing high-resolution data for relevant regions such as East Asia (CORDEX-EA) using regional climate models that use CMIP6 scenario data as input. Small-scale atmospheric phenomena and topographic effects can be represented, which are difficult by global climate models.
- Statistical Downscaling: Obtaining higher resolution data (1km) using a statistical technique (e.g., PRISM)

Obs. and SSP Data

High Res. (1km) daily data over S. Korea

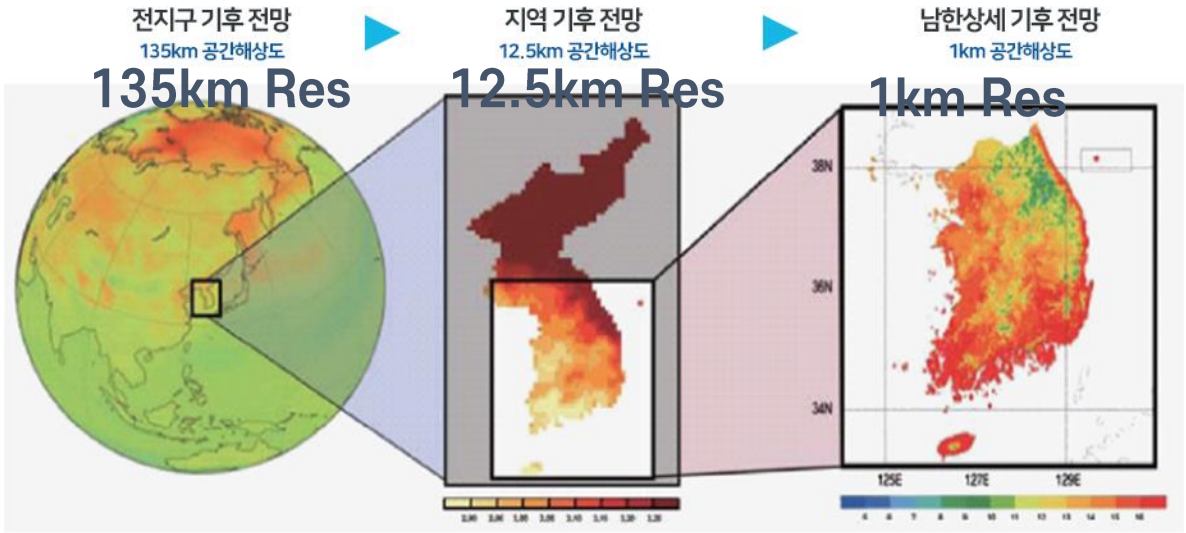
- Present Climate (2000-2019): Statistical downscaling applied to Korean station obs. data
- Future Scenario(2021-2100): SSP1-2.6, SSP5-8.5 (Dynamical and Statistical Downscaling)
  - Regional Climate Model (RCM, CORDEX): HadGEM3-RA, CCLM, WRF, RegCM, GRIMs

SSP (Shared Socioeconomic Pathway) Scenario



High-CO2 emission (SSP5-8.5)

Low-CO2 emission (SSP2-4.5)



HadGEM2-AO	HadGEM3-RA	PRIDE
CMIP6 (UKESM) SSP data	RCM : Dynamical Downscaling	Statistical Downscaling

BC → PRISM

National Institute of Meteorological Sciences

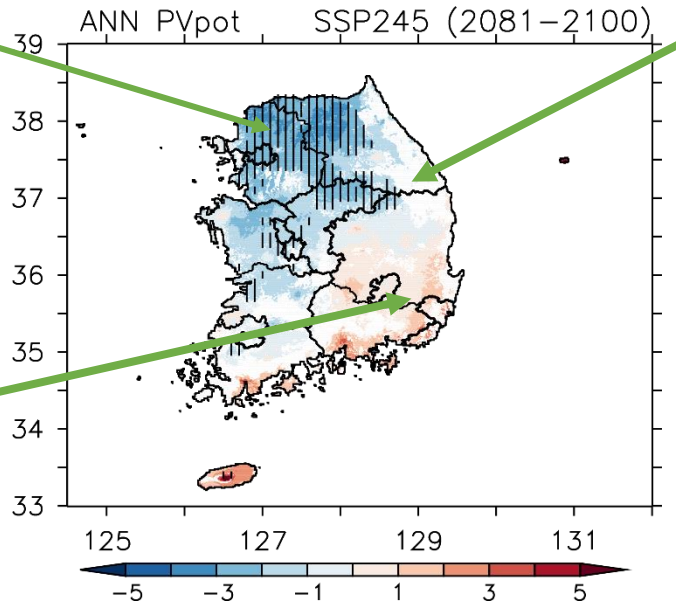
Ensemble mean projection

Considering both of the model consensus and Significance Tabaldi et al. 2011

Significant Agreement: When at least 60% of the ensemble members show a statistically significant change (according to student t-test) and agree on the direction of change, denoted **in color and vertical lines → high confidence in the future change**

Significant Disagreement: When at least 60% of the ensemble members show a statistically significant change and disagree on the direction of change, **in white → low confidence**

Non-significant Agreement: at least 60% of the ensemble members agree on the direction but does not show significant change, denoted **just in color → little change**



Solar Power Generation

Solar Photovoltaic Power Generation Potentials

$$PVpot(t) = P_R \frac{RSDS(t)}{RSDS_{stc}}$$

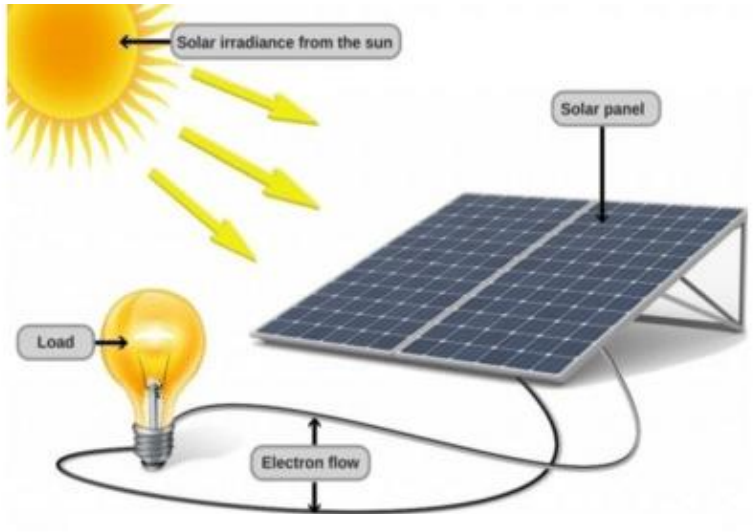
- *RSDS:* Surface-Downwelling Shortwave radiation
- *STC*: Standard test conditions ($RSDS_{STC}$ = 1,000 Wm^{-2})
- P_R : performance ratio

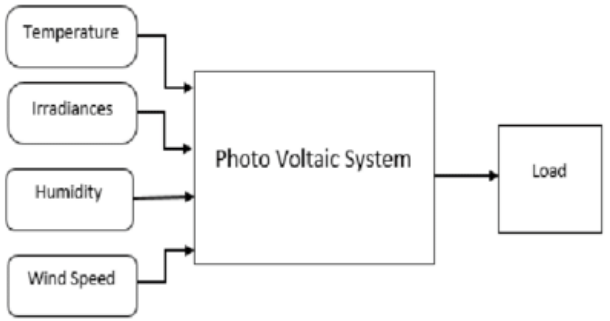
$$P_R = 1 + \gamma(T_{cell}(t) - T_{STC}),\ T_{STC} = 25℃,\ \gamma = -0.005℃^{-1}$$

$$T_{cell}(t) = c_1 + c_2 TAS(t) + c_3 RSDS(t) + c_4 VWS(t)$$

$$c_1 = 4.3℃,\ c_2 = 0.943,\ c_3 = 0.028℃m^2W^{-1},\ c_4 = -1.528℃sm^{-1}$$

- PVpot = f(the amount of resource, influence of other atmospheric variables that has on the efficiency of the PV cells)



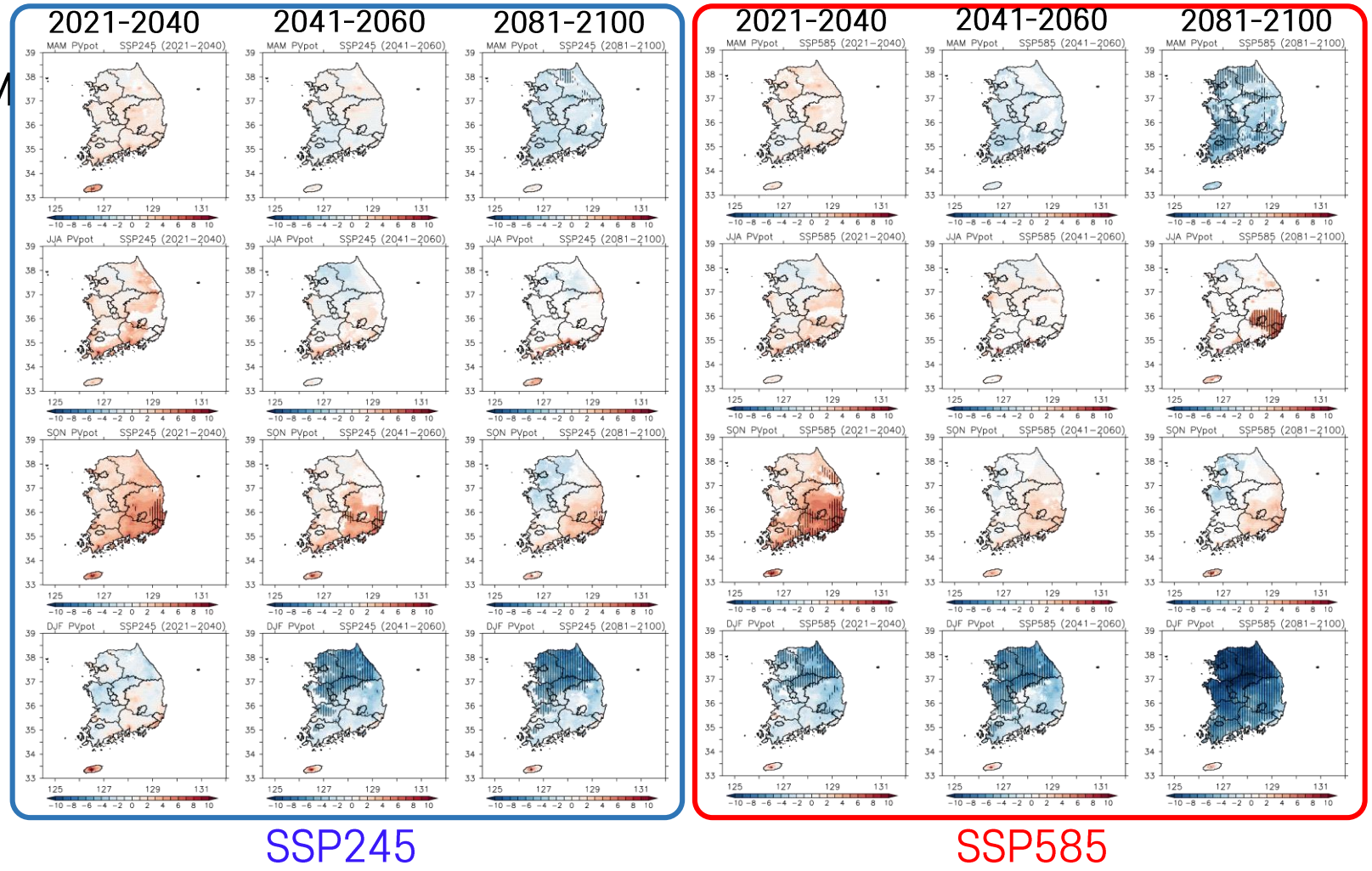


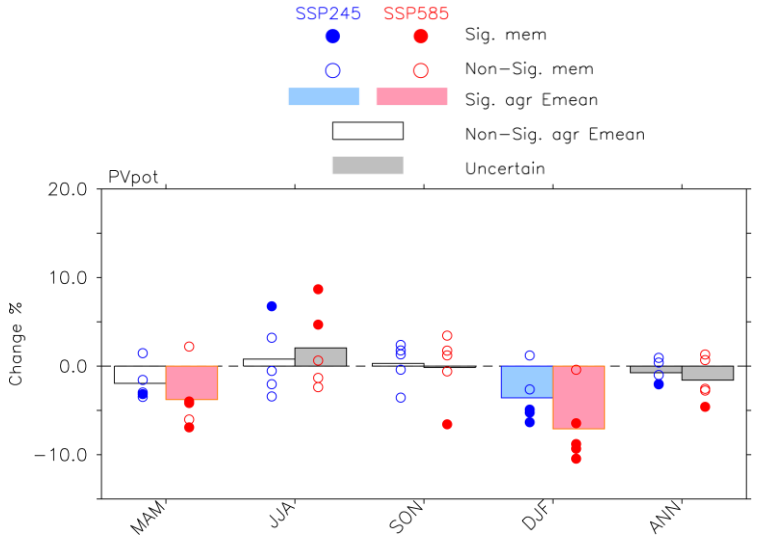
Jerez et al. 2015, Park et al. 2022, Poddar et al. 2021

Projection of Solar Power

Mean Change of PVpot

Relative to present climate (2000~2019)

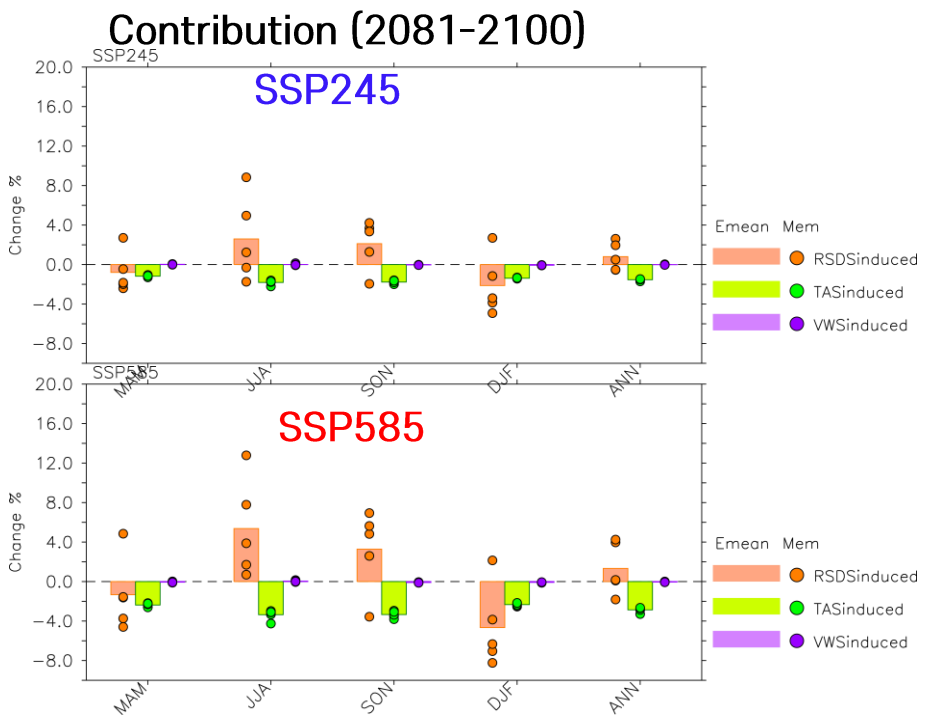


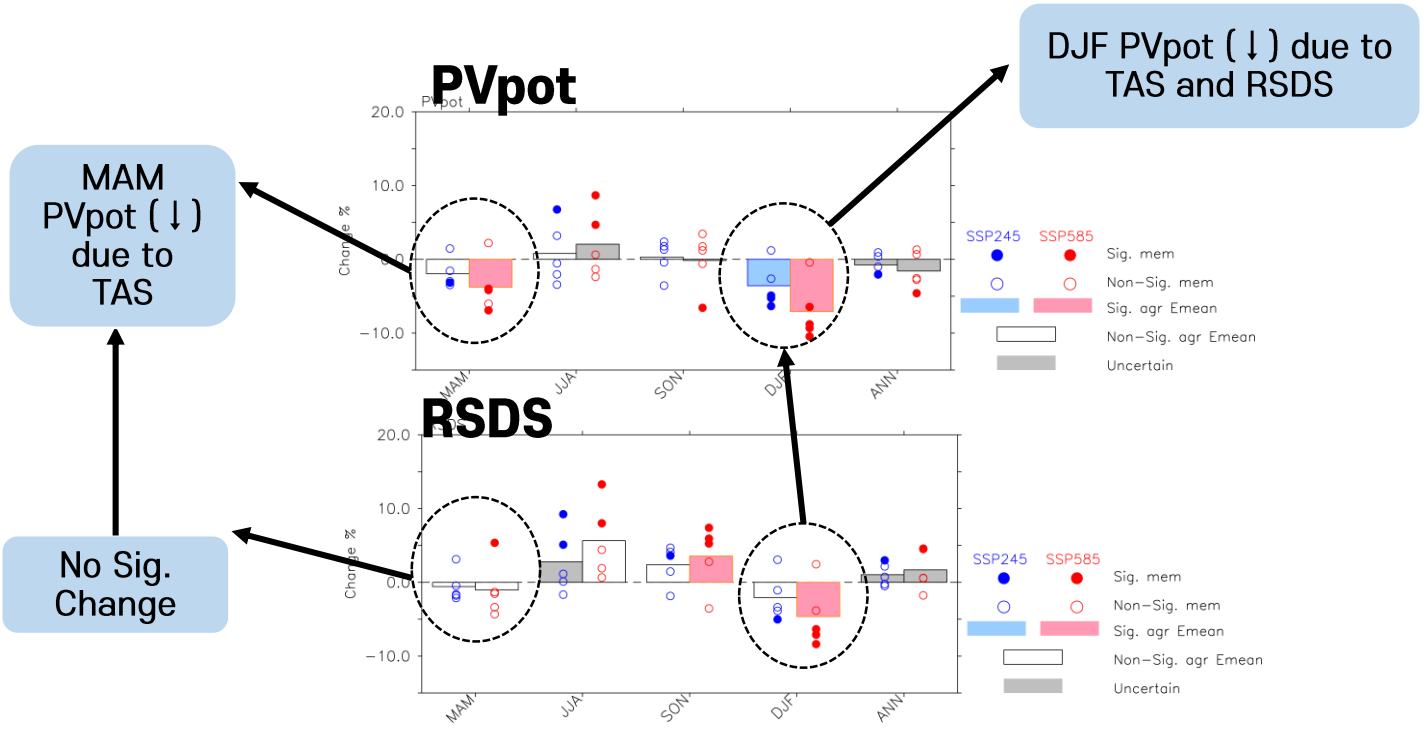


- For low-CO2 emission scenario no significant change in all seasons except winter, when there shows a decrease tendency toward the late-21st century.
- For high-CO2 emission, in spring and winter PVpot tends to decrease significantly.
- In winter, higher CO2 emission will cause the reduction of about 10% in average in the solar power generation

What induced the mean change of solar power

TAS-, VWS-, and RSDS-induced change





MAM PVpot (↓) due to TAS

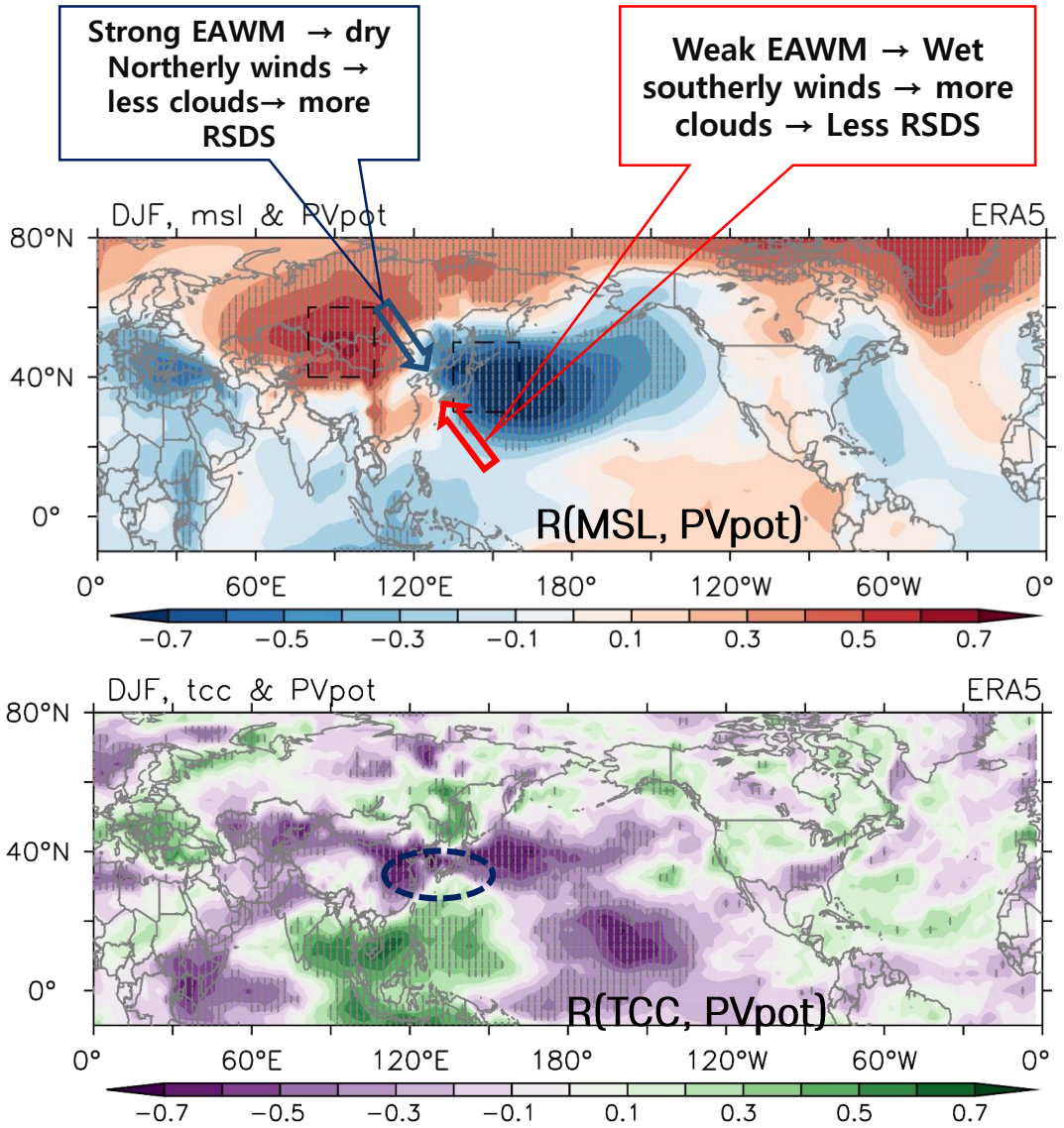
DJF PVpot (↓) due to TAS and RSDS

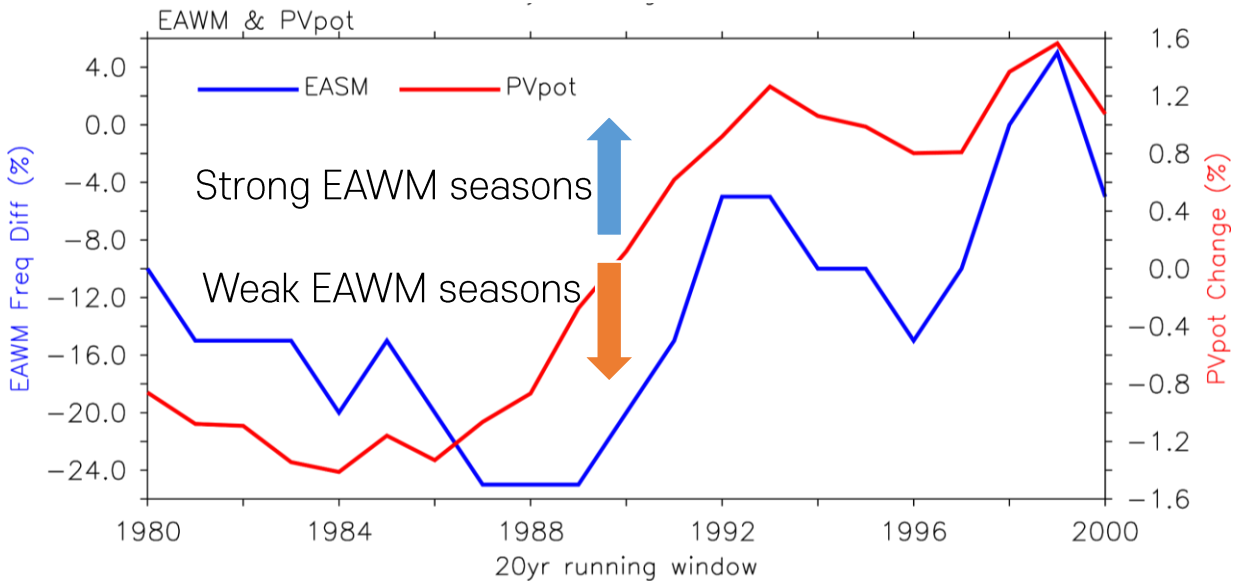
No Sig. Change

- Main contribution of TAS and RSDS to the mean change of PVpot
- No sig. change of PVpot in Summer (JJA) and Fall (SON) due to the offset of TAS and RSDS

What induced the mean change of solar power

Attributable to Activity of East Asia Winter Monsoon





Decrease (Increase) tendency of solar power generation when weak (Strong) EAWM seasons are dominant over a 20-year running period.

Wind Power Generation Potential

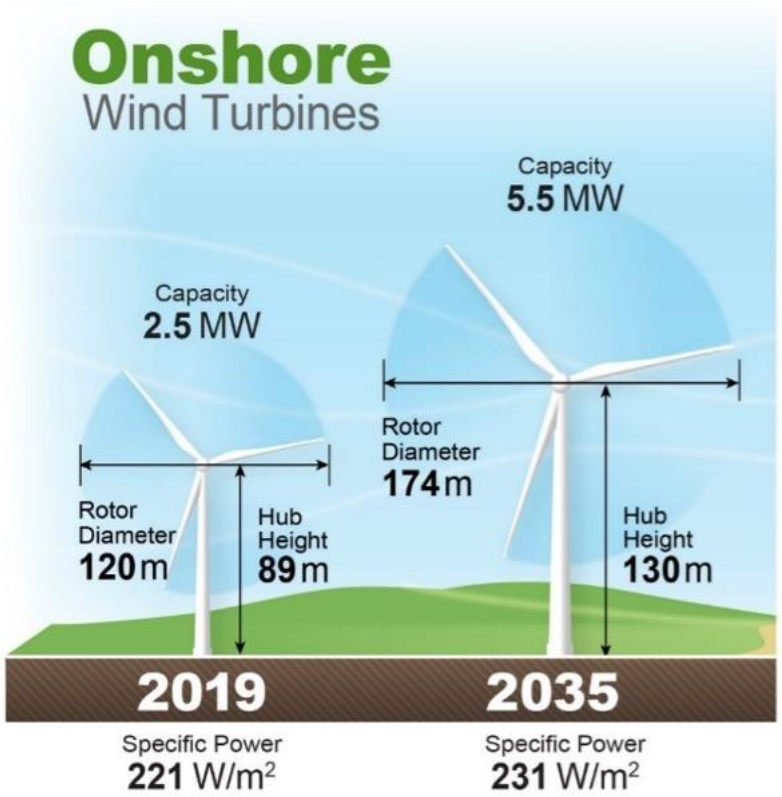
Wind Energy Density

$$WED = \frac{1}{2}\rho V^3$$

- WED(Wind Energy Density, W/m^2): Kinetic Energy Flux associated with Winds

  $\rho: air\ density (= 1.2\ Kg/m^3)$,

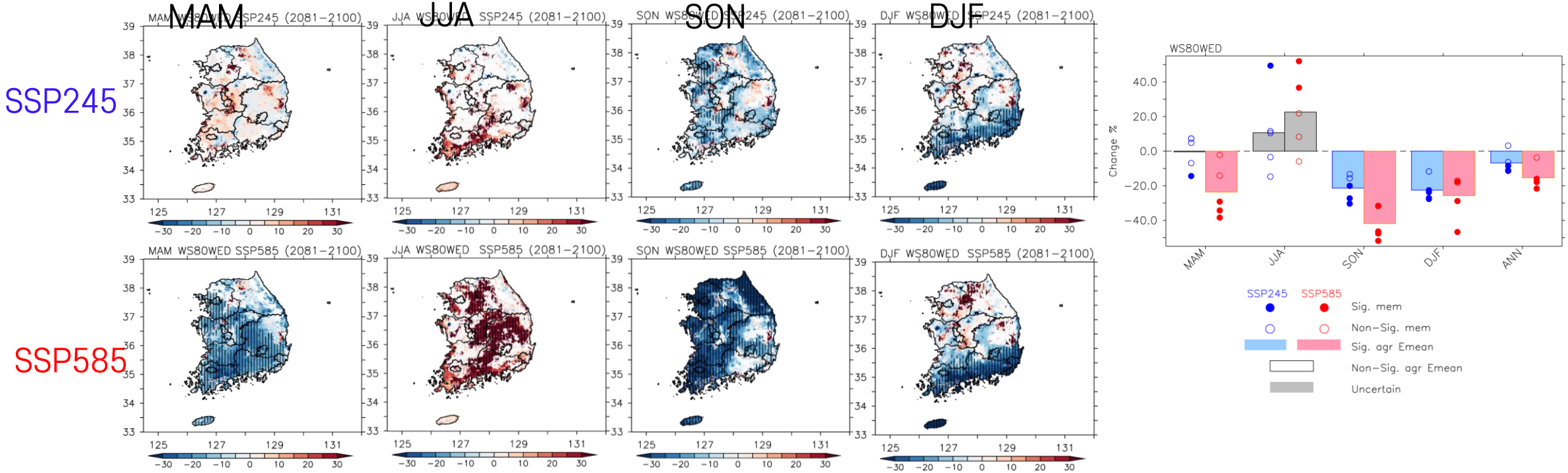
  $V_z: wind\ speed\ at\ hub\ height\ (80m, = V_{10}\frac{80}{10}, Power\ Law)$



Projection of Wind Power

Mean Change of WED

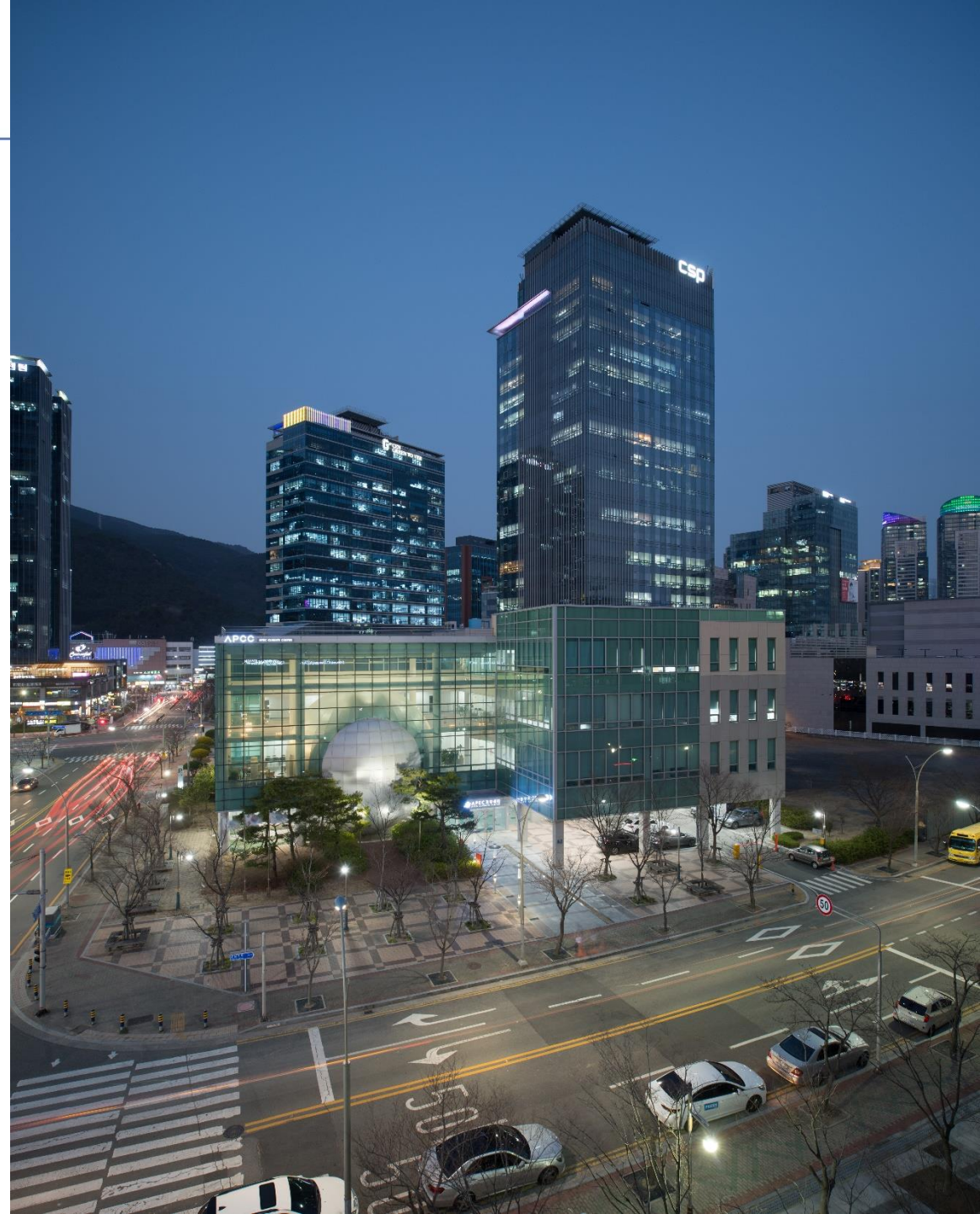
Change of WED over 2081-2100 relative to present climate (2000~2019)



- For low-CO2 emission scenario, significant decrease of WED in SON and DJF
- For high-CO2 emission scenario, significant decrease in MAM, SON, and DJF.
  - ✓ Maximum decline over the southern part of South Korea in winter, the south eastern part and northern part in fall.
- High-CO2 emission scenario shows the more reduction of WED than low-CO2 emission scenario.

Conclusions

- Climate change affects the energy generation by solar and wind power.
- The degree of reduction in the energy generation under the future warmer climate varies from region to region of South Korea.
- Solar power generation decline in winter could be attributed to the EAWM activity.
- Future changes in renewable energy generation capacity should be considered when selecting locations and technology for the regional renewable energy generation system development and plans.

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Thank You!
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