Hybrid Energy Forecasting and Trading Competition (Wind Forecasting)

Haejoong Lee

Sogang University, EE

2025.06.04

NICE LAB
Networking for Intelligence Communications and Energy

서강대학교 SOGANG UNIVERSITY

Hybrid Energy Forecasting and Trading Competition

☐ Contents

- Competition Overview (HEFTCom24)
- Data Preprocessing & Cleansing
- Feature Engineering
- Modeling Strategy
- Challenges & Lessons Learned
- Common Strategies Used by Winning Teams in Forecasting Competitions

전자공학과 김홍석 교수 연구팀,
국제 신재생 에너지 발전량 예측 및 거래 대회 Student Team 부문 최종 2위

▲ (위 왼쪽부터) 전자공학과 김홍석 교수, 송근주 석박사통합과정, 이해중 석박사통합과정
(아래 왼쪽부터) 임예지 석박사통합과정, 강희주 석사졸업생, 김민수 박사과정

Hybrid Energy Forecasting and Trading Competition

☐ Competition Overview (HEFTCom24)

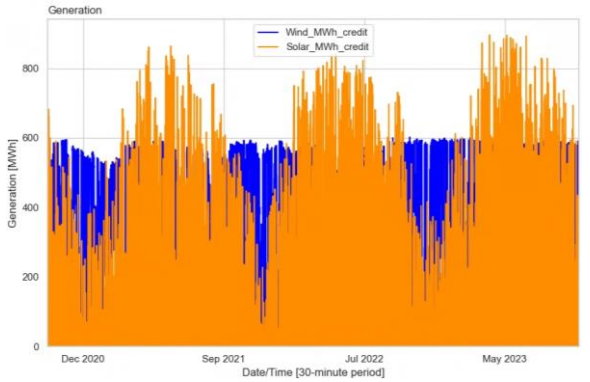
Hybrid Energy Forecasting and Trading Competition

This challenge has ended

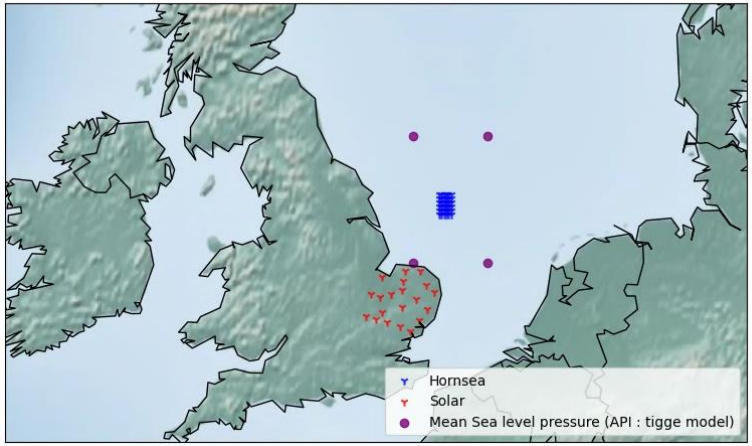
The purpose of this competition was to develop state-of-the-art forecasting and energy trading techniques to accelerate the global transition to net-zero carbon emission footprint.

The competition was organised by Dr. Jethro Browell (University of Glasgow), the IEEE Power and Energy Society Working Group on Energy Forecasting and Analytics and was sponsored by Ørsted, one of the world's largest renewable energy companies, and rebase.energy

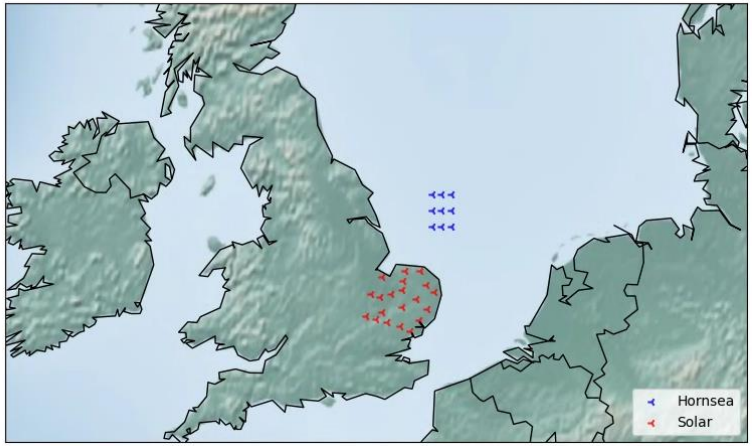
Read more on IEEE DataPort



DWD model



NCEP model



Competition Period : 2024.02.19. ~ 2024.05.18 (day-ahead forecasting)

Hybrid Energy Forecasting and Trading Competition

☐ Competition Overview (HEFTCom24)

Hornsea 1 Wind Farm

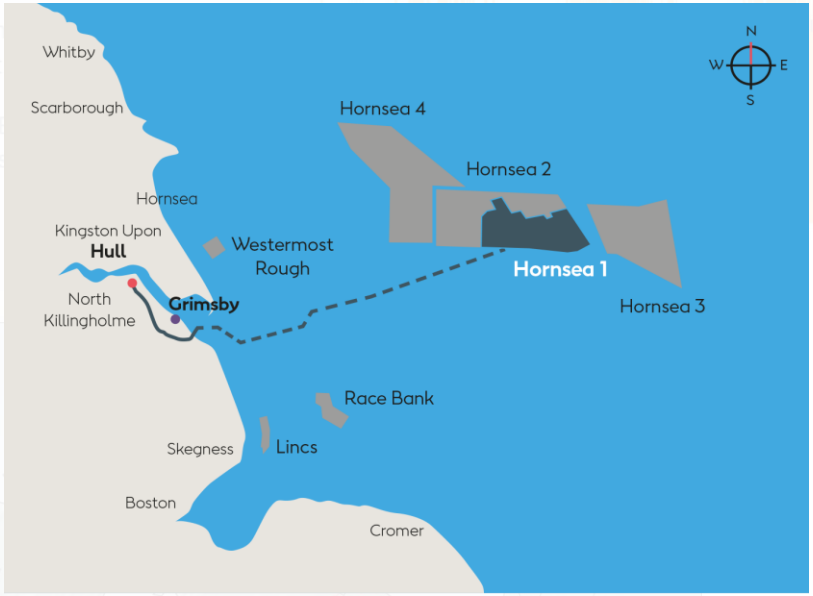
Powering over 1 million homes with green electricity

Hornsea 1, located in the North Sea, generates enough green energy to power over 1 million UK homes. The wind farm comprises 174 turbines and covers an area of 407 square kilometres (157.2 square miles), which is over five times the size of the city of Hull.

1.2 GW
The combined total capacity of the project

174
7MW wind turbines

900 km
Cable route



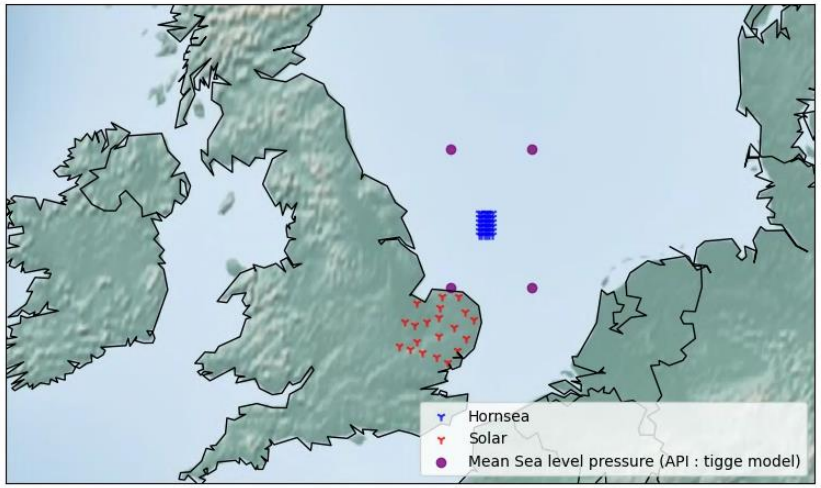
Competition Period : 2024.02.19. ~ 2024.05.18 (day-ahead forecasting)

- Reference : https://orsted.co.uk/energy-solutions/offshore-wind/our-wind-farms/hornsea1

Hybrid Energy Forecasting and Trading Competition

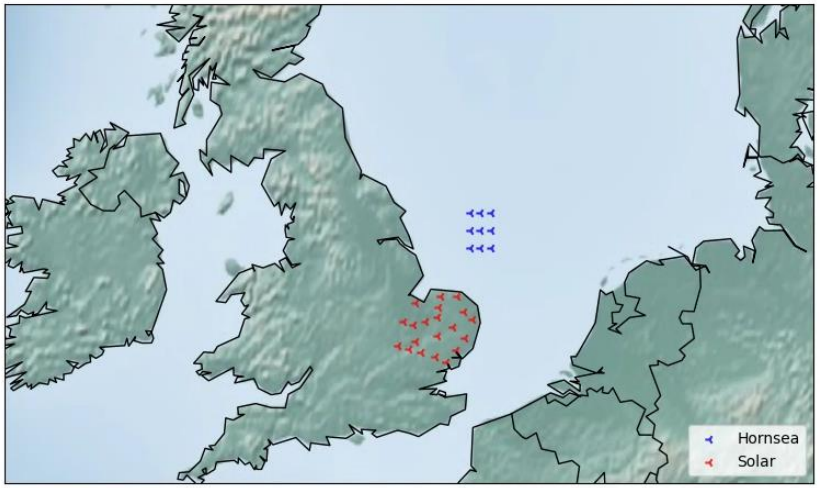
☐ Weather Data (2020-09-20 ~ 2024-01-29)

- DWD : 독일 기상청



- PES 10 (PV)
  - 20 sites → 1 site (by avg.)
  - 3 Features
- Hornsea 1 (Wind)
  - 36 sites → 1 site (by avg.)
  - 6 Features

NCEP : 미국 국립환경예측센터

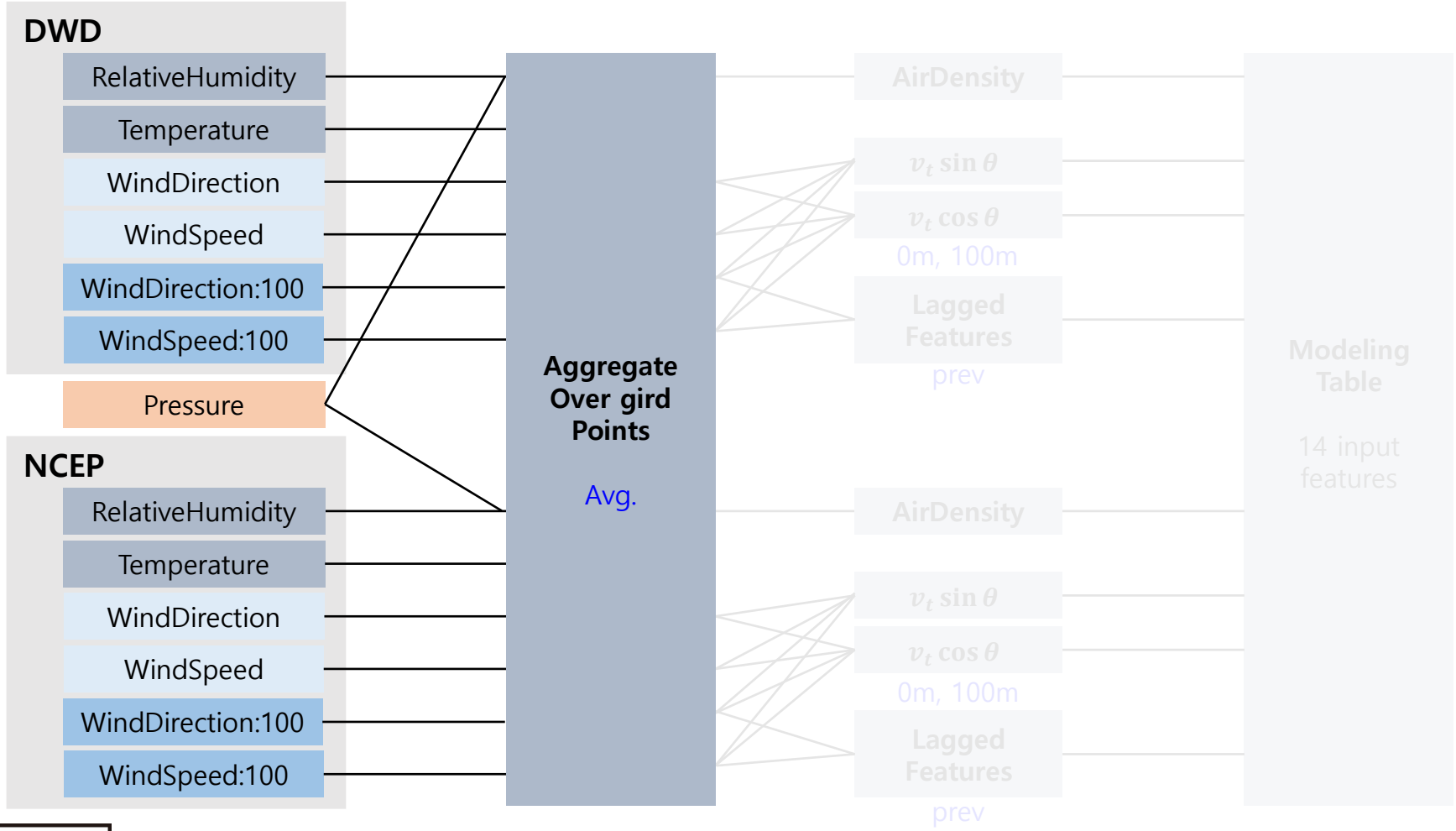


- PES 10 (PV)
  - 20 sites → 1 site (by avg.)
  - 3 Features
- Hornsea 1 (Wind)
  - 9 sites → 1 site (by avg.)
  - 6 Features

Hybrid Energy Forecasting and Trading Competition

☐ Data Preprocessing & Cleansing

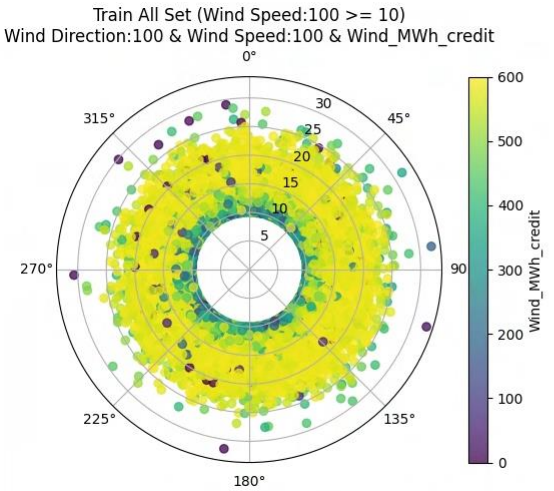
- Data Aggregation by average

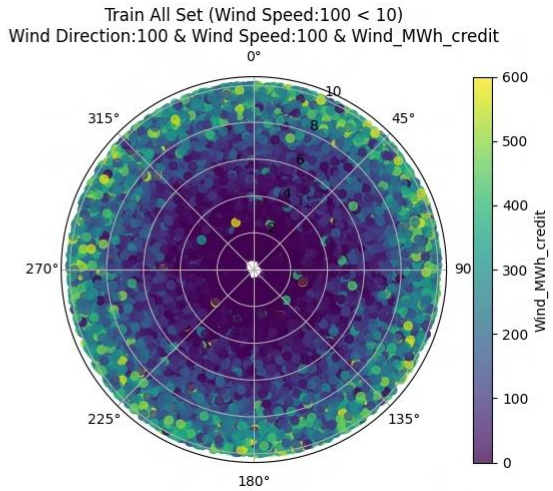


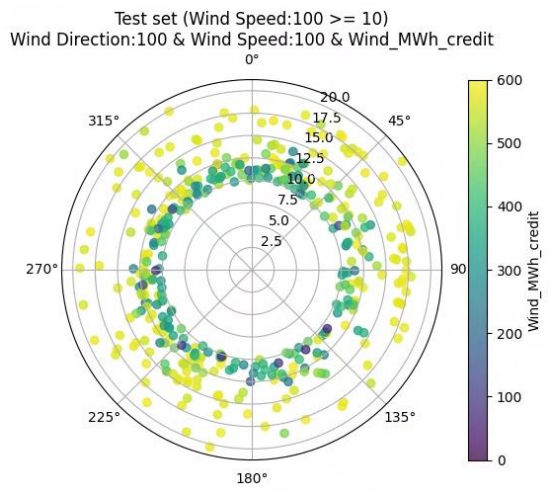
Hybrid Energy Forecasting and Trading Competition

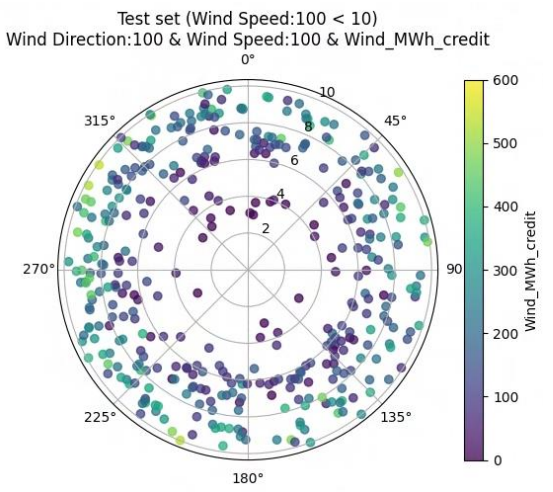
☐ Data Preprocessing & Cleansing

- 풍향과 풍속에 따른 발전량 분포 시각화







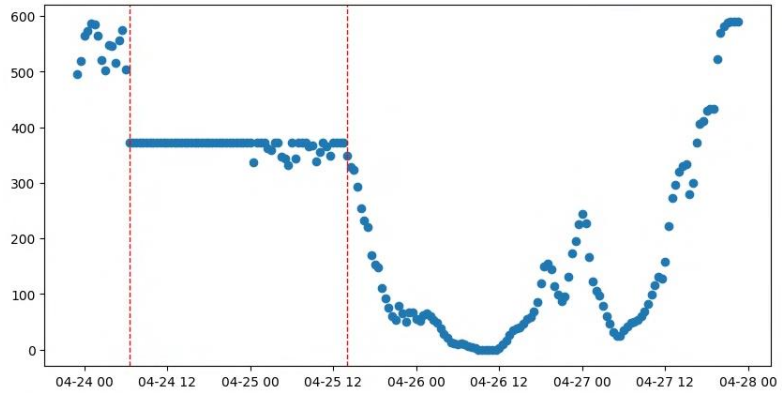



```
first cleansing :
before data cleansing : 57258
after data cleansing : 56909
```

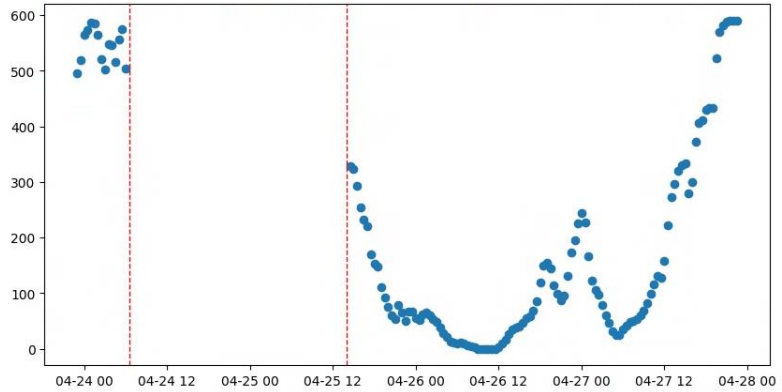
Hybrid Energy Forecasting and Trading Competition

☐ Data Preprocessing & Cleansing

- Curtail Issue



» 과거 학습 데이터에 대한 출력 제한 이력 존재 → 풍력 발전 모델 성능 저하 요인

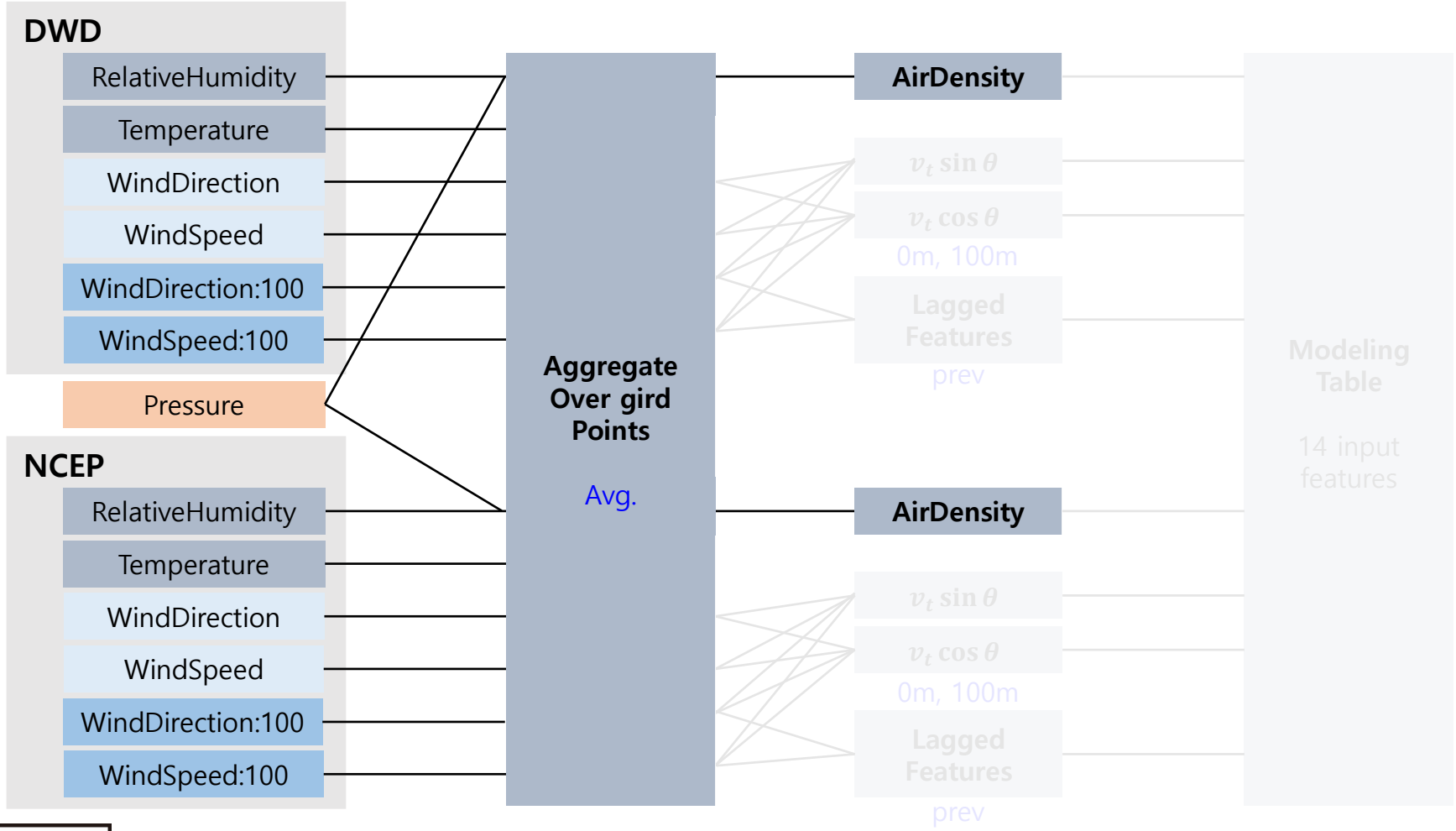



```
Second cleansing :
before data cleansing : 56909
after data cleansing : 56845
```

Hybrid Energy Forecasting and Trading Competition

☐ Feature Engineering for wind forecasting

- RelativeHumidity + Temperature + Pressure → AirDensity



Hybrid Energy Forecasting and Trading Competition

☐ Feature Engineering for wind forecasting

- **Wind power output equation**

$$P = \frac{1}{2} \cdot \rho \cdot A \cdot v^3 \cdot C_p$$

- ρ : Air density (kg/m^3)
- A : Swept area of the rotor blades (m^2)
- v : Wind speed (m/s)
- C_p: Power coefficient (a measure of turbine efficiency)

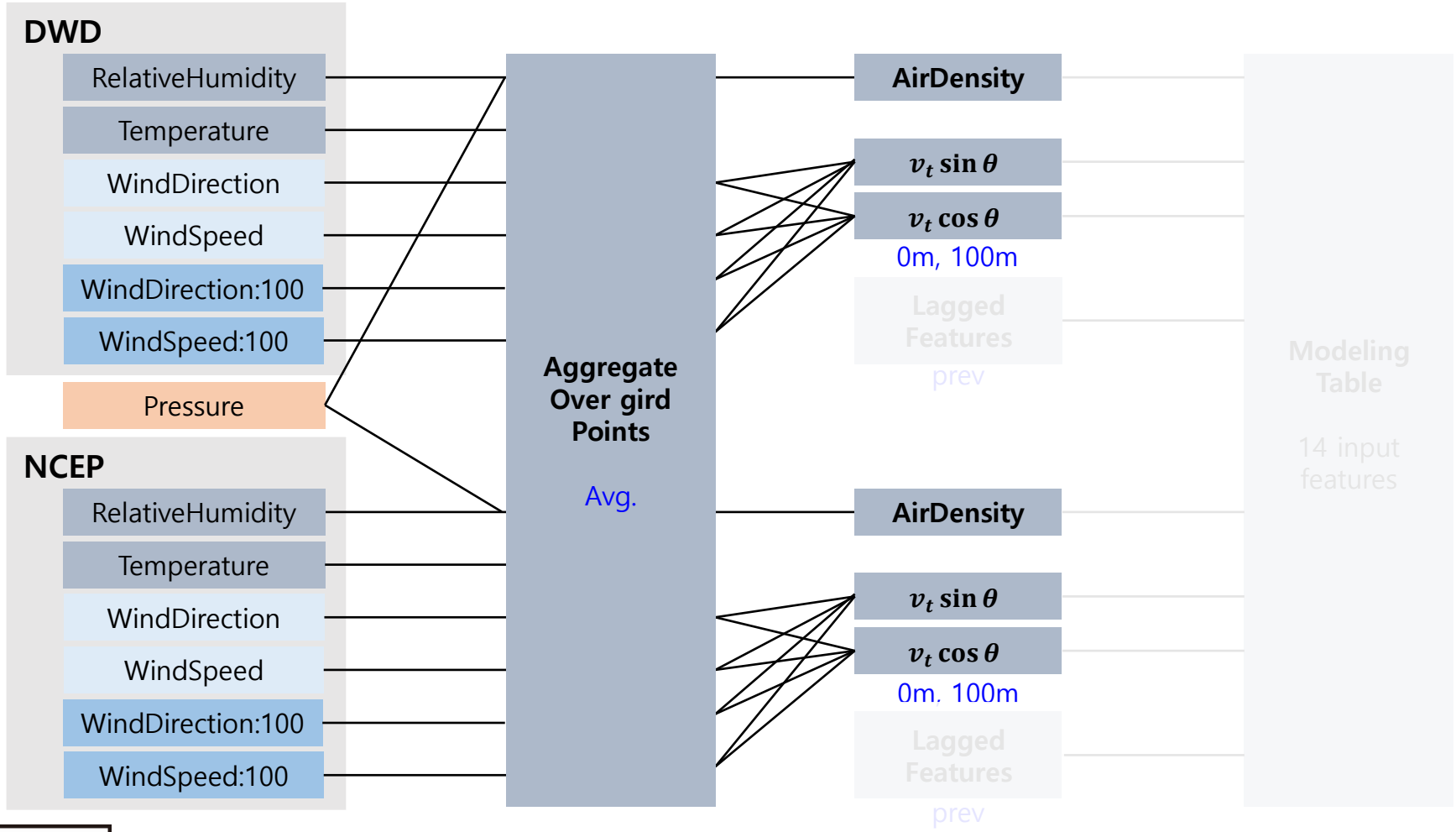
```python
def air_density(pressure, temperature, relative_humidity):
    """
    Calculate air density in kg/m^3 given pressure in Pa, temperature in K, and relative humidity as a fraction.
    """
    # Calculate saturation vapor pressure
    e_s = 6.1078 * 10 ** ((7.5 * temperature) / (temperature + 237.3))
    # Calculate vapor pressure
    e = relative_humidity * e_s
    # Calculate dry air pressure
    p_dry = pressure - e
    # Calculate air density
    rho = (p_dry / (287.058 * temperature)) + ((e / (287.058 * temperature)) * (1 - 0.378 * (e / p_dry)))
    return rho
```

- Reference : $https://www.omnicalculator.com/physics/air-density$

Hybrid Energy Forecasting and Trading Competition

☐ Feature Engineering for wind forecasting

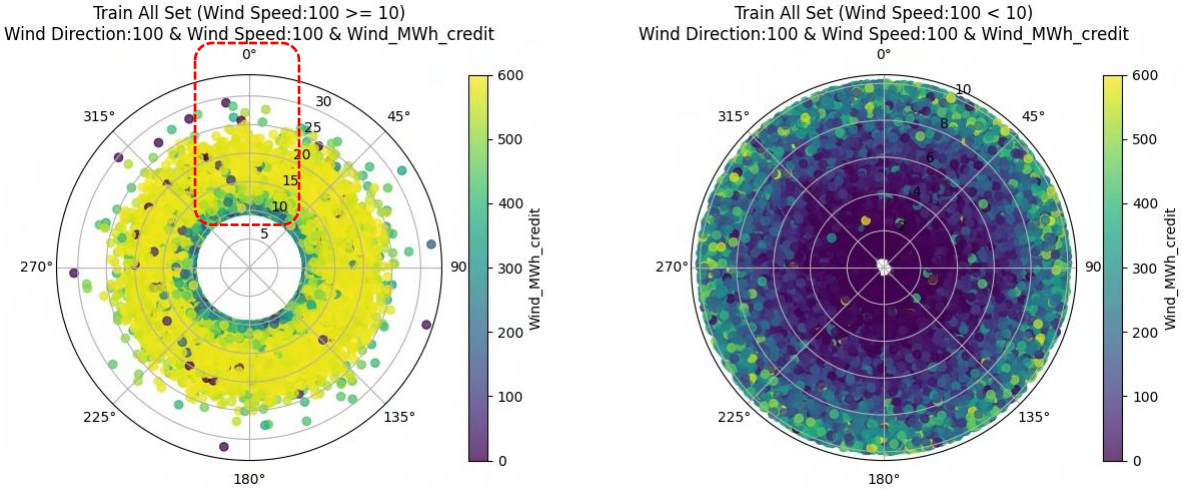
- WindDirection, WindSpeed → $v_t \sin\theta$, $v_t \cos\theta$



Hybrid Energy Forecasting and Trading Competition

☐ Feature Engineering for wind forecasting

- **The inherent periodicity of wind direction**



$v_t \sin\theta$

$v_t \cos\theta$

» $0^\circ = 360^\circ$ 을 연속적으로 표현 가능 → 가까운 방향은 벡터로도 가깝게 표현

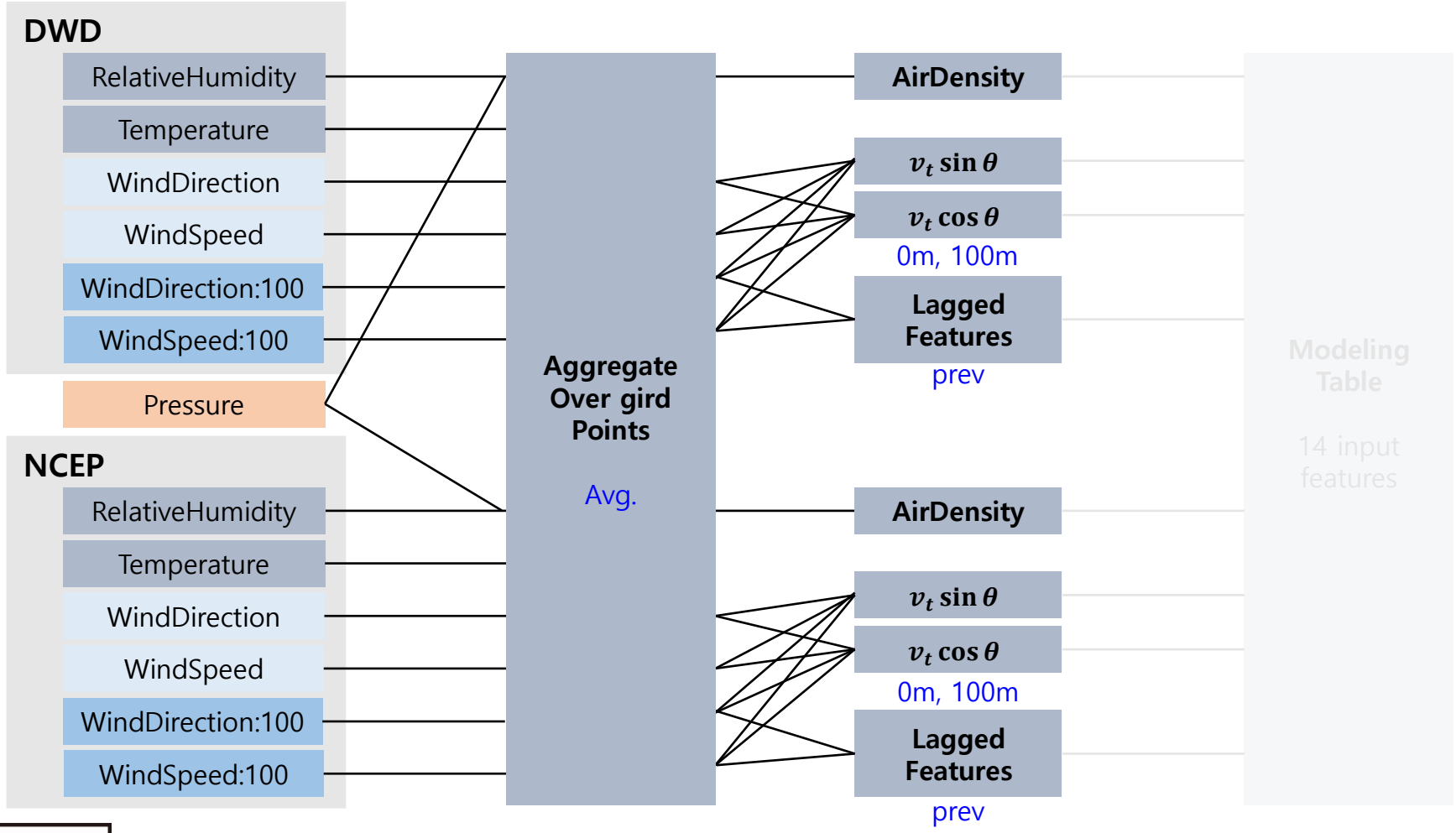
» 불연속성 없이 학습 가능 → 벡터 연산으로 발전량 예측 도움

- Reference : $https://www.omnicalculator.com/physics/air-density$

Hybrid Energy Forecasting and Trading Competition

☐ Feature Engineering for wind forecasting

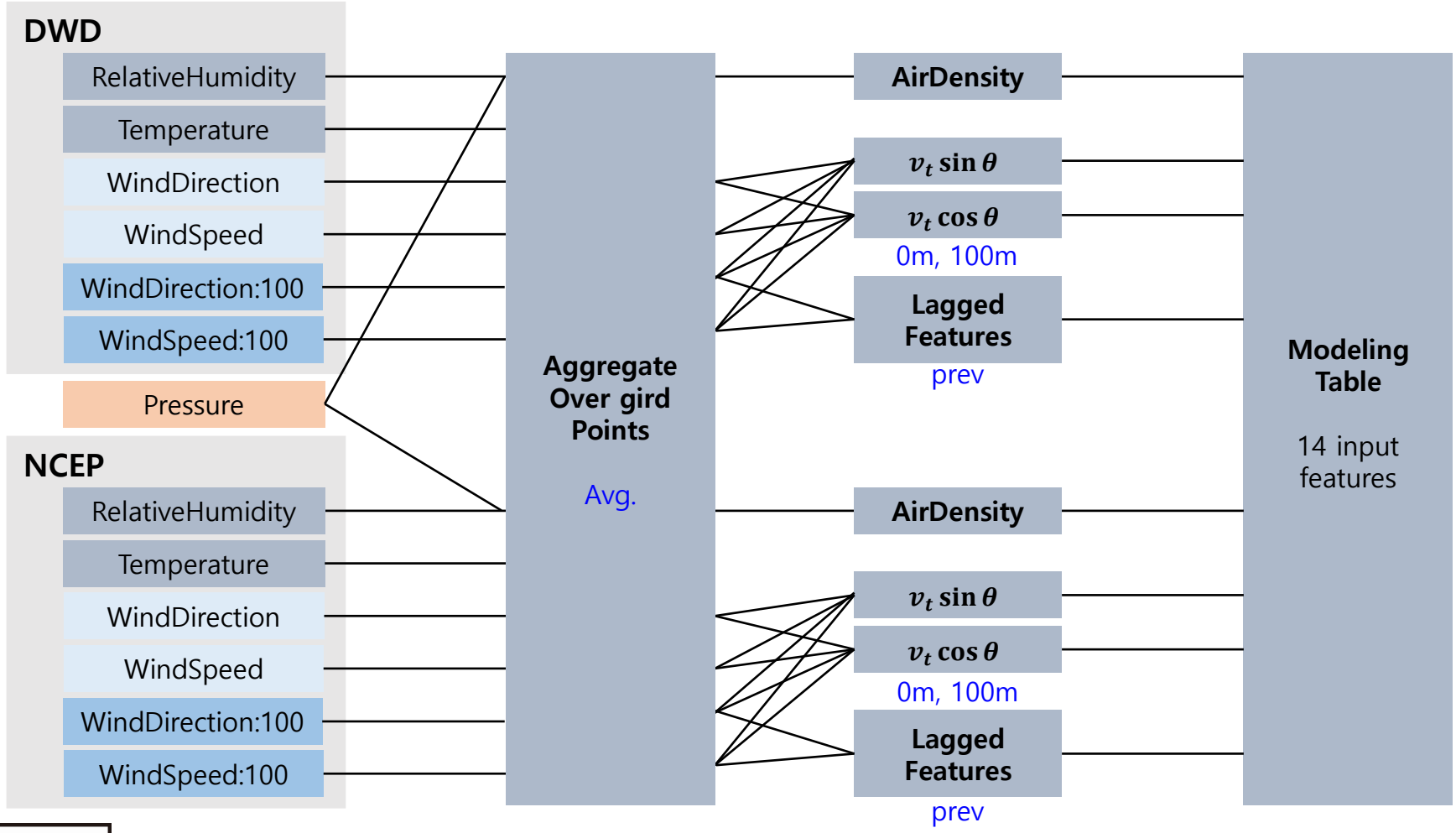
- WindDirection:100, WindSpeed:100 → Lagged Features



Hybrid Energy Forecasting and Trading Competition

☐ Feature Engineering for wind forecasting

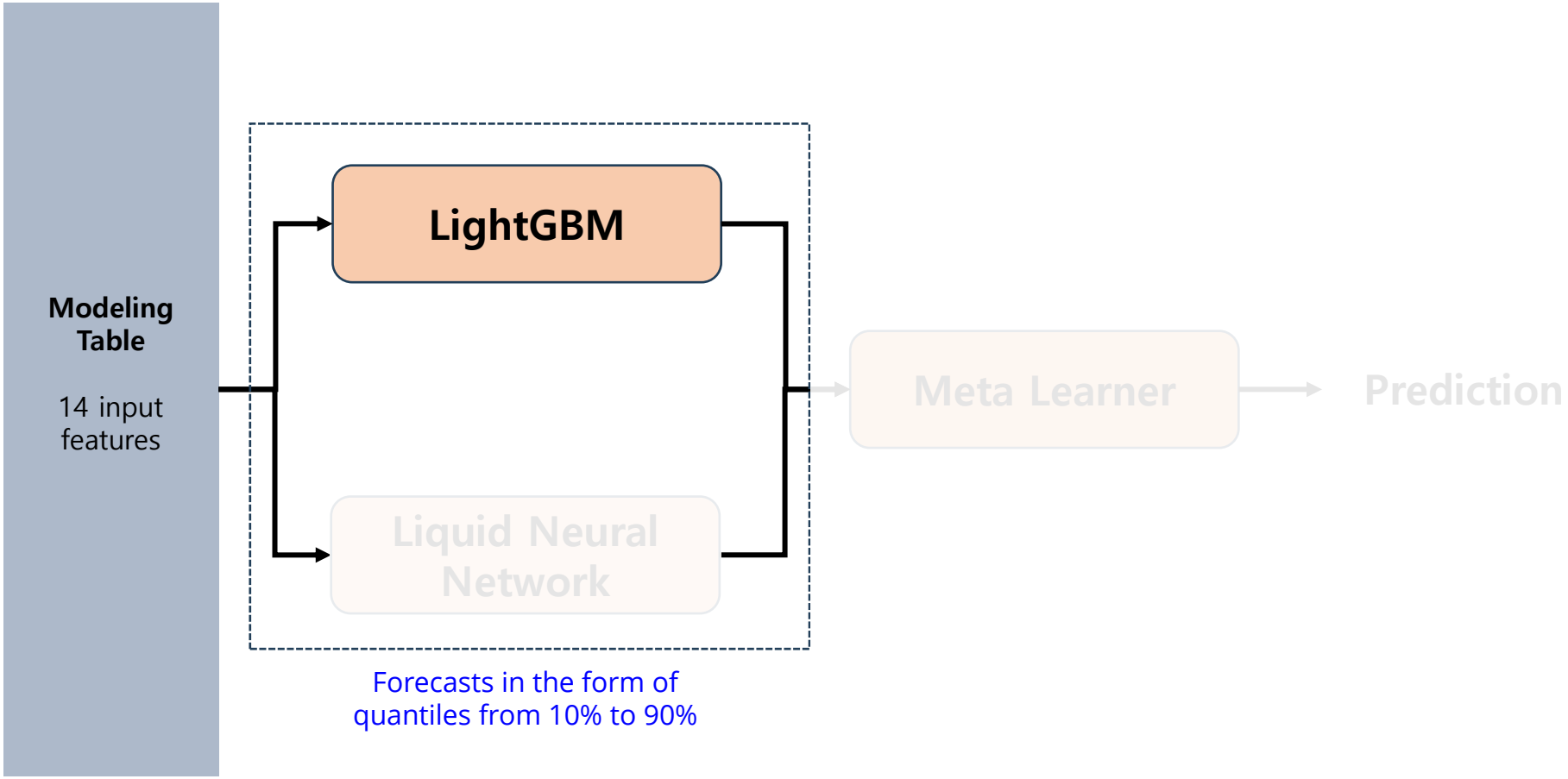
- 14 inputs (features)



Hybrid Energy Forecasting and Trading Competition

☐ Modeling Strategy

- Ensemble : Machine Learning + Deep Learning

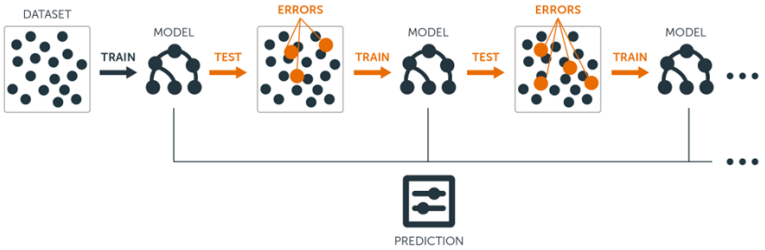


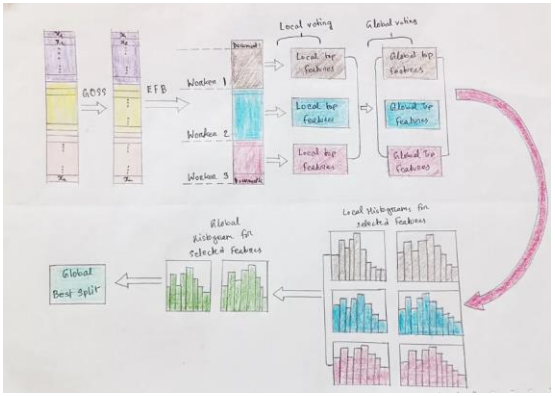
Hybrid Energy Forecasting and Trading Competition

☐ Modeling Strategy

- LightGBM

» leaf-wise tree 성장 + 히스토그램 처리 + 병렬/분산 학습을 통해 빠르고 정확하며 대용량 데이터에도 잘 확장되는 gradient boosting 프레임워크





» leaf wise tree growth

- Tree를 확장할 때, loss 감소가 큰 node를 선택하여 분기
- 정확도가 높지만, 작은 데이터셋에서는 과적합 가능성 존재

» histogram based tree splitting

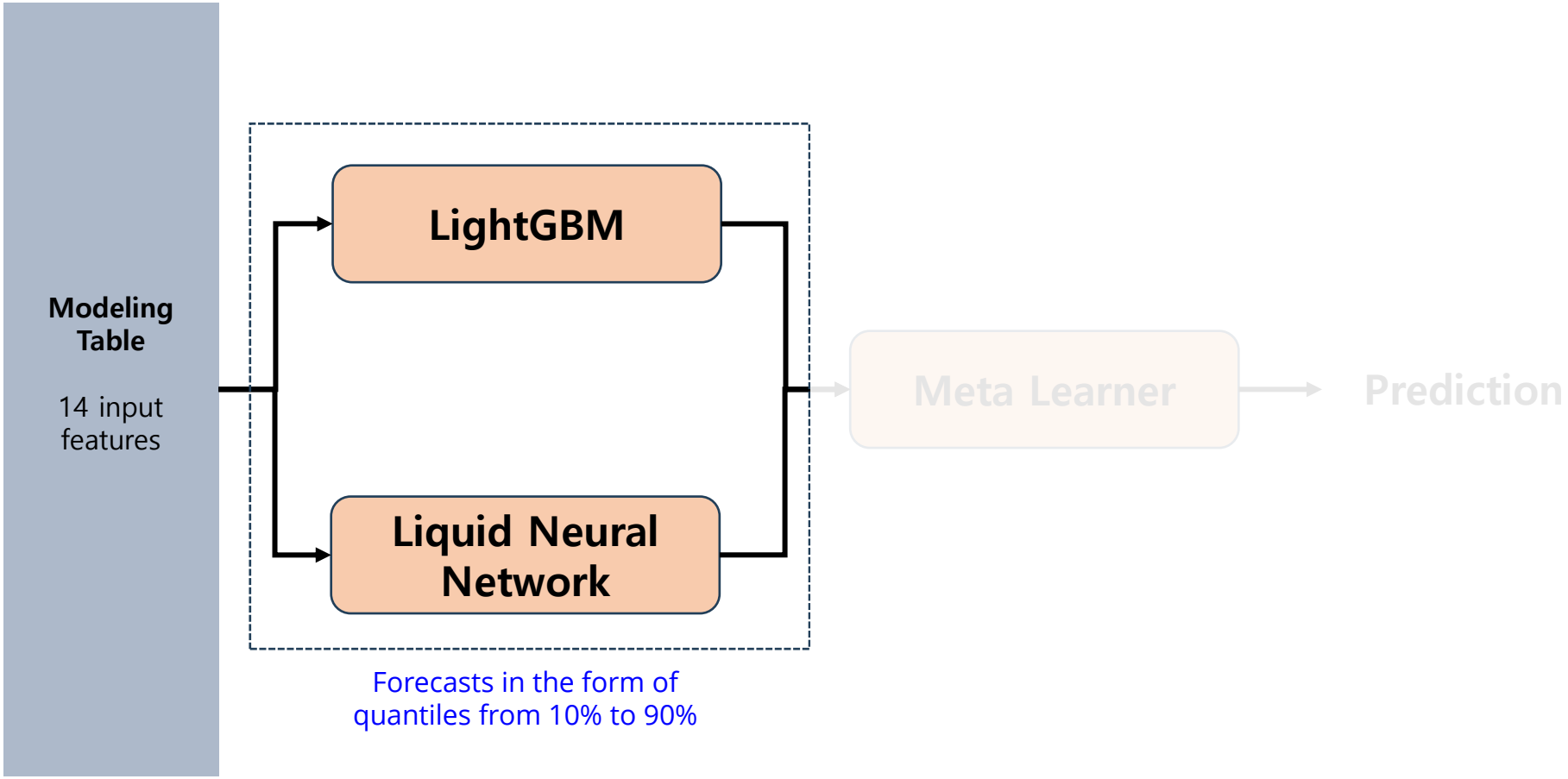
- 연속형 feature를 히스토그램 bin으로 변환하여 처리
- 연산량과 메모리 사용량을 줄임 → 대규모 데이터 처리에 유리

• Reference : Mastering LightGBM: An In-Depth Guide to Efficient Gradient Boosting

Hybrid Energy Forecasting and Trading Competition

☐ Modeling Strategy

- Ensemble : Machine Learning + Deep Learning

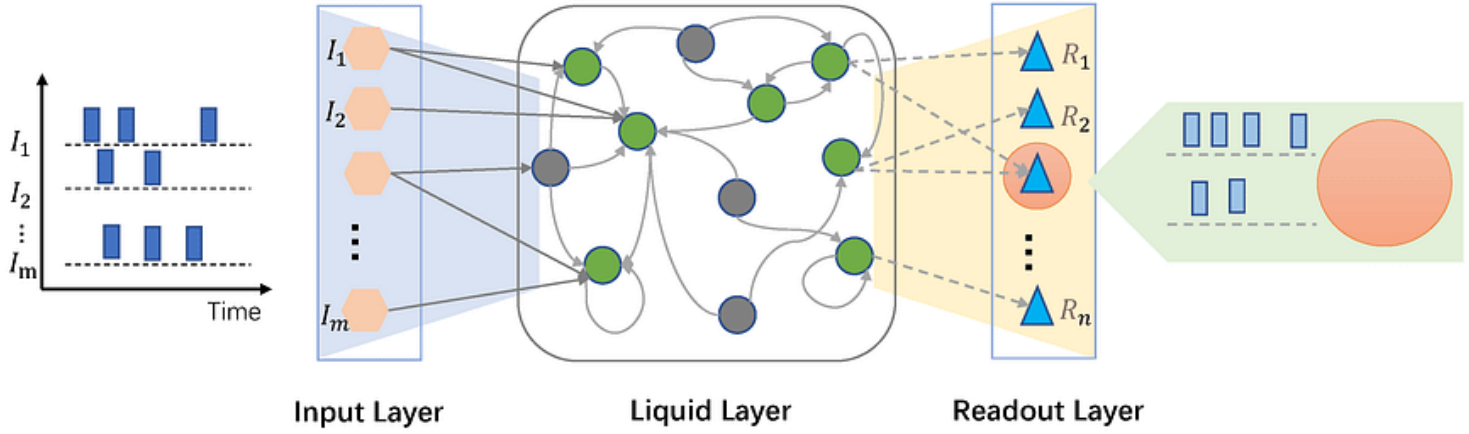


Hybrid Energy Forecasting and Trading Competition

☐ Modeling Strategy

- Liquid Neural Network

» Dynamic Architecture, Continual Learning을 통해, 시간 정보를 다루는 데 강력하며 시계열 예측, 로봇 제어, 의료 진단 등 실시간 반응이 중요한 분야에 적합한 신경망



» 풍력 발전에서의 LNN 도입 시 기대효과

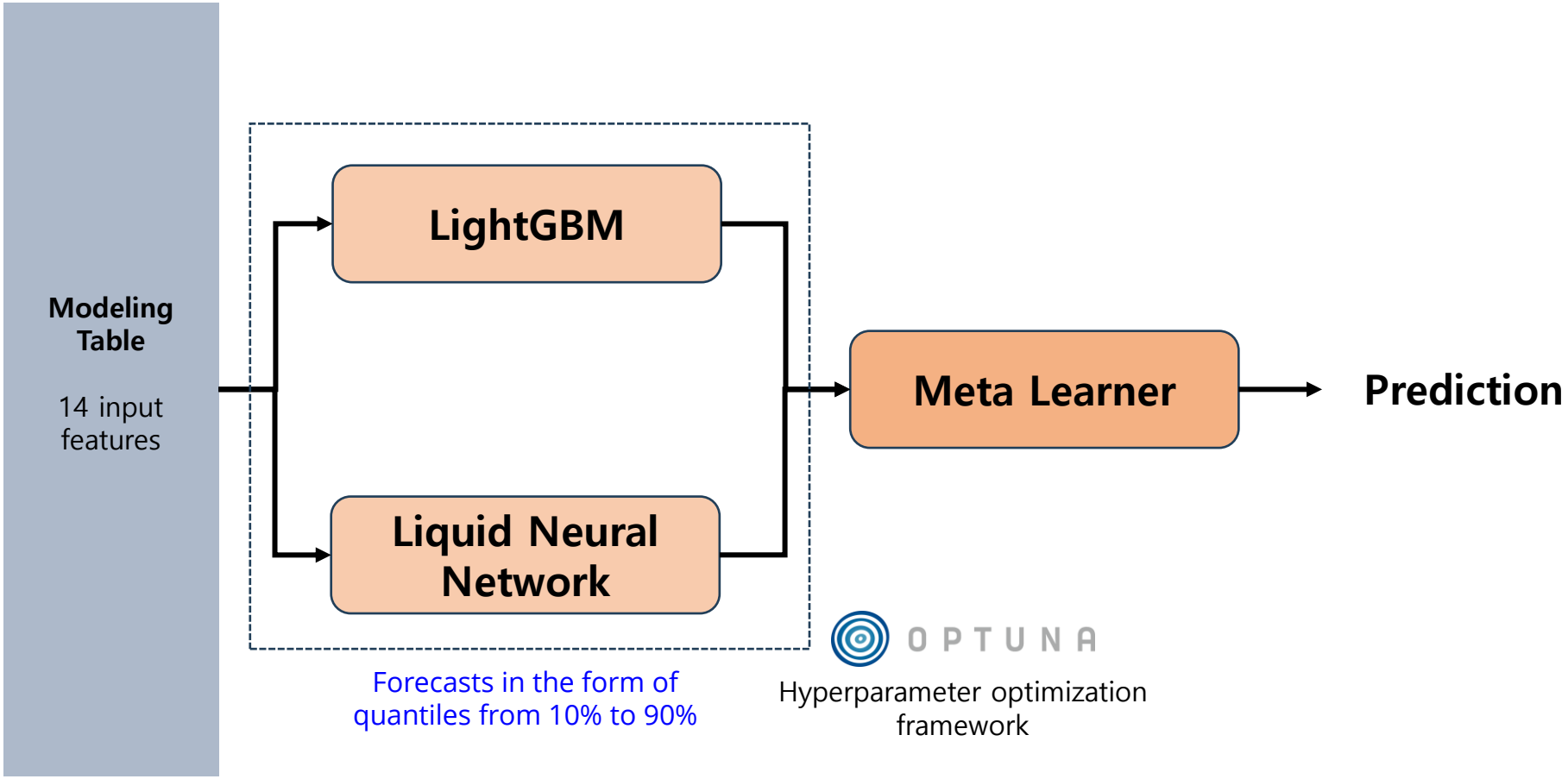
- 정확도 향상, 짧은 forecast horizon 에서 유리
- 돌풍으로 인한 출력 변동성 대응

- Reference : Liquid Neural Networks: Simple Implementation

Hybrid Energy Forecasting and Trading Competition

☐ Modeling Strategy

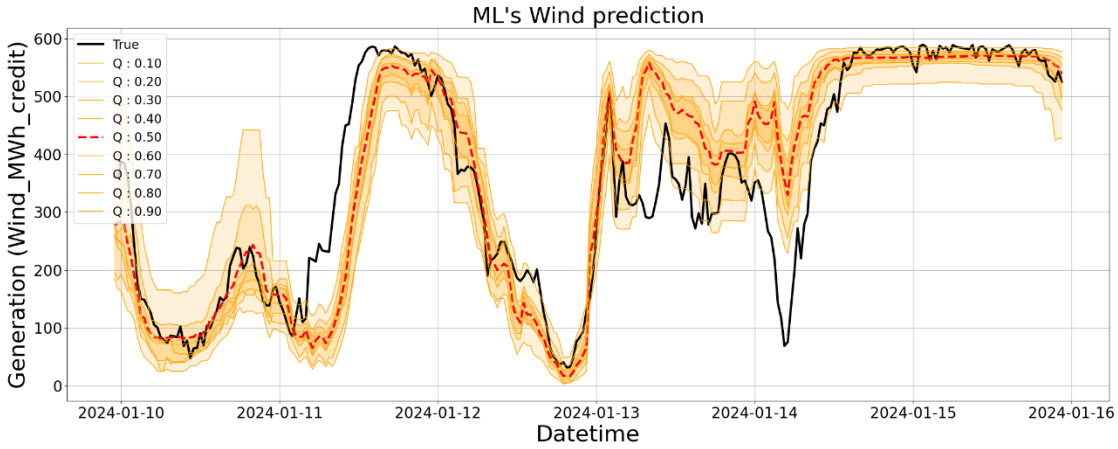
- Ensemble : Machine Learning + Deep Learning



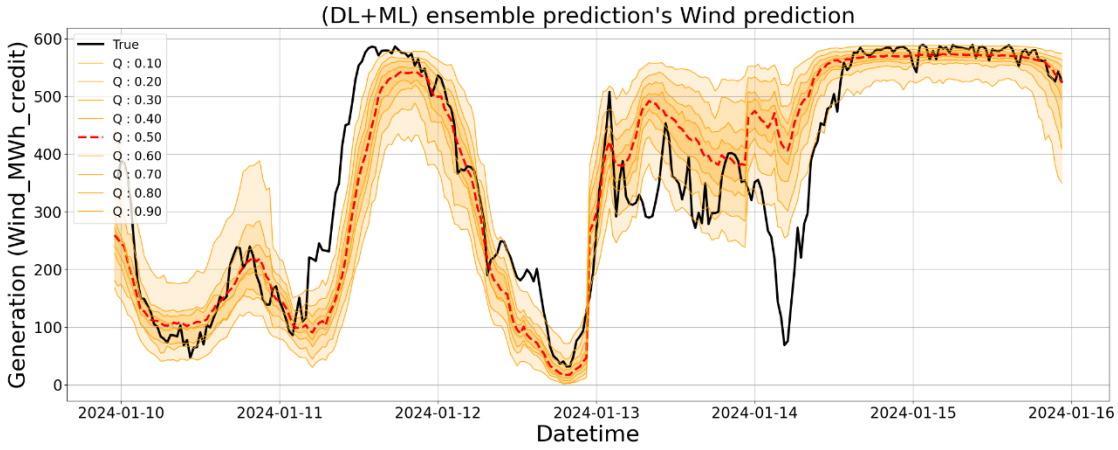
Hybrid Energy Forecasting and Trading Competition

☐ Modeling Strategy

- Ensemble : LightGBM + Liquid Neural Network




```
Day-2024-01-09 23:00 ~ 2024-01-10 22:30's Pinball Score (Wind) : 16.201122973509953
Day-2024-01-10 23:00 ~ 2024-01-11 22:30's Pinball Score (Wind) : 40.440263230759086
Day-2024-01-11 23:00 ~ 2024-01-12 22:30's Pinball Score (Wind) : 14.20489609039897
Day-2024-01-12 23:00 ~ 2024-01-13 22:30's Pinball Score (Wind) : 36.43402976297001
Day-2024-01-13 23:00 ~ 2024-01-14 22:30's Pinball Score (Wind) : 39.07469945274777
Day-2024-01-14 23:00 ~ 2024-01-15 22:30's Pinball Score (Wind) : 5.322552931530035
Mean pinball score : 25.27959407365264
```

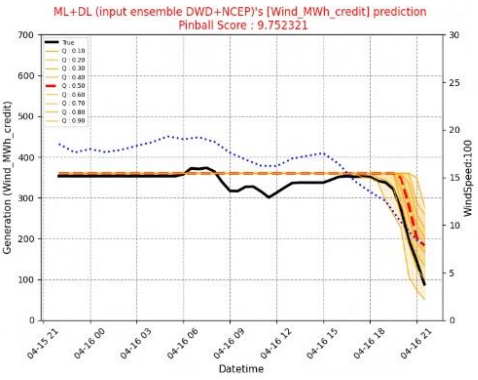


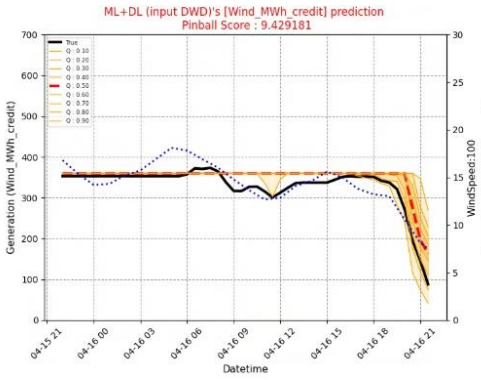

```
Day-2024-01-09 23:00 ~ 2024-01-10 22:30's Pinball Score (Wind) : 15.80251960706054
Day-2024-01-10 23:00 ~ 2024-01-11 22:30's Pinball Score (Wind) : 36.36726747699518
Day-2024-01-11 23:00 ~ 2024-01-12 22:30's Pinball Score (Wind) : 19.544088804959376
Day-2024-01-12 23:00 ~ 2024-01-13 22:30's Pinball Score (Wind) : 30.383578957727266
Day-2024-01-13 23:00 ~ 2024-01-14 22:30's Pinball Score (Wind) : 41.87256381248272
Day-2024-01-14 23:00 ~ 2024-01-15 22:30's Pinball Score (Wind) : 5.0815312923258595
Mean pinball score : 24.841924991925154
```

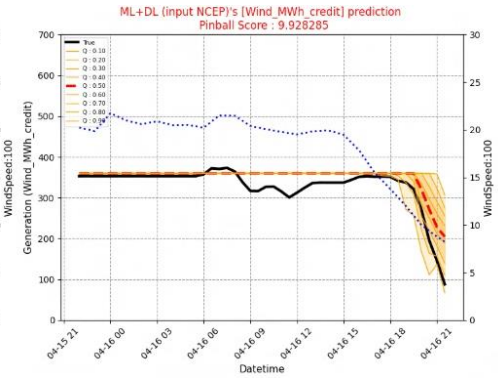
Hybrid Energy Forecasting and Trading Competition

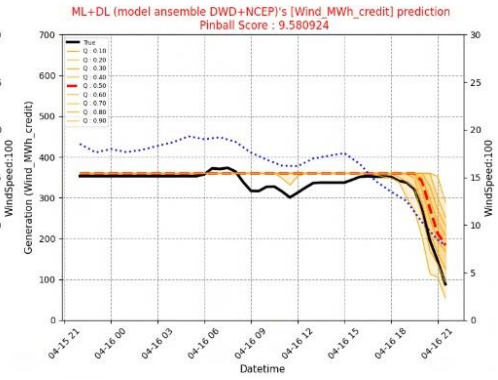
☐ Challenges & Lessons Learned

- NCEP, DWD 의 기상 예측 데이터의 변동성







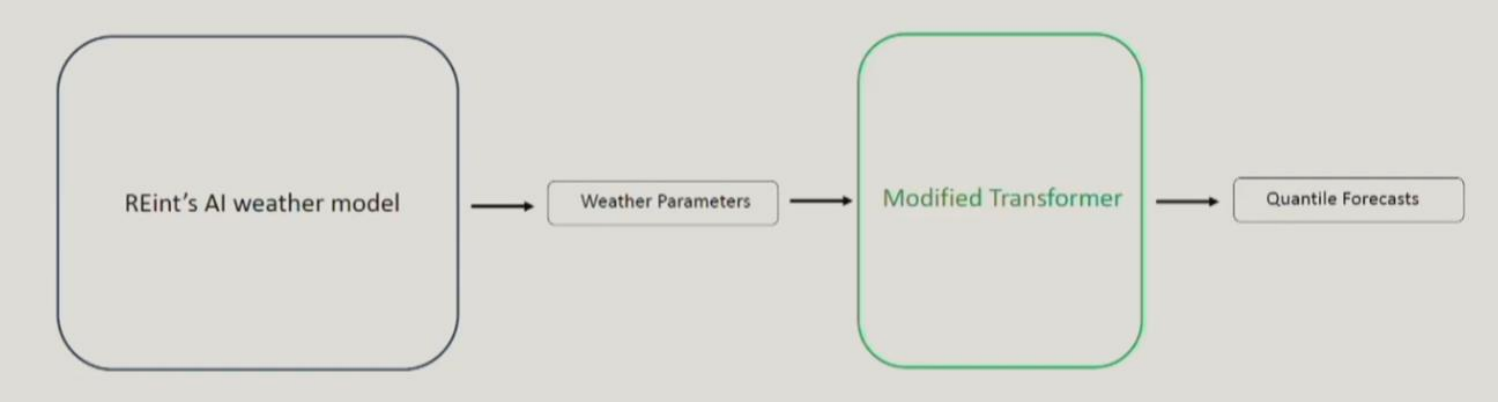


- curtailment issue
  - » 계통 제약, 안정성을 위해 의도적으로 출력을 제한 (출력 제한 빈도 ↑)
- summer-time
  - » 매년 3월 마지막 일요일 → 시계를 1시간 앞당김
  - » 매년 10월 마지막 일요일 → 시계를 1시간 되돌림
  - » 실측, 예측 모두 동일한 기준 시간대(UTC) 사용

Hybrid Energy Forecasting and Trading Competition

☐ ISF 2024 Practitioner Speaker

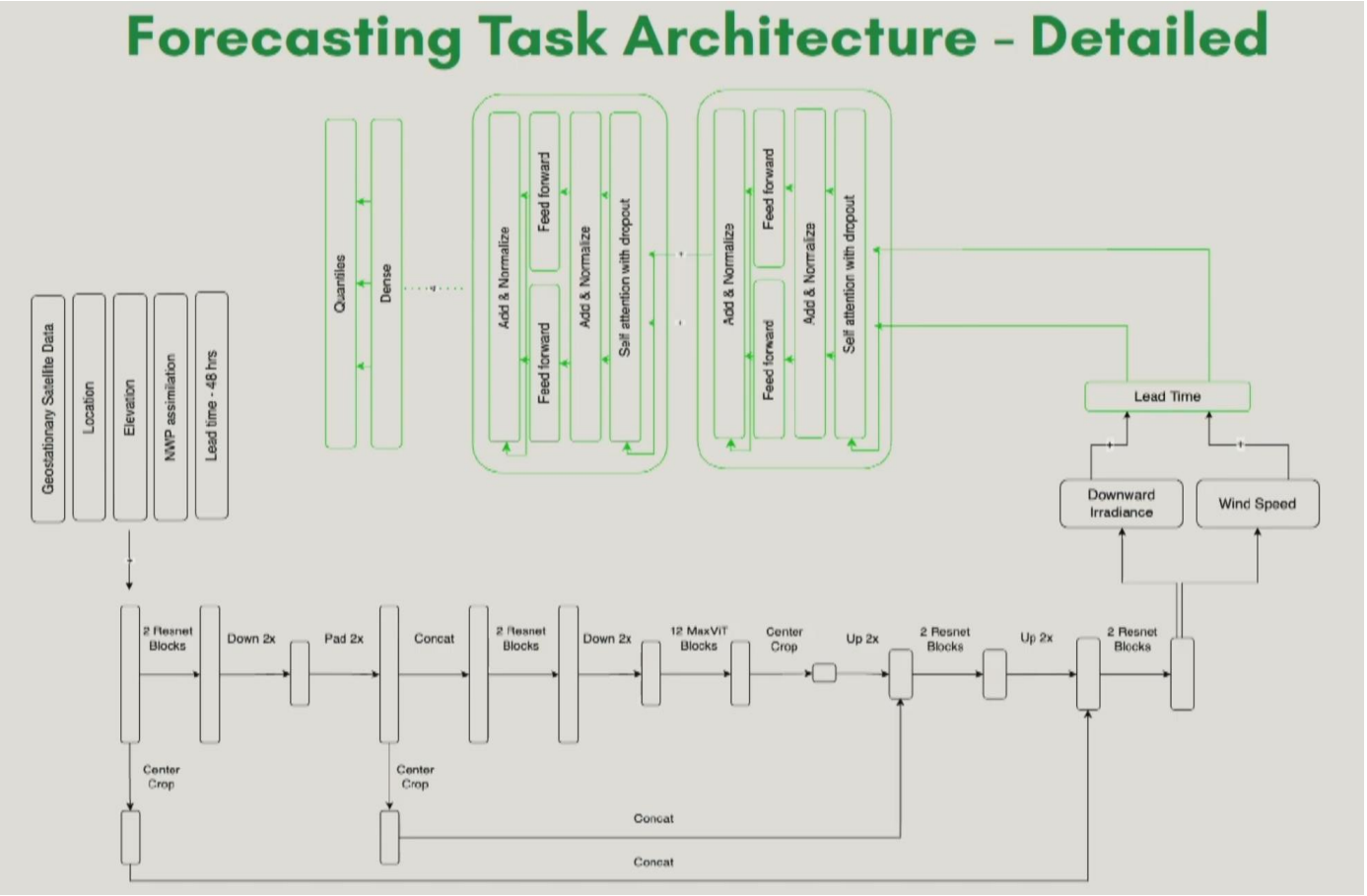
- UI BUD : Forecasting Rank (3)



Hybrid Energy Forecasting and Trading Competition

☐ ISF 2024 Practitioner Speaker

- UI BUD : Forecasting Rank (3)

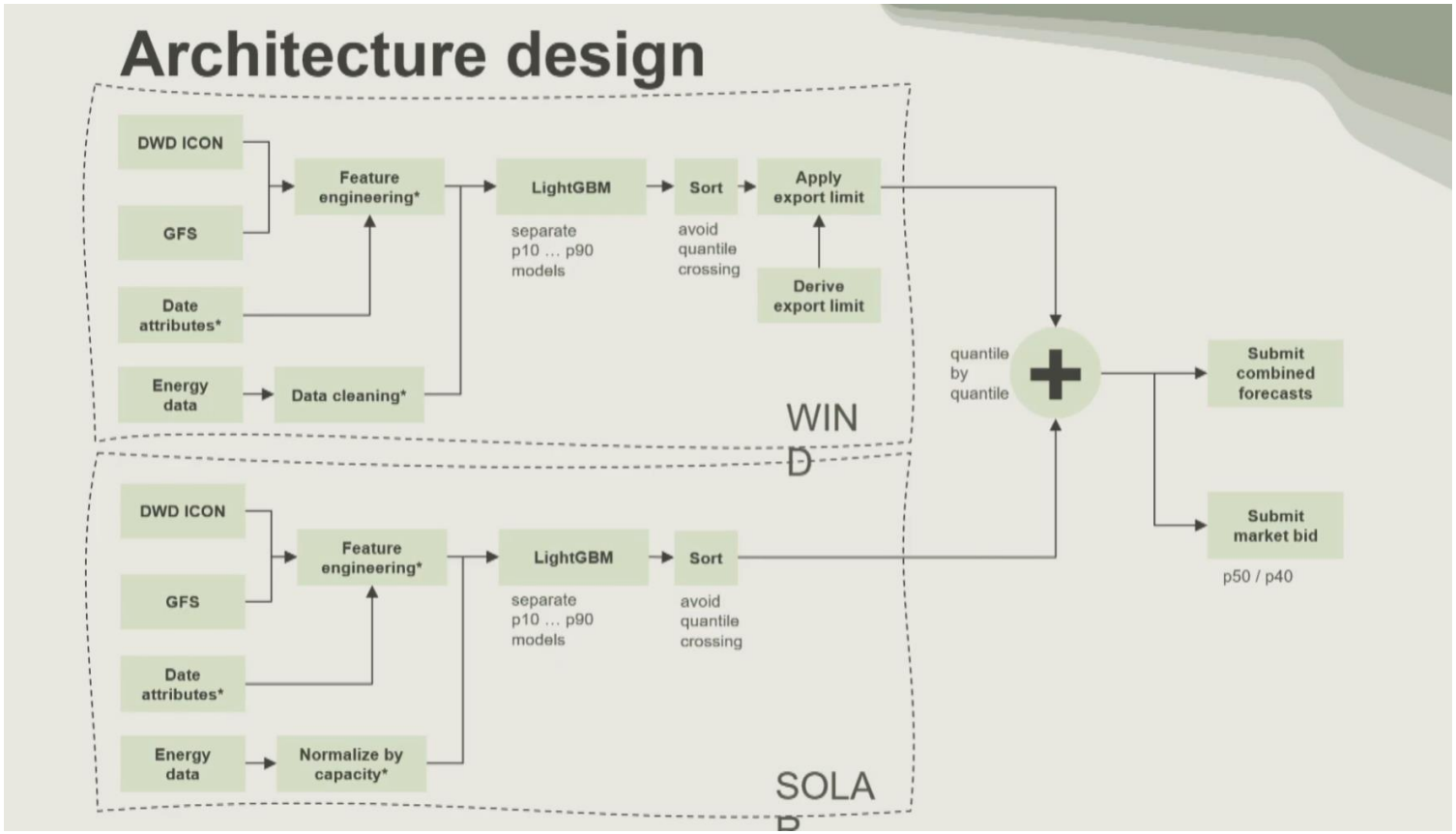


- Reference : Jethro Browell, ISF 2024 Practitioner Speaker

Hybrid Energy Forecasting and Trading Competition

☐ ISF 2024 Practitioner Speaker

- UI BUD : Forecasting Rank (2)

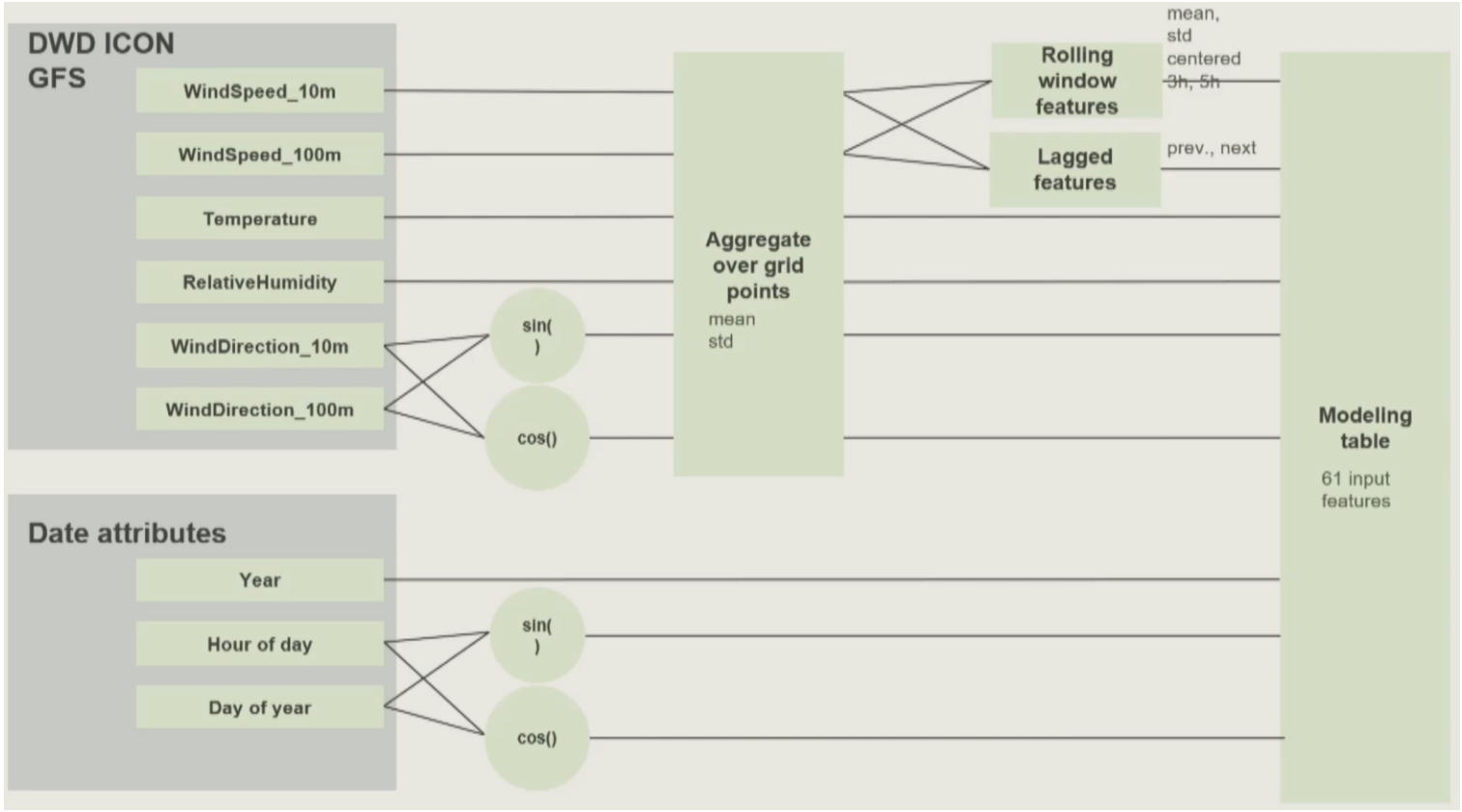


- Reference : Jethro Browell, ISF 2024 Practitioner Speaker

Hybrid Energy Forecasting and Trading Competition

☐ ISF 2024 Practitioner Speaker

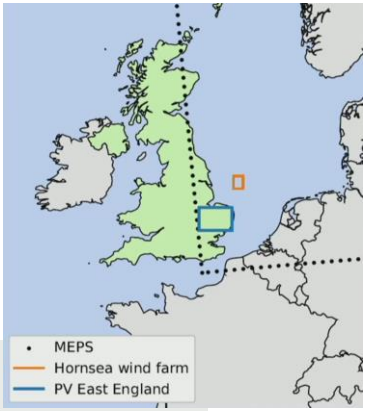
- UI BUD : Forecasting Rank (2)

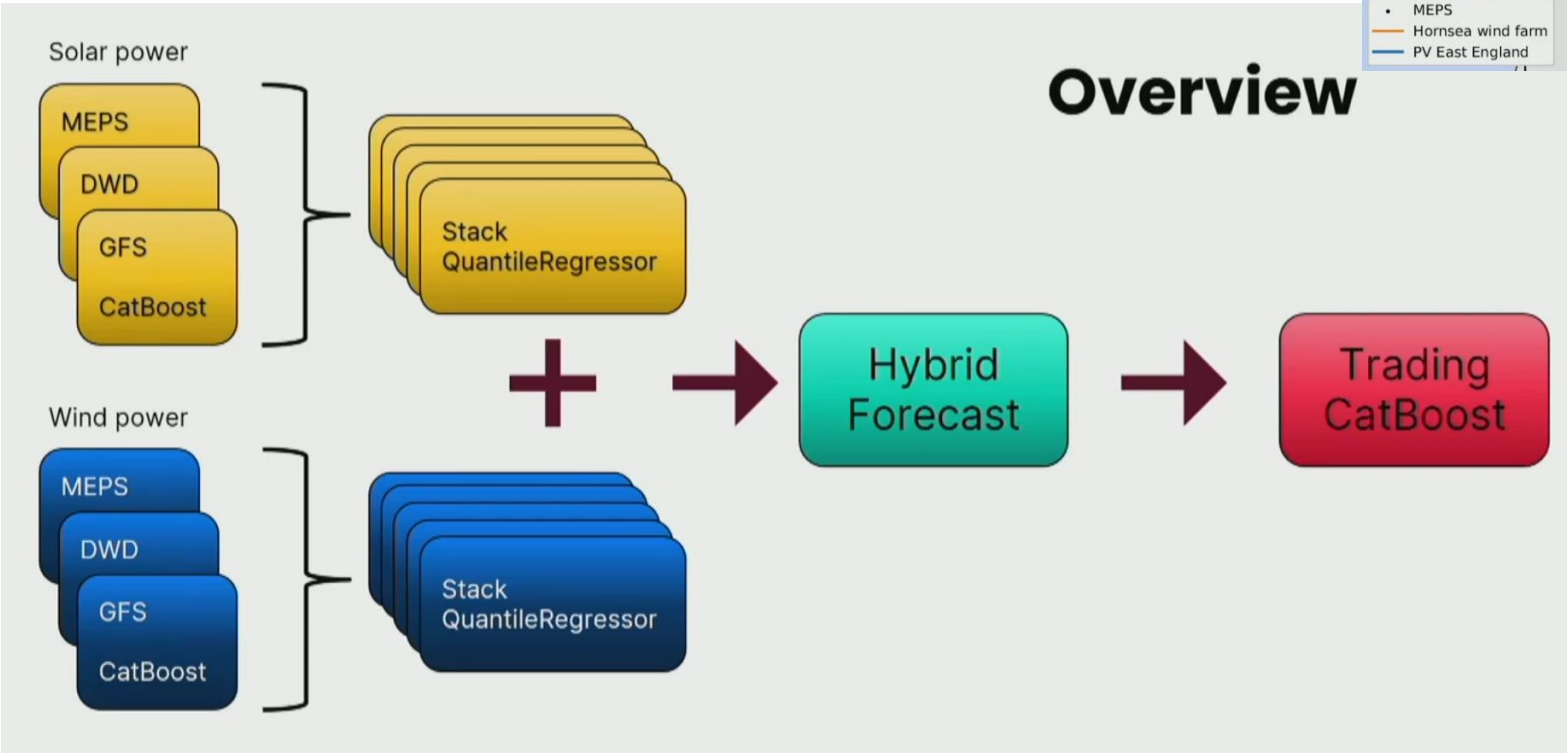


- Reference : Jethro Browell, ISF 2024 Practitioner Speaker

Hybrid Energy Forecasting and Trading Competition

- ISF 2024 Practitioner Speaker
  - UI BUD : Forecasting Rank (1)





- Reference : Jethro Browell, ISF 2024 Practitioner Speaker

Hybrid Energy Forecasting and Trading Competition

☐ ISF 2024 Practitioner Speaker

- UI BUD : Forecasting Rank (1)

Data – Wind power

Weather features

- Wind speed
- Wind direction
- Temperature
- Air pressure
- Relative humidity

Feature engineering

- (Weather features).diff()
- Wind speed lags [-2, -1, 0, 1, 2]
- sin(Wind direction)
- cos(Wind direction)

Datetime features

- Sin(hour), cos(hour),
- Sin(month), cos(month)
- Minute, year

Target

- Wind power

- Reference : Jethro Browell, ISF 2024 Practitioner Speaker

Networking
Next

Intelligence
Innovative

Communications
Creative

Energy
Envisioning

NICELAB

Networking for Intelligence Communications and Energy