

GENOA | ITALY | 11th.14th June 2019



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## Climate forecast enabled knowledge services

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# An Approach for the Solar Energy Assessment using Weather Medium-Range Forecasting

Isabel M. Moreno-Garcia, Rafael López-Luque,  
Marta Varo-Martínez, Luis M. Fernández-Ahumada,  
José C. Ramírez-Faz and F. Casares de la Torre





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An Approach for the  
Solar Energy Assessment  
using  
Weather Medium-Range  
Forecasting

Moreno-Garcia, Isabel M.

Introduction

Methodology

SEAP service

Planning tool workflow

Results

Data collection

Data processing &  
storage

Web application

Conclusion

Research Group Physics  
for Renewable Energies.  
University of Córdoba

# Outline



## ❖ Introduction: CLARA Project, services

## ❖ Methodology

- SEAP service
- Planning tool workflow

## ❖ Results

- Data collection
- Data processing & storage
- Web application

## ❖ Conclusions



CLARA GRANT AGREEMENT N° 730482



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# Introduction



## Climate forecast enabled knowledge services



<http://www.clara-project.eu/>

The aim of CLARA innovation action is to develop a set of **climate services** building upon the newly developed *Copernicus Climate Change Services (C3S)* near term forecasts and sectorial information systems (SIS) and sustain their marketability and value.



Atmosphere (CAMS)



Marine (CMEMS)



Land (CLMS)



Climate (C3S)



Emergency (EMS)



Security



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# Introduction



## CLARA Services

### Disaster risk reduction



Economic risk assessment of flood risk

### Water management



Water resource management model



Water supply assessment tool



Reservoir operation assessment tool

### Agriculture



Water requirements for irrigation



Soil water budget usable predictor

### Renewable energy



Smart climate hydropower tool



Smart hydropower assessment tool



Gwh prediction



Solar energy assessment and planning tool

### Air quality and health



AirCloud



Air quality and climate change

### Horizontal services



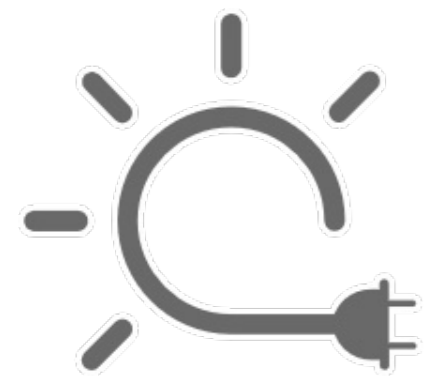
Post processed decadal predictions



Clime



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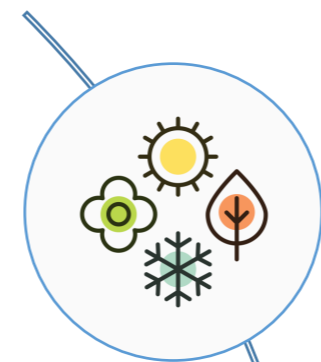
# SEAP

Solar Energy Assessment and Planning Tool



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## Aims of the service



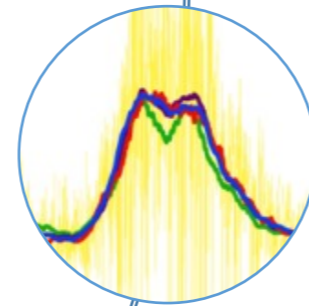
### Seasonal forecast

Operational assessment of solar energy on different time scales



### Valuable information

Energy production for the coming months



### Characterization of variability

Management of the generation



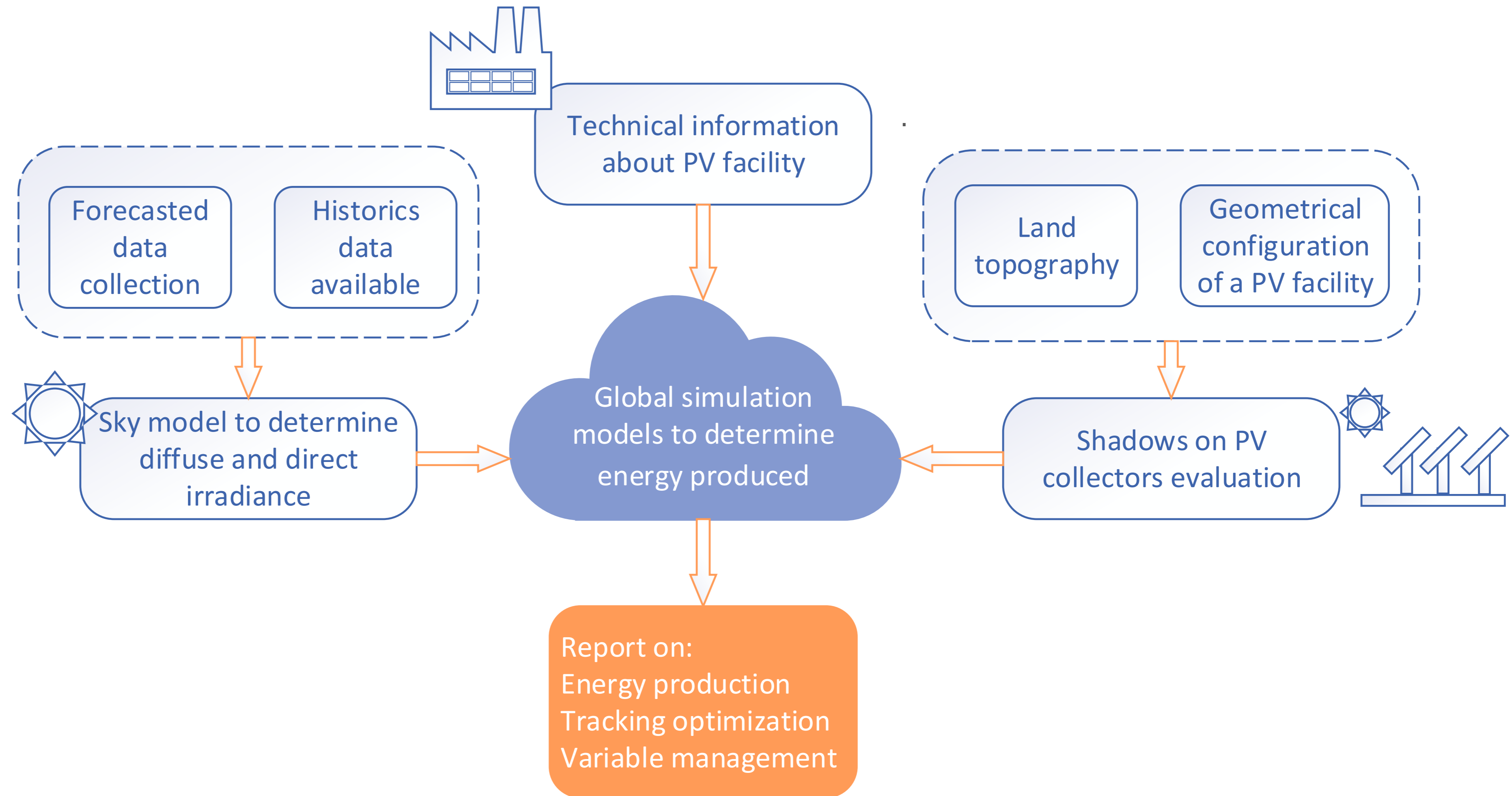
### Economic and environmental benefits

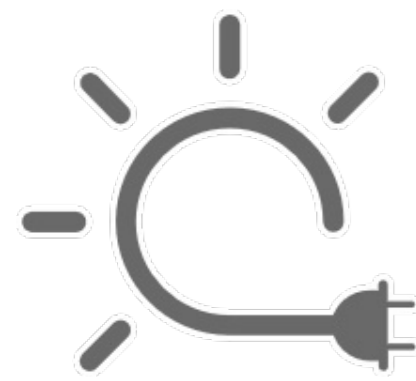
Robust decision-making by planning offices





# SEAP service





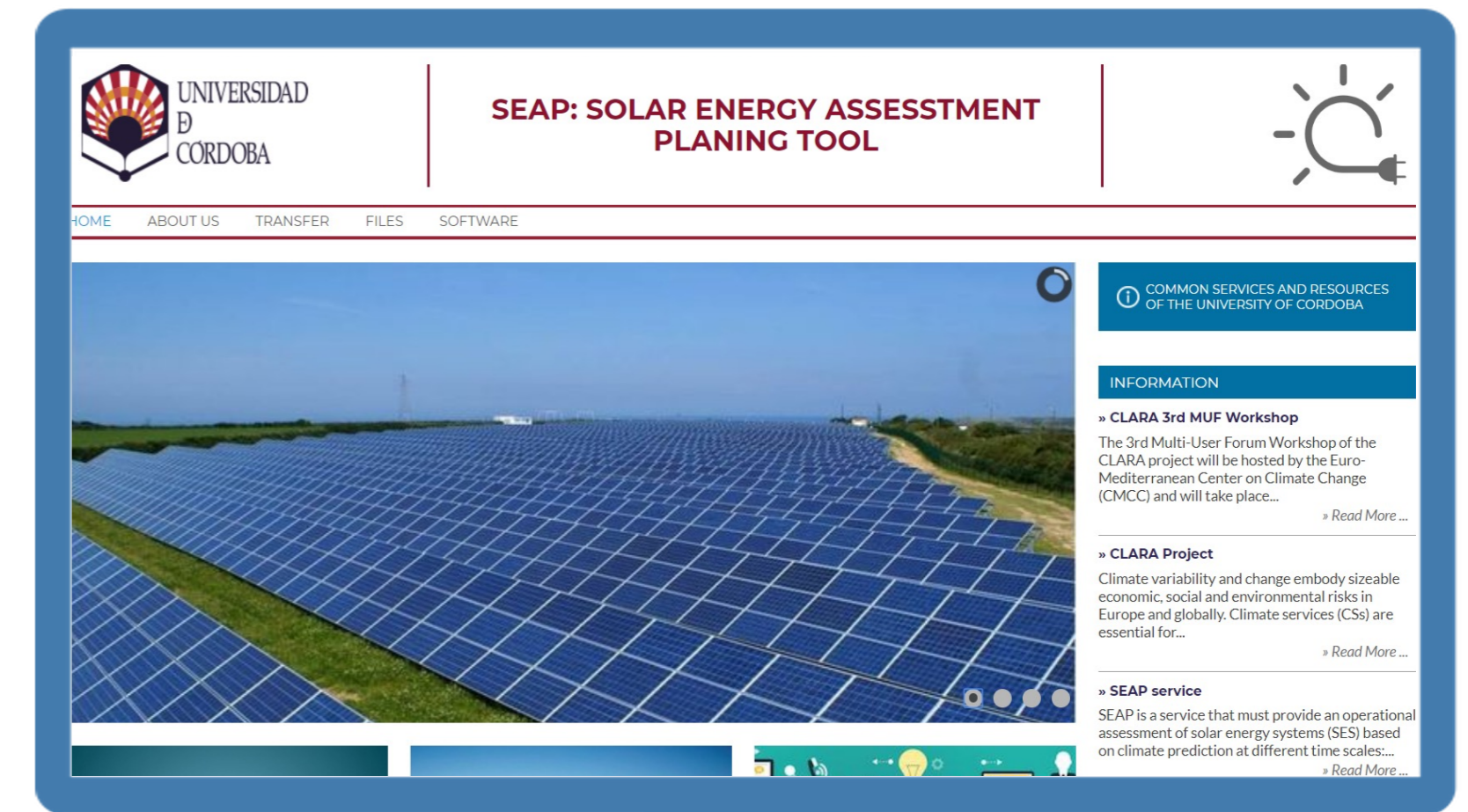
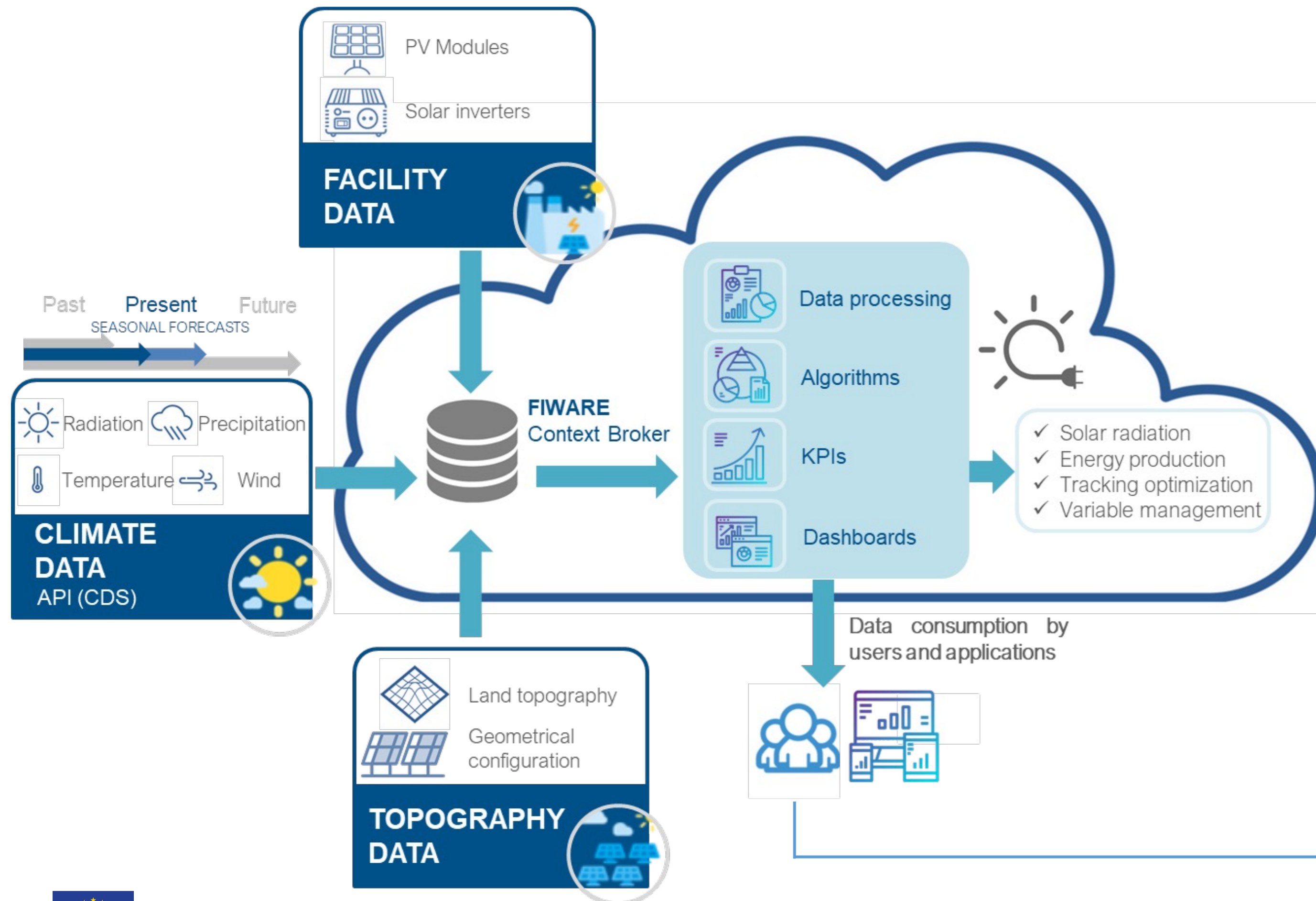
# SEAP

Solar Energy Assessment and Planning Tool



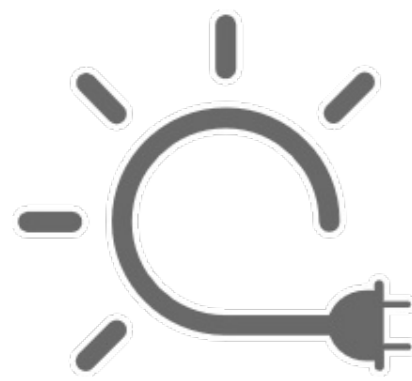
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## Workflow and system structure



Web tool





# SEAP

## Solar Energy Assessment and Planning Tool

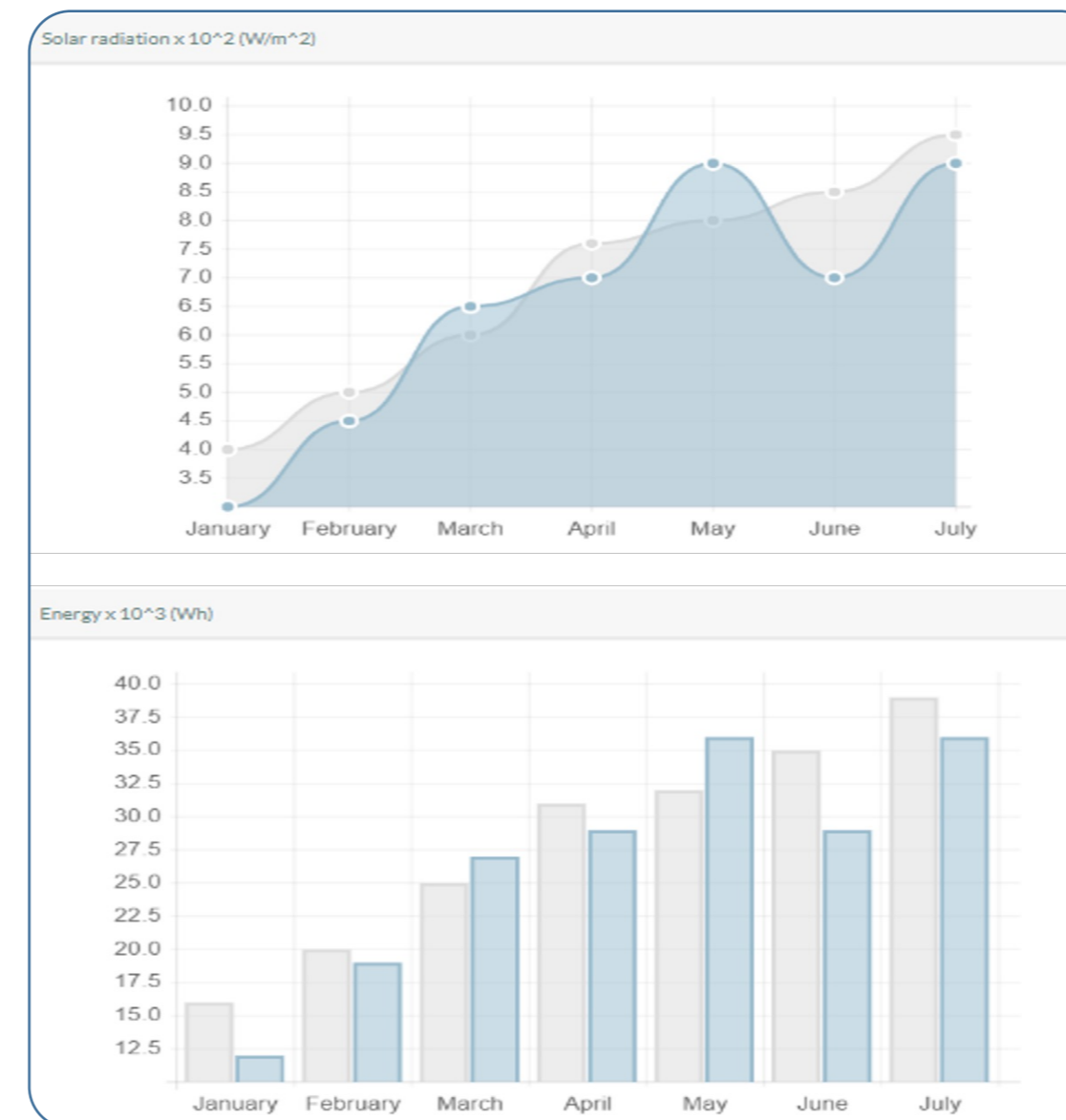


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The screenshot shows the SEAP web application interface. At the top, there is a navigation bar with the Universidad de Córdoba logo and a search bar. Below the navigation bar, there are several panels:

- Map Panel:** Shows a map of Posadas, Argentina, with a location pin for "Parque Posadas".
- INSTALLATION Panel:**
  - Name: Central La Sierrezuela
  - Address: Crta. Villaviciosa Km.45, Posadas (Posadas), 14730 (Córdoba)
  - Geolocation (lat, long): 37.8804, -4.7858
  - Number of Generators: 2
  - Generator Power: 1500.00
  - Generator width: 10.00
  - Generator height: 75.00
  - Distance between generators: 1.00
  - Generators Eviction: 0
  - Get date: From: 01-01-2018, To: 31-07-2018
- MODULE Panel:**
  - Model: TRINA TSM-220-PC05
  - Open circuit voltage (V): 37.00
  - Short circuit current (A): 8.00
  - Maximum power point (W): 220.00
  - Maximum power voltage (V): 29.00
  - Maximum power current (A): 8.00
  - Absorption coefficient of the cells: 1.00000
  - Power temperature coefficient of PV modules: 1.00000
  - Irradiance coefficient of PV modules: 1.00000
  - Module width: 1.00
  - Module height: 1.00
- ORIENTATION Panel:**
  - Horizontal Norte-Sur
  - Azimuth: 1.00
  - Elevation: 1.00
  - Inclination: 1.00
- INVERTER Panel:**
  - Model: Vestron
  - Maximum Power of the Inverter (W): 25000.00
  - Nominal Power of the Inverter (W): 28000.00
  - Consumption (W): 40

## Outputs



## Graphs

```

{
  "name": "Central La Sierrezuela",
  "address": "Crta. Villaviciosa Km.45",
  "cpostal": "14730",
  "locality": "Posadas",
  "province": "Posadas",
  "country": "C\u00f3rdoba",
  "geolocation": "37.8804, -4.7858",
  "ngenerator": "2",
  "powerxgenerator": "1500.00",
  "twidth": "10.00",
  "theight": "75.00",
  "tdistance": "1.00",
  "sombreo": "{}",
  "status": 1,
  "orientation": {
    "name": "Horizontal Norte-Sur",
    "azimut": "1.00",
    "elevation": "1.00",
    "inclination": "1.00"
  },
  "modules": {
    "name": "TRINA TSM-220-PC05",
    "opencircuitvoltage": "37.00",
    "shortcircuitcurrent": "8.00",
    "maximumpowerpointtrack": "220.00"
  }
}

```

## JSON







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# Pilot plant



**Magtel**  
Operaciones



- ❖ 6.1 MW
- ❖ 8 transformer center of 400 kW
- ❖ Two-axis solar trackers



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# Data collection



## Python script to retrieve data from Copernicus Climate Change Service

```

import cdsapi

c = cdsapi.Client()

c.retrieve(
    'seasonal-original-single-levels',
    {
        'originating_centre': 'cmcc',
        'system': '3',
        'area': '39/-5/37/-3', # North, West, South, East. Specify as North/West/South/East in Geographi
        'grid': '1.0/1.0',
        'variable': [
            '10m_u_component_of_wind', '10m_v_component_of_wind', '2m_temperature',
            'surface_solar_radiation_downwards', 'total_precipitation'
        ],
        'year': '2018',
        'month': '01',
        'day': '01',
        'format': 'grib',
        'leadtime_hour': [ ]
    },
    'data.grib')

```

```

a501 0000 120b 0100 0001 0600 0000 0000
1562 0000 0000 0000 0000 0000 0000 0000
0f1f 0904 c430 3030 3100 0000 0300 0100
0000 0000 0000 2000 ff00 0002 0002 0096
6480 1194 8000 927c 800d ac03 e803 e800
0000 0000 0000 1808 8017 c030 b400 1800
0000 4eda 0084 e560 c5a7 e000 3737 3737
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
4752 4942 0000 8001 0000 3c80 5080 ff80
a601 0000 120b 0100 0001 0600 0000 0000
1562 0000 0000 0000 0000 0000 0000 0000
0f1f 0904 c430 3030 3100 0000 0300 0100
0000 0000 0000 2000 ff00 0002 0002 0096
6480 1194 8000 927c 800d ac03 e803 e800
0000 0000 0000 1808 8018 412c 1390 18ba
3100 0264 c061 1bc0 0000 0000 3737 3737
0000 0000 0000 0000 0000 0000 0000 0000

```





# Data collection



## Data standardisation



```

20181101, 6, 10u, 1.92
20181101, 6, 10v, 4.20
20181101, 6, 2t, 283.81
-----
20181101, 12, 10u, 3.5
20181101, 12, 10v, 3.9
20181101, 12, 2t, 285.7
-----
20181101, 18, 10u, 3.5
20181101, 18, 10v, 3.9
20181101, 18, 2t, 285.7
-----
20181101, 24, 10u, 3.5
20181101, 24, 10v, 3.9
20181101, 24, 2t, 285.7
20181101, 24, ssrd, 285.7
20181101, 24, tp, 285.7
-----
20181101, 30, 10u, 1.92
20181101, 30, 10v, 4.20
20181101, 30, 2t, 283.81
  
```

```

cliente-0000, 2018-11-01
06:00:00, 10u=1.92, 10v=4.20,
2t=283.81
-----
cliente-0000, 2018-11-01
12:00:00, 10u=3.5, 10v=3.9,
2t=285.7
-----
cliente-0000, 2018-11-01
18:00:00, 10u=3.5, 10v=3.9,
2t=285.7
-----
cliente-0000, 2018-11-02
00:00:00, 10u=3.5, 10v=3.9,
2t=285.7, ssrd=285.7, tp=285.7
-----
cliente-0000, 2018-11-02
06:00:00, 10u=1.92, 10v=4.20,
2t=283.81
  
```

```

{
  "devices": [
    {
      "device_id":
      "cliente:simio:0000",
      "entity_name":
      "cliente:simio:0000",
      "entity_type": "Simio",
      "timezone": "Europe/Madrid",
      "attributes": [
        {
          "object_id": "c10u",
          "name": "c10u",
          "type": "Number"
        },
        {
          "object_id": "c10v",
          "name": "c10v",
          "type": "Number"
        }
      ]
    }
  ]
}
  
```





# Data collection



## Data facility introduced by users

The screenshot shows the SEAP Solar Energy Assessment and Planning Tool interface. The main content area is titled 'TYPE OF FACILITY' and features three tabs: 'Static generators', 'Single-Axis generators', and 'Two-axis generators'. The 'Two-axis generators' tab is selected. Below the tabs, there is a 'Configuration parameters' section with the following fields:

- Number of generators: 30
- Power per generator (Watts): 112200
- Width (meters): 5,992
- Height (meters): 8,25
- Distance between meters (degrees): 20

A 'Submit' button is located at the bottom of the configuration section. To the right of the configuration fields, there is a diagram illustrating the two-axis rotation of a solar panel. The diagram shows a rectangular panel tilted at an angle, with two dashed lines representing the axes of rotation. The top axis is labeled 'Axis of rotation' and has a curved arrow indicating rotation. The bottom axis is also labeled 'Axis of rotation' and has a curved arrow. The cardinal directions W (West), N (North), S (South), and E (East) are marked around the panel.





# Data processing & storage



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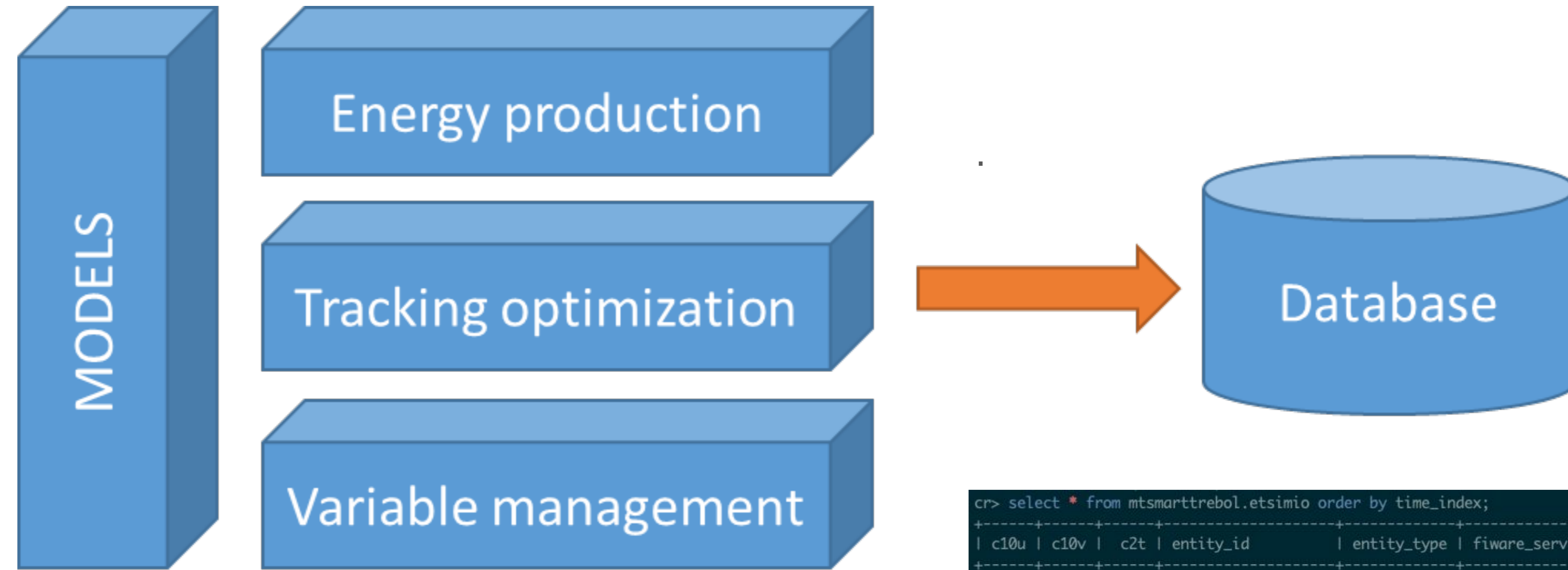
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```

def fraccionradiacion(Latitud, dia_jul, vhora, GLOBALMEDIDA):
    #Rem "Esta subrutina permite la descomposici n de la radiaci n diaria"
    #Rem "medida en un lugar(J) en sus componentes directa y difusa(J), as  como"
    #Rem "en los valores instant neos (W/m2) de directa y difusa"
    #Rem "M x90) TODO COLLARES-PEREIRA, Solar Energy, Vol 22,n 2,1979"
    Pi = 3.141592
    lista= GEOSOLTIERRA(latitud, dia_jul, vhora)
    RADTEO=lista[2]
    KH = GLOBALMEDIDA / RADTEO
    if KH <= 0.17:
        difusaestimada = 0.99 * GLOBALMEDIDA
    if (KH < 0.8) and (KH > 0.17):
        difusaestimada = (1.188 - 2.272 * KH + 9.473 * KH ** 2 - 21.856 * KH ** 3 + 14.648 * KH ** 4)
    if (KH < 1) and (KH >= 0.8):
        difusaestimada = 0.18 * GLOBALMEDIDA
    if (KH >= 1):
        difusaestimada = 0.18 * GLOBALMEDIDA
        print ("Errorrrr")
    directaestimada = GLOBALMEDIDA - difusaestimada
    durdia=lista[1]
    ws = Pi / 24 * durdia
    WH = vhora / 24 * 2 * Pi
    difusainst = Pi / 24 * (math.cos(WH) - math.cos(ws)) / (math.sin(ws) - ws * math.cos(ws)) * difusa
    aa = 0.409 + 0.5016 * math.sin(ws - 1.047)
    bb = 0.6609 - 0.4767 * math.sin(ws - 1.047)
    globalinst = (aa + bb * math.cos(vhora * 2 * Pi / 24)) * Pi / 24 * (math.cos(vhora / 24 * 2 * Pi)
    directainst = globalinst - difusainst
    return directaestimada, difusaestimada, directainst, difusainst
  
```

```

cr> select * from mtsmarttrebol.etsimio order by time_index;
+-----+-----+-----+-----+-----+-----+-----+-----+
| c10u | c10v | c2t | entity_id | entity_type | fiware_servicepath | ssrd | time_index | tp |
+-----+-----+-----+-----+-----+-----+-----+-----+
| 2.2 | 3.3 | 4.4 | cliente:simio:0000 | Simio | /rabanales | 5.5 | 1555945273000 | 6.6 |
| 12.2 | 13.3 | 14.4 | cliente:simio:0000 | Simio | /rabanales | 15.5 | 1555945539000 | 16.6 |
| 12.2 | 13.3 | 14.4 | cliente:simio:0000 | Simio | /rabanales | 15.5 | 1555946122000 | 16.6 |
+-----+-----+-----+-----+-----+-----+-----+-----+
SELECT 3 rows in set (0.041 sec)
  
```





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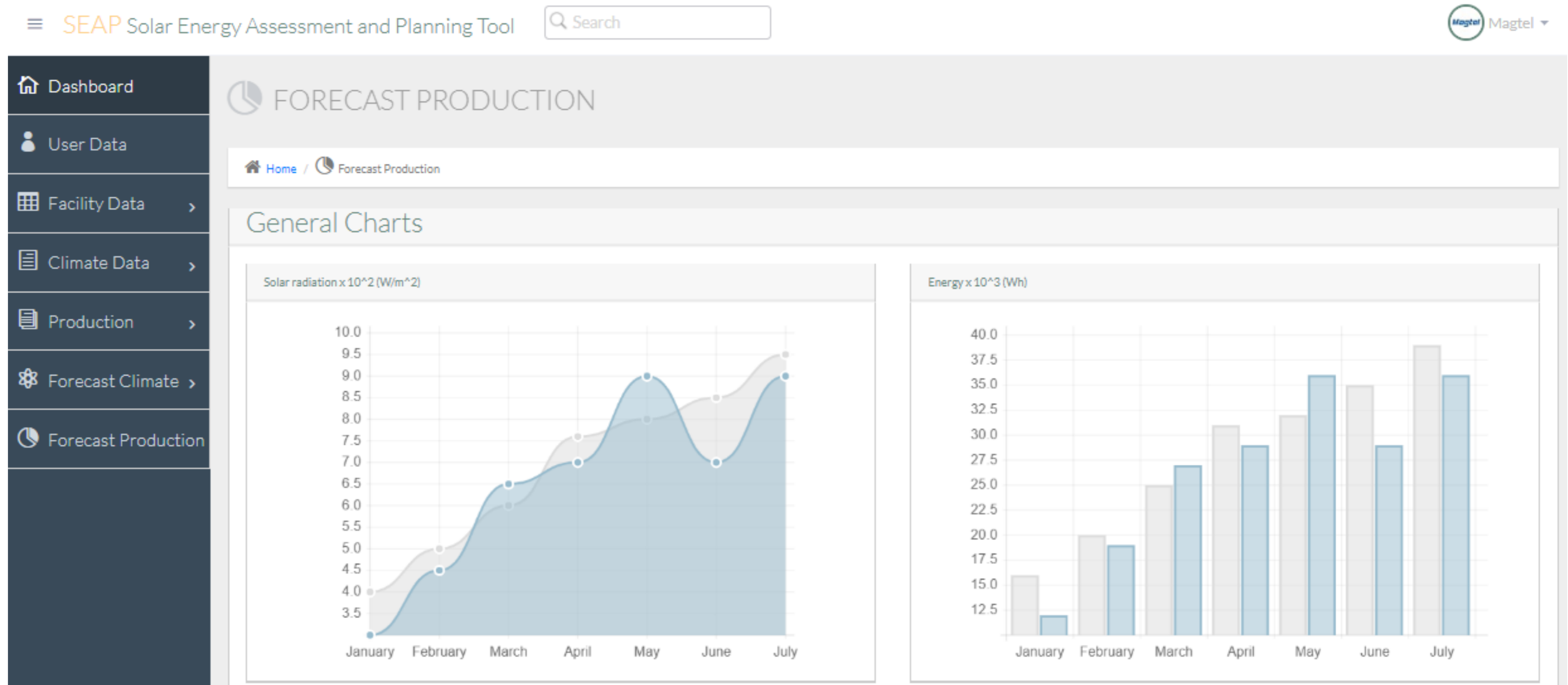
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# Web application



## On-line monitoring application for SEAP service



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# Conclusion



- ❖ The SEAP service is enabled to give a global simulation to determine energy produced, providing forecasts from short-term to long-term to climate change conditions.
- ❖ This service offers alternatives for PV plants the user can act on, either managing the priority of consumption in autonomous installations or determining the most appropriate tracking for each day.



**Thank you for your attention.**

isabel.moreno@uco.es

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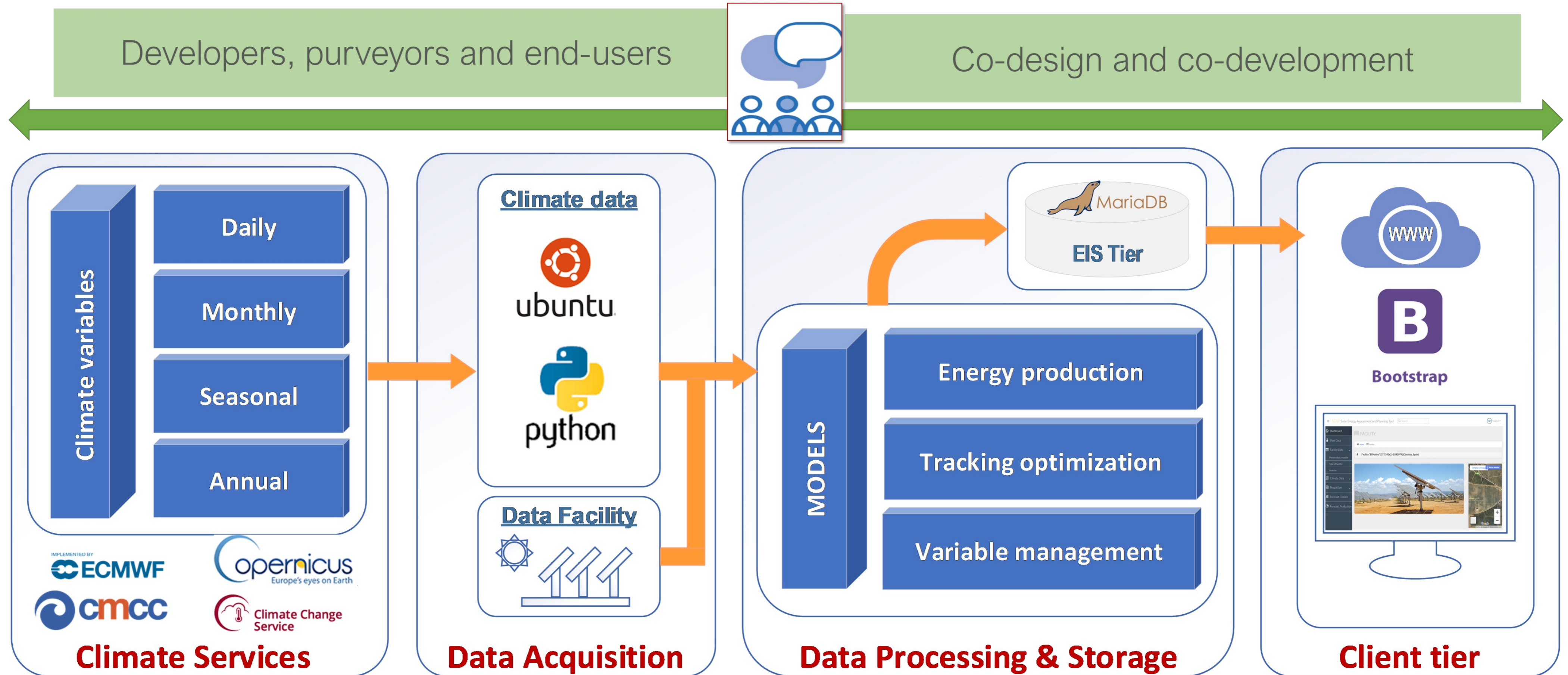
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# Planning tool workflow

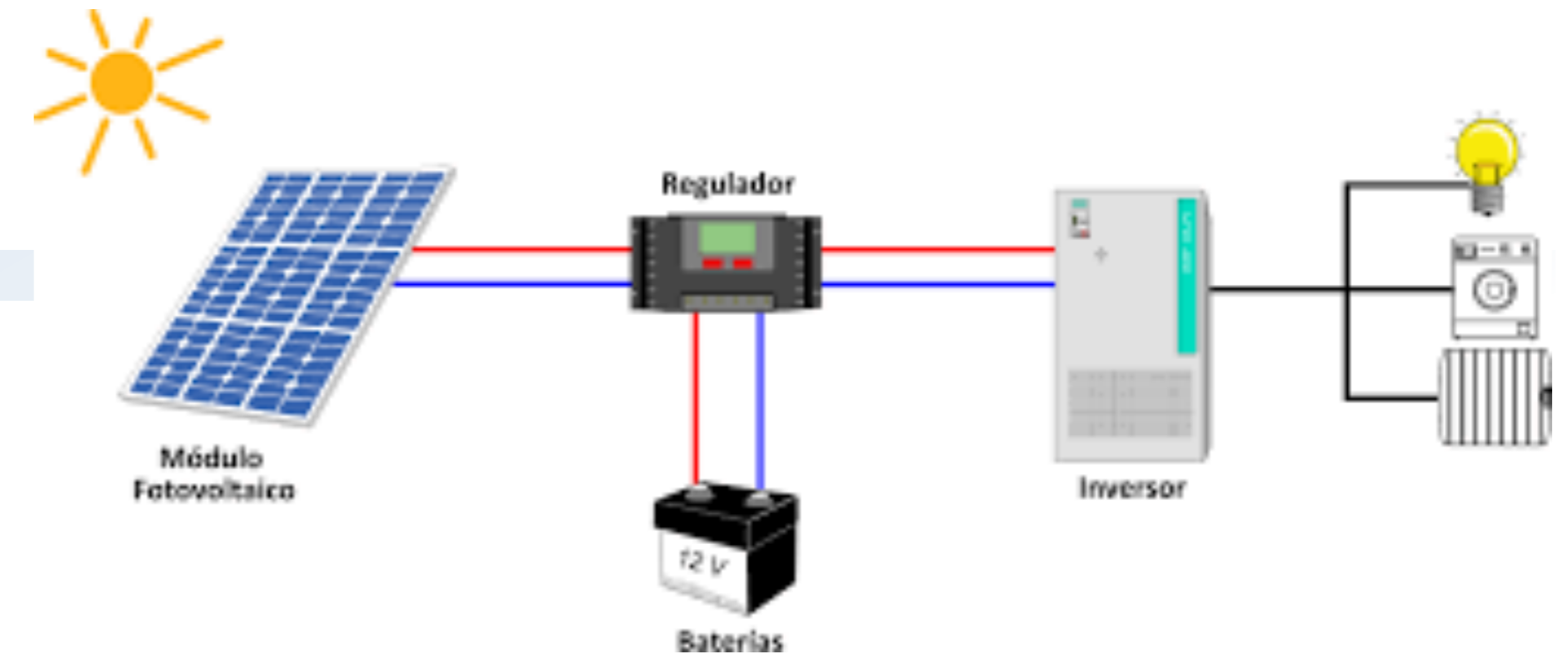


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# Historial investigador TEP-215

Grupo TEP 215. Física para las Energías Renovables



Tesis Doctoral –Caracterización del balance energético en instalaciones fotovoltaicas autónomas en la España peninsular. 1993

## Aproximación a la caracterización matemática del balance energético diario:

### Ecuaciones consideradas para el balance energético:

$$B'_i = B_{i-1} + \underbrace{\eta_G A_G H_{g\beta i}} - L_i$$

$$B'_i = B_{i-1} + E_i$$

$$B_i = \begin{cases} C_U & \text{si } B'_i \geq C_U \\ B'_i & \text{si } 0 < B'_i < C_U \\ 0 & \text{si } B'_i \leq 0 \end{cases}$$

$$m(y_i / K_S, E, \delta, \eta_B) = a_1(E, \delta \eta_B) \left[ \frac{K_S}{\delta} \right]^{\phi_1(E, \delta \eta_B)} + c_1(E, \delta \eta_B)$$

$$s(y_i / K_S, E, \delta, \eta_B) = a_2(E, \delta \eta_B) \left[ \frac{K_S}{\delta} \right]^{\phi_2(E, \delta \eta_B)} + c_2(E, \delta \eta_B)$$

**Caracterización estocástica:** Se considera  $B'_i$  suma de dos variables estocásticas con interdependencia temporal



# Historial investigador

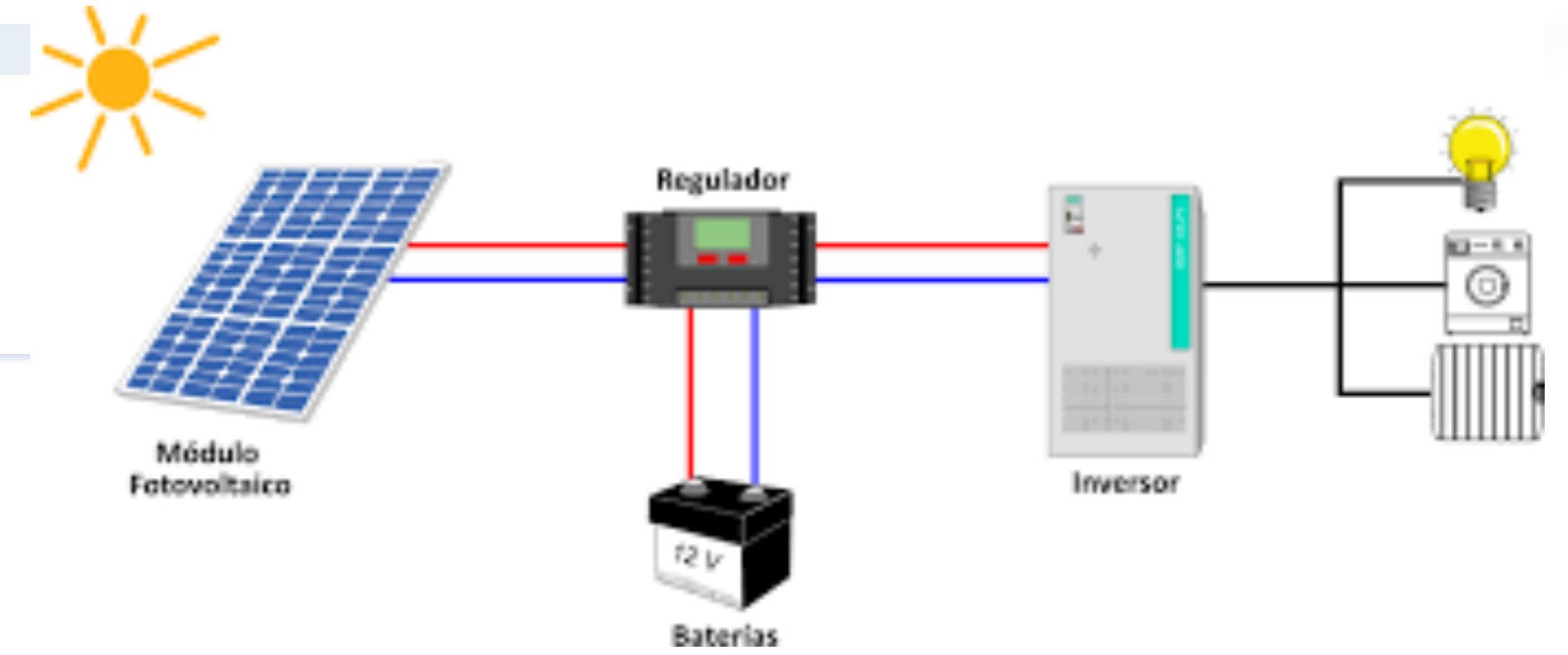
1. Historial académico

2. Actividad investigadora

3. Actividad docente

4. Experiencia en gestión

## Dimensionado óptimo y caracterización de plantas solares fotovoltaicas



Tesis doctoral Rosario Posadillo Sánchez de Puerta, *Estudio del Abastecimiento de Demandas Energéticas Variables mediante Energía Solar Fotovoltaica*. 2003

## Historial investigador TEP-215

$$LLP = \frac{\int_{\text{time}} \text{Energy deficit}}{\int_{\text{time}} \text{Energy demand}}$$

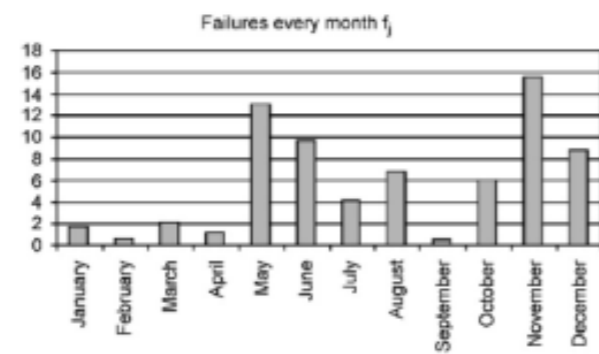


Fig. 3. Monthly distribution of expected failures for systems with twenty 80Wp modules and 30 accumulator cells.

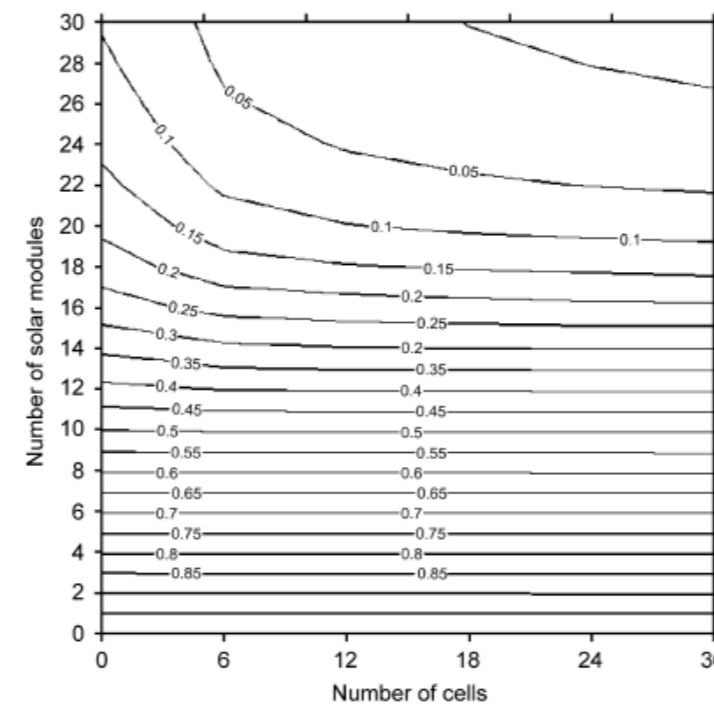
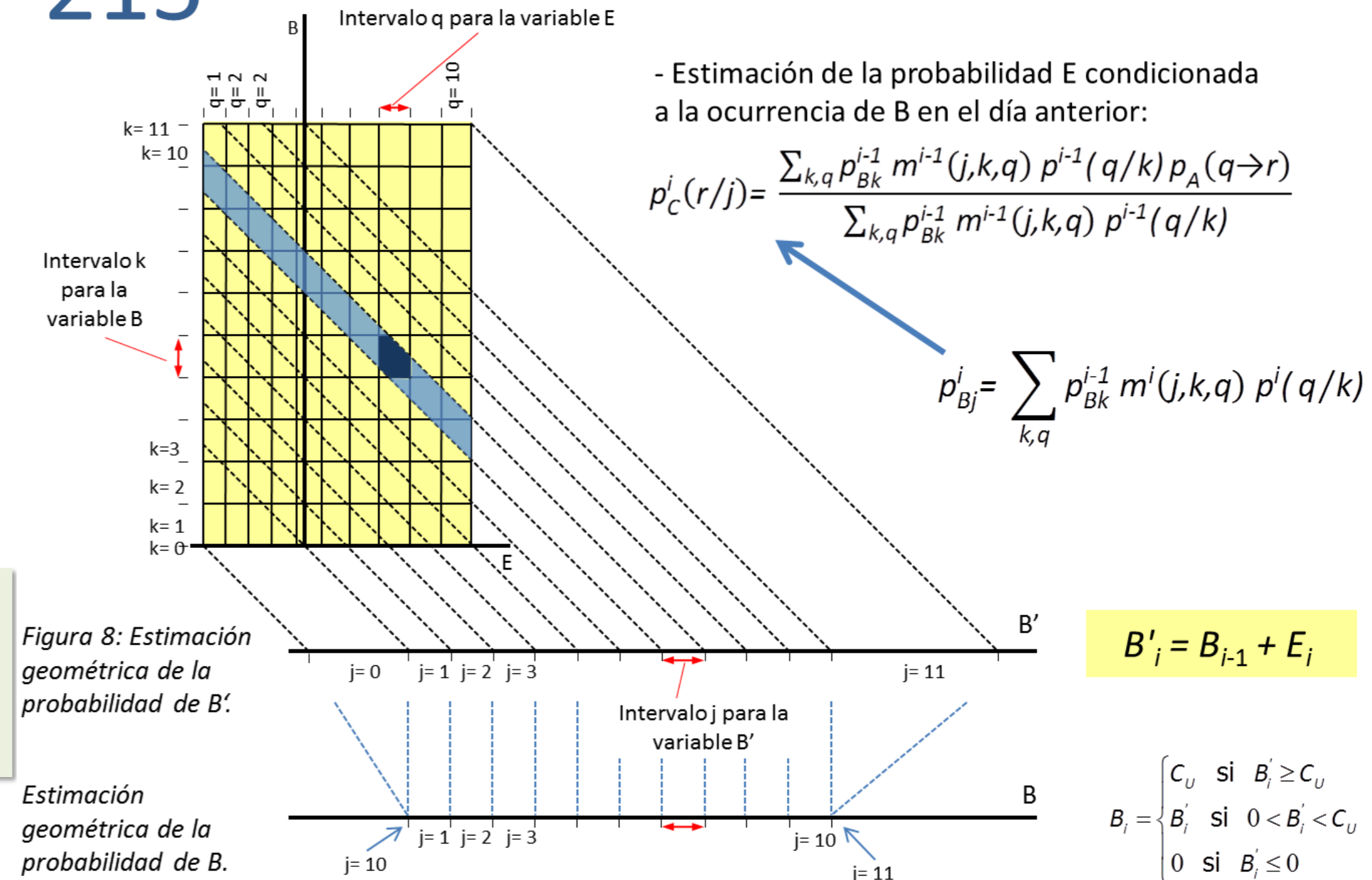


Fig. 4. Distribution of annual LLP according to the number of accumulator Cells and number of 80Wp modules in the installation.

Tesis doctoral Francisco Casares De La Torre, *Herramientas mejoradas para la caracterización de sistemas fotovoltaicos autónomos*. 2015





# Historial investigador

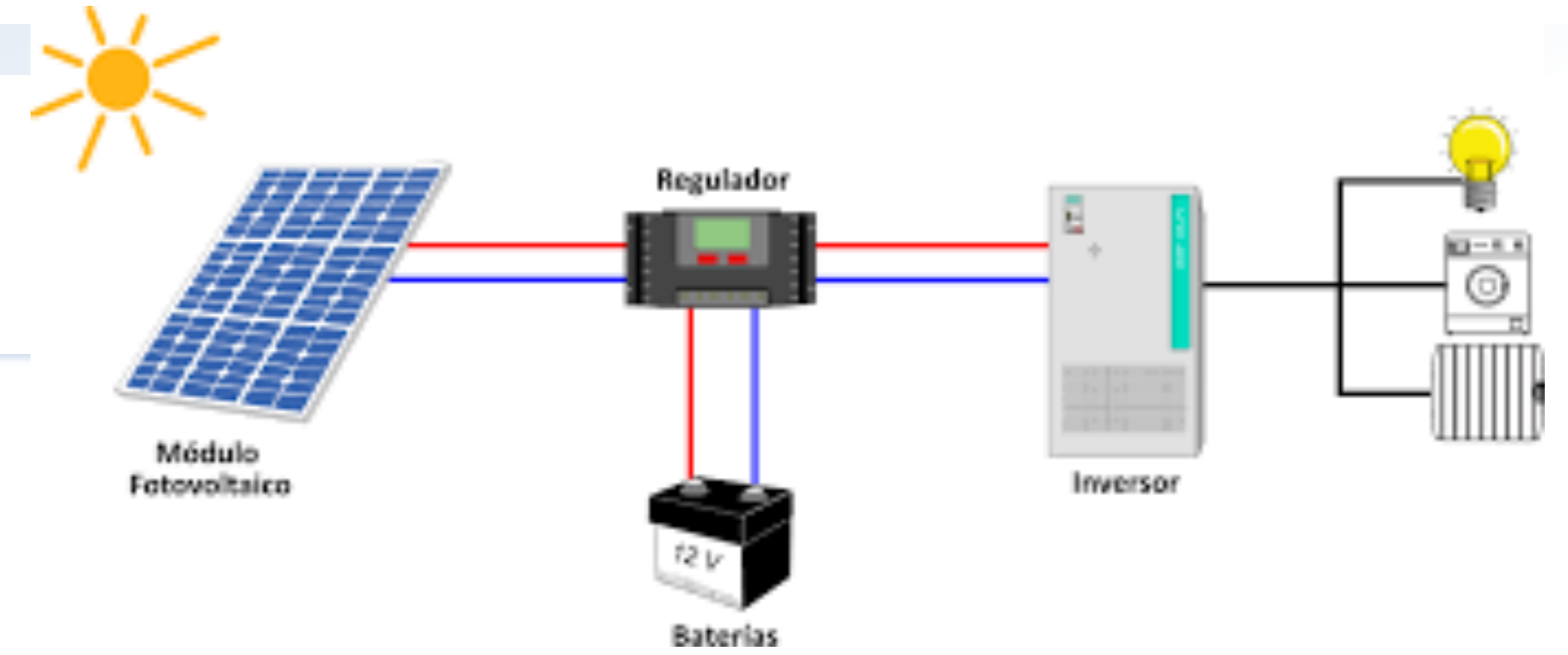
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## Dimensionado óptimo y caracterización de plantas solares fotovoltaicas



Tesis doctoral Rosario Posadillo Sánchez de Puerta, *Estudio del Abastecimiento de Demandas Energéticas Variables mediante Energía Solar Fotovoltaica*. 2003

$$LLP = \frac{\int_{\text{time}} \text{Energy deficit}}{\int_{\text{time}} \text{Energy demand}}$$

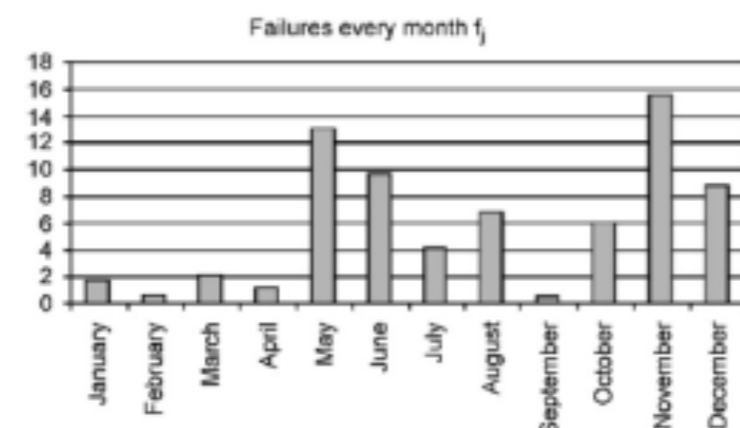


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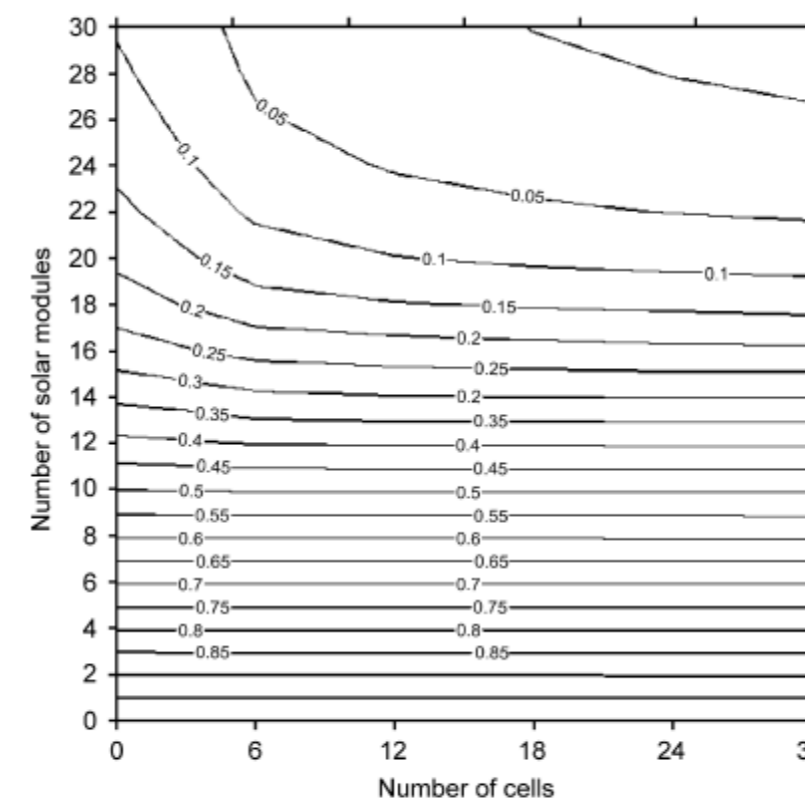
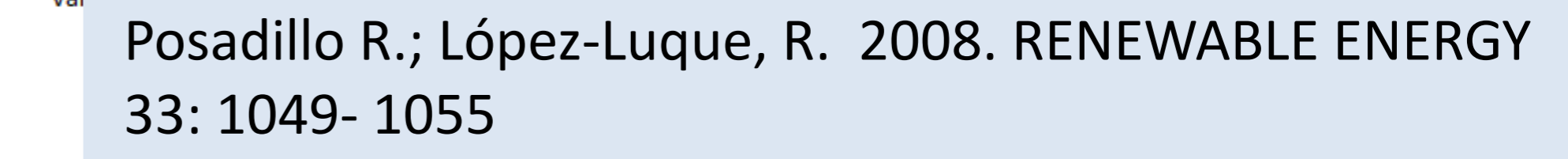
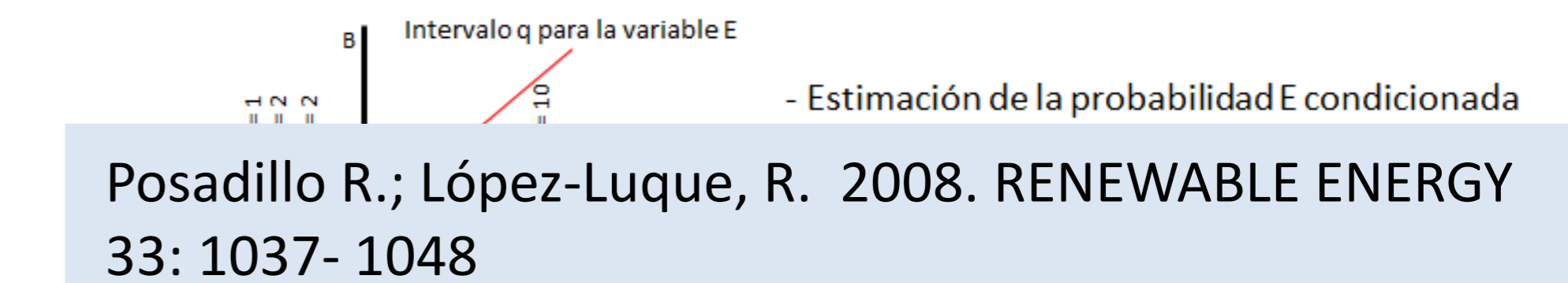
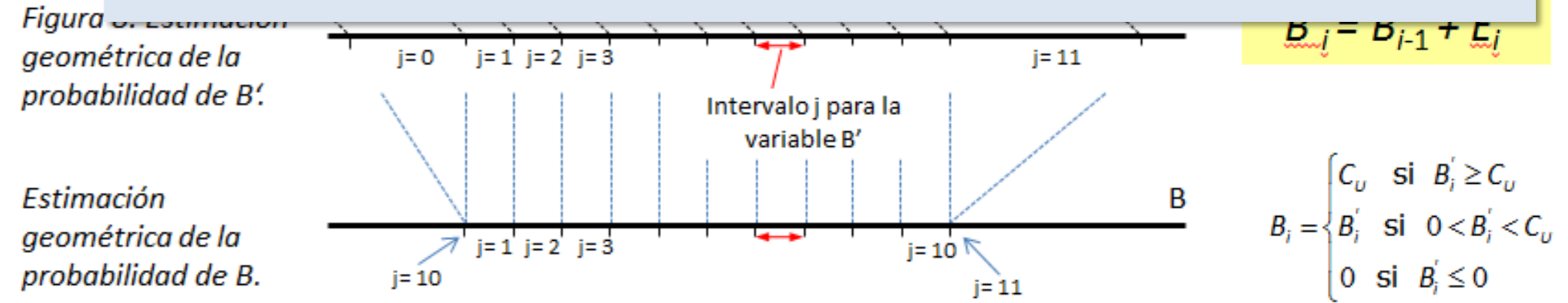


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Tesis doctoral Francisco Casares de la Torre, *Herramientas mejoradas para la caracterización de sistemas fotovoltaicos autónomos*. 2015



Casares F.J. et al. 2014. ENERGY 72: 393- 404





# Historial investigador

## Medida y Caracterización de la radiación solar

1. Historial académico

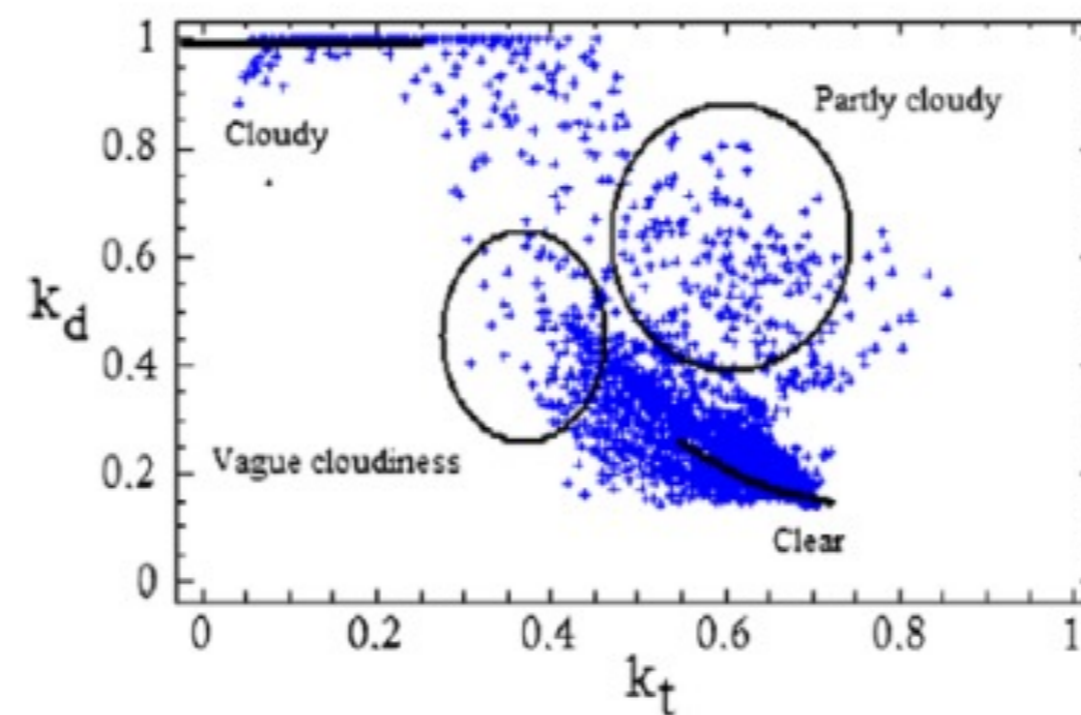
2. Actividad investigadora

3. Actividad docente

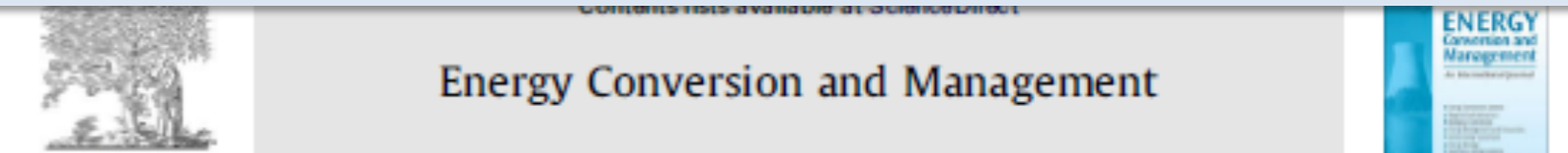
4. Experiencia en gestión



Tesis doctoral Gerardo Pedrós Pérez. Caracterización de la Radiación Global Ultravioleta Solar (290-385nm). Universidad: de Córdoba. 1998.



Posadillo R.; López-Luque, R. 2010. ENERGY CONVERSION AND MANAGEMENT 51: 627- 635



Posadillo R.; López-Luque, R. 2009. ENERGY CONVERSION AND MANAGEMENT 50: 223- 231

R. Posadillo\*, R. López Luque

Grupo de Investigación de Física para las Energías y Recursos Renovables, Dpto. de Física Aplicada, UCO, Edificio C2 Campus de Rabanales, 14071 Córdoba, Spain

ARTICLE INFO

ABSTRACT

Article history:

An analysis of models for the estimation of hourly diffuse irradiation based on the interrelations between

Posadillo R.; López-Luque, R. 2009. ENERGY CONVERSION AND MANAGEMENT 50: 2324- 2330



# Historial investigador

1. Historial académico

Modelado y simulación de instalaciones fotovoltaicas autónomas

2. Actividad investigadora

Medida y Caracterización de la radiación solar

3. Actividad docente

Creación del Grupo PAIDI:  
**TEP215: FISICA PARA LAS ENERGIAS Y RECURSOS RENOVABLES**

4. Experiencia en gestión

Disponibilidad de recurso solar en fachadas de edificios

Desarrollo de prototipos y mejora de dispositivos de aprovechamiento solar





# Historial investigador

## Disponibilidad de recurso solar en fachadas de edificios

1. Historial académico

2. Actividad investigadora

3. Actividad docente

4. Experiencia en gestión

Tesis doctoral José C. Ramírez Faz, *Desarrollo de una metodología basada en el análisis de imagen y desarrollo de un prototipo para la evaluación y cuantificación de variables asociadas a la radiación solar*. 2012

Casares, F.J. et al. 2014. ENERGY AND BUILDINGS 82: 696- 702

$$r = r(\varphi, \theta) \quad \frac{\delta r^2}{\delta \varphi} \frac{\delta \xi}{\delta \theta} - \frac{\delta r^2}{\delta \theta} \frac{\delta \xi}{\delta \varphi} = 2\rho(\varphi, \theta)$$

$$\xi = \xi(\varphi, \theta)$$

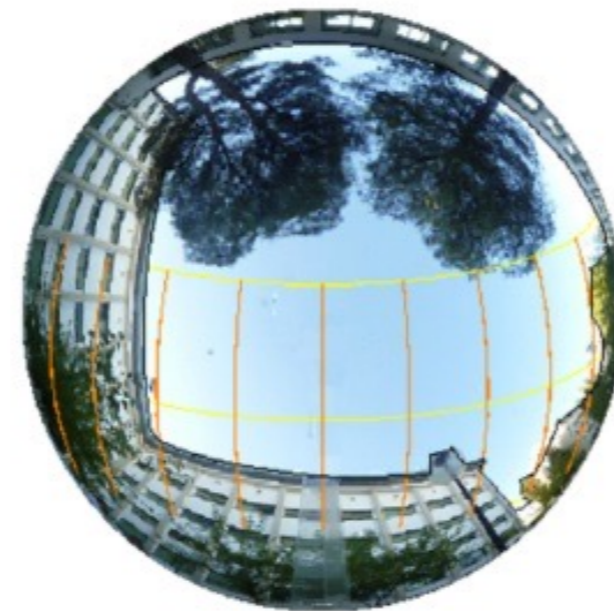
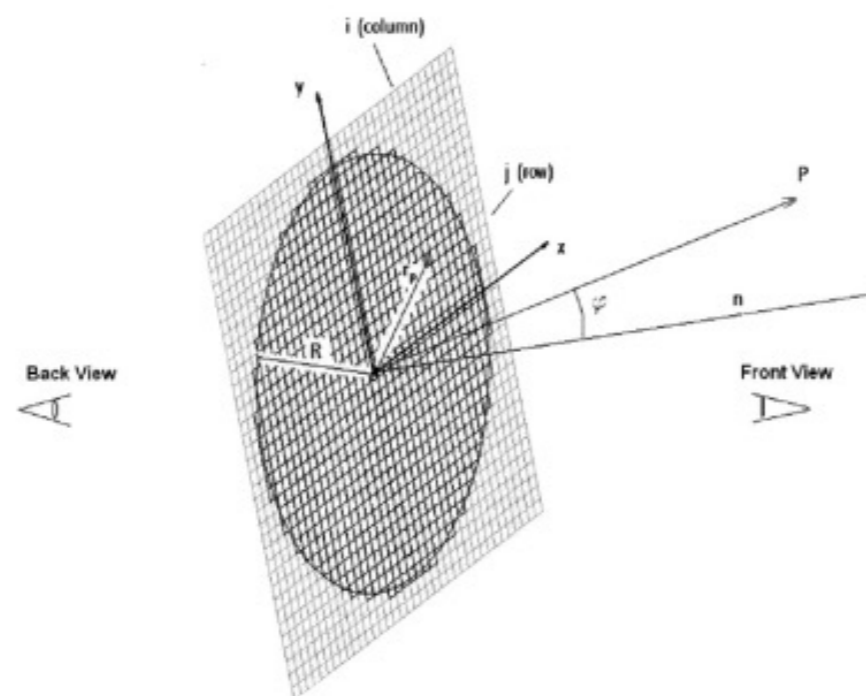
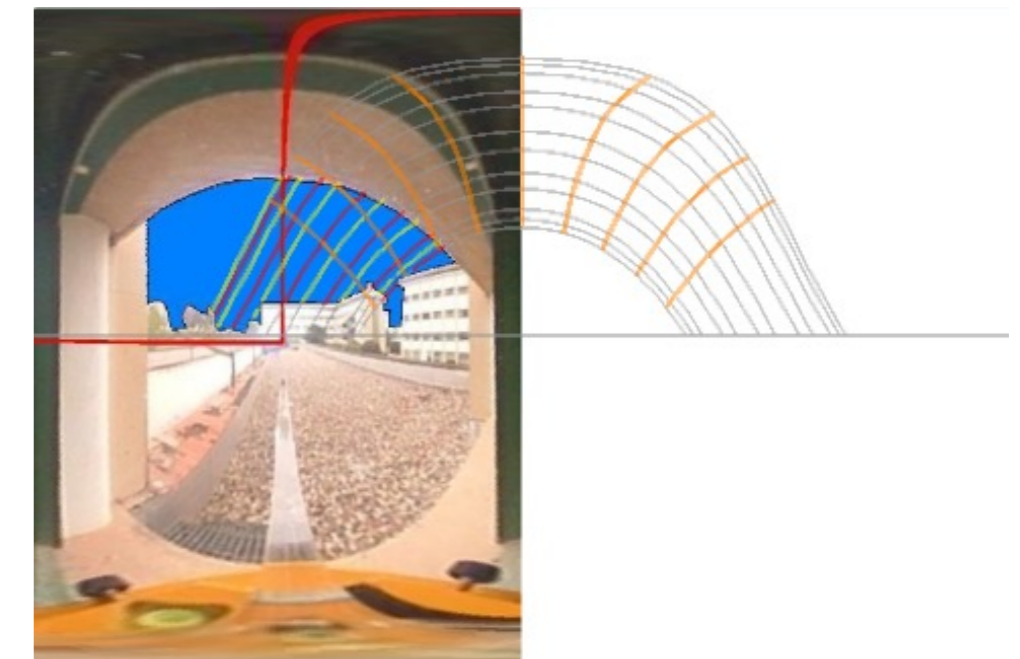


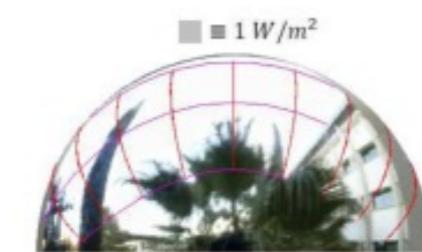
Fig. 6. Transformed image.

Ramírez-Faz, J.; López-Luque, R. 2012. RENEWABLE ENERGY 37: 426- 433



Ramírez-Faz, J.C. et al. 2015. RENEWABLE ENERGY 74: 279- 286

Ramírez et. al. ENERGY AND BUILDINGS, 6: 391- 397



$$r_{max} = 8.6 \text{ W}^{1/2} \text{ m}^{-1}$$





# Historial académico, docente e investigador

## Disponibilidad de recurso solar en fachadas de edificios

1. Historial académico

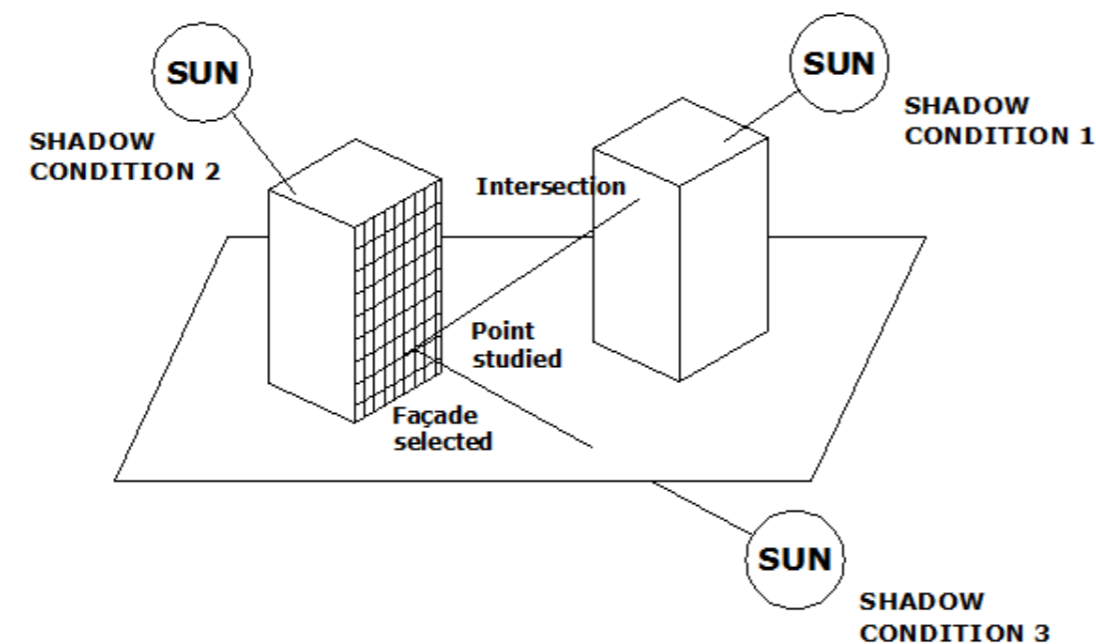
2. Actividad investigadora

3. Actividad docente

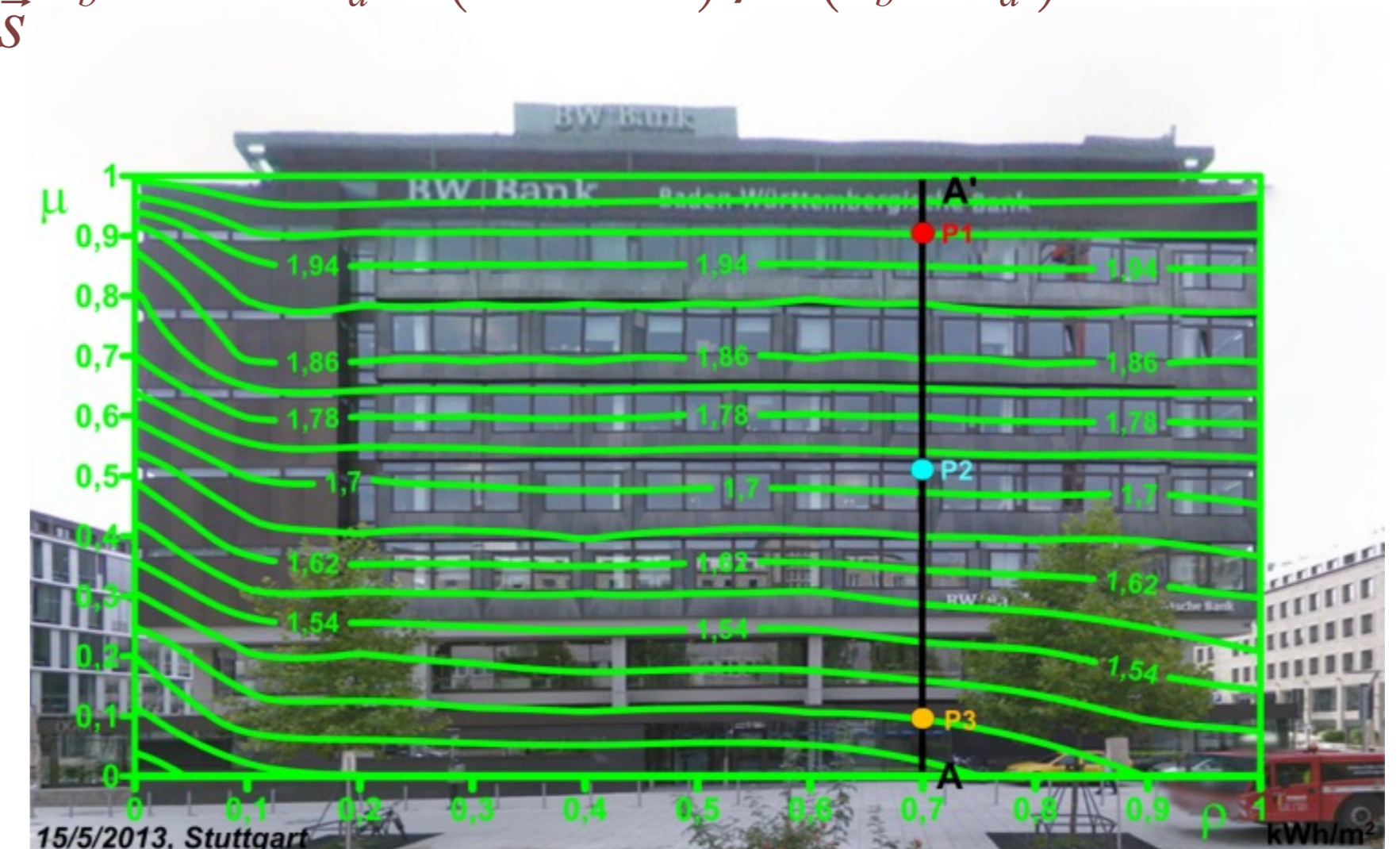
4. Experiencia en gestión

Márquez-García, A. et al. 2016. INTERNATIONAL JOURNAL OF LOW-CARBON TECHNOLOGIES 11(1): 61-65

Márquez-García, A.; Varo-Martínez, M.; López-Luque, R. 2013. Solar energy in urban environments: a new solar radiation model for the analysis of energy on façades. LAP Lambert Academic Publishing. Saarbrücken, Germany



$$I = SS \cdot \frac{\vec{n} \cdot \vec{s}}{\vec{k} \cdot \vec{s}} I_b + SVF \cdot I_d + (1 - SVF) \cdot \rho' \cdot (I_b + I_d)$$







# Historial investigador

## Desarrollo de prototipos y mejora de dispositivos de aprovechamiento solar

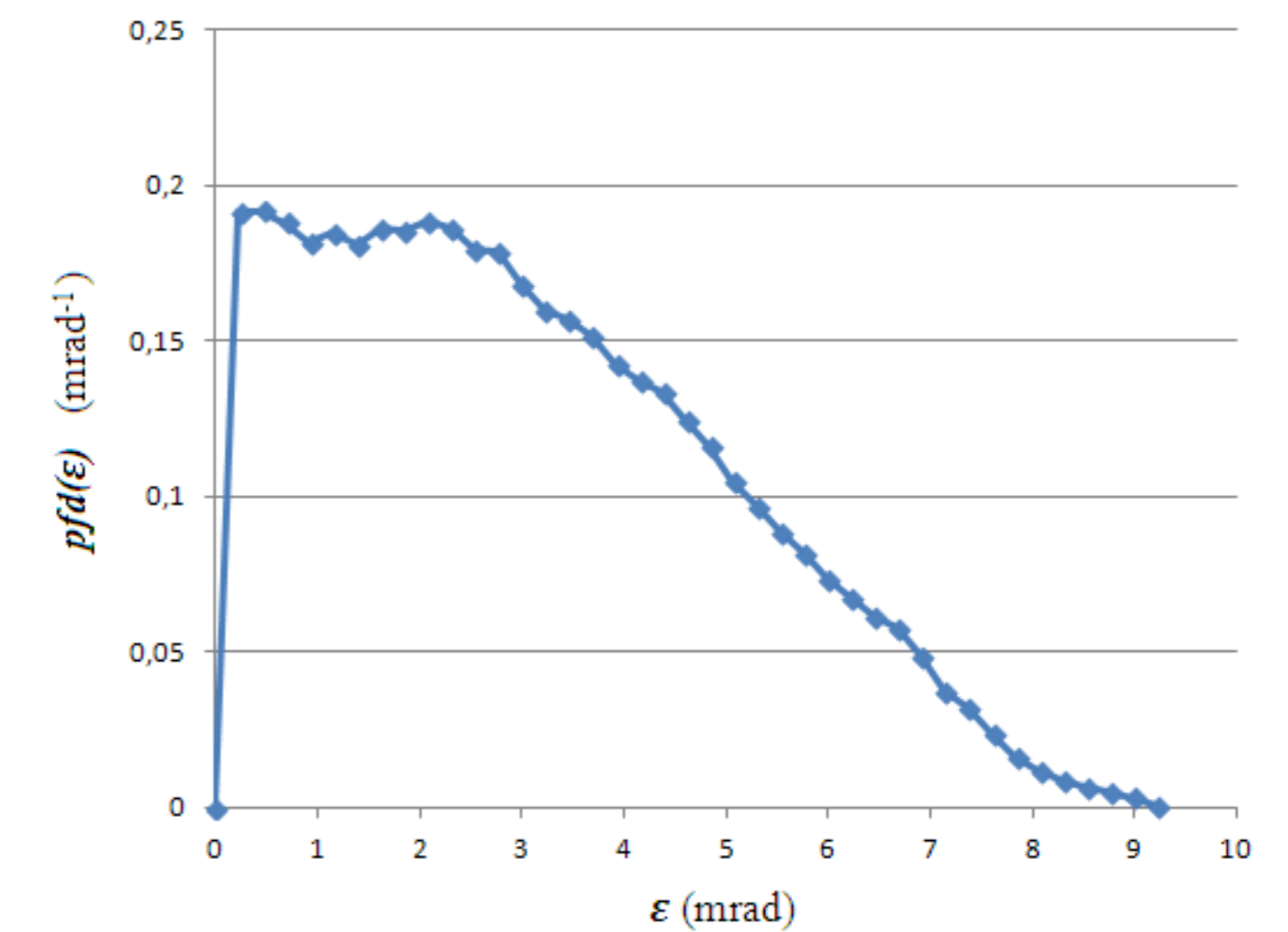
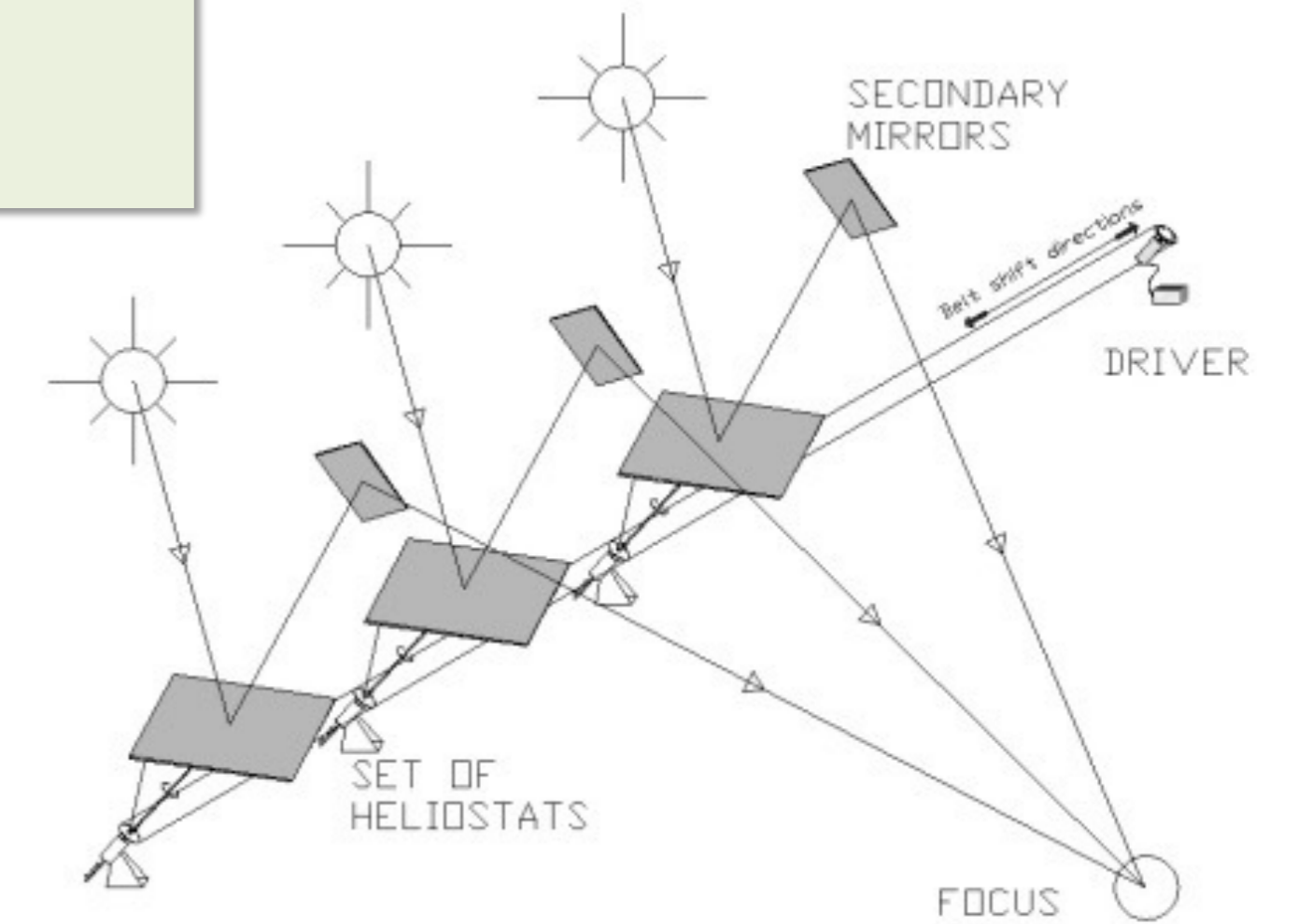
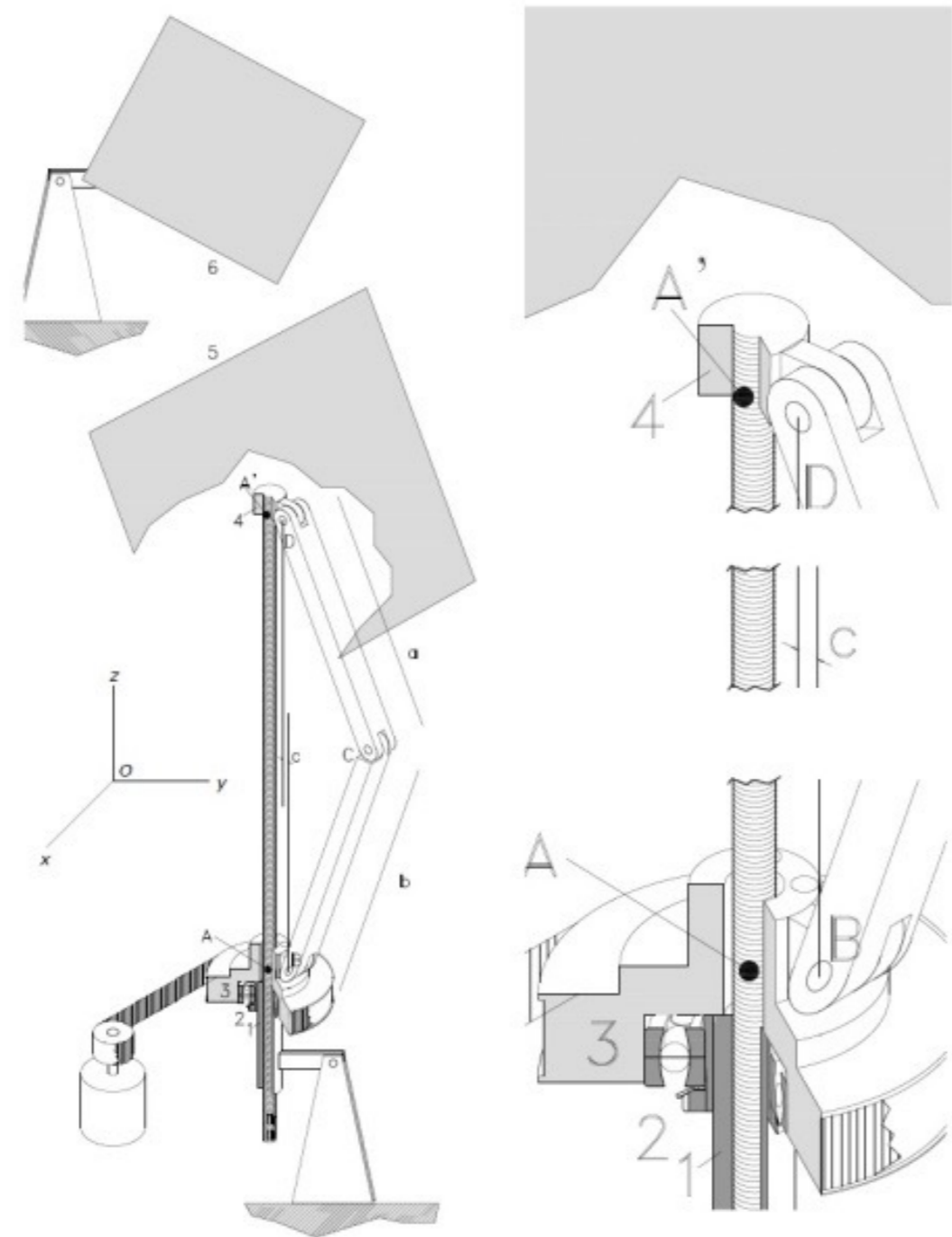
1. Historial académico

2. Actividad investigadora

3. Actividad docente

4. Experiencia en gestión

Tesis doctoral Manuel Torres Roldán, *Diseño de un heliostato polar innovador y simplificado para la integración en edificios y entornos urbanos.* 2016

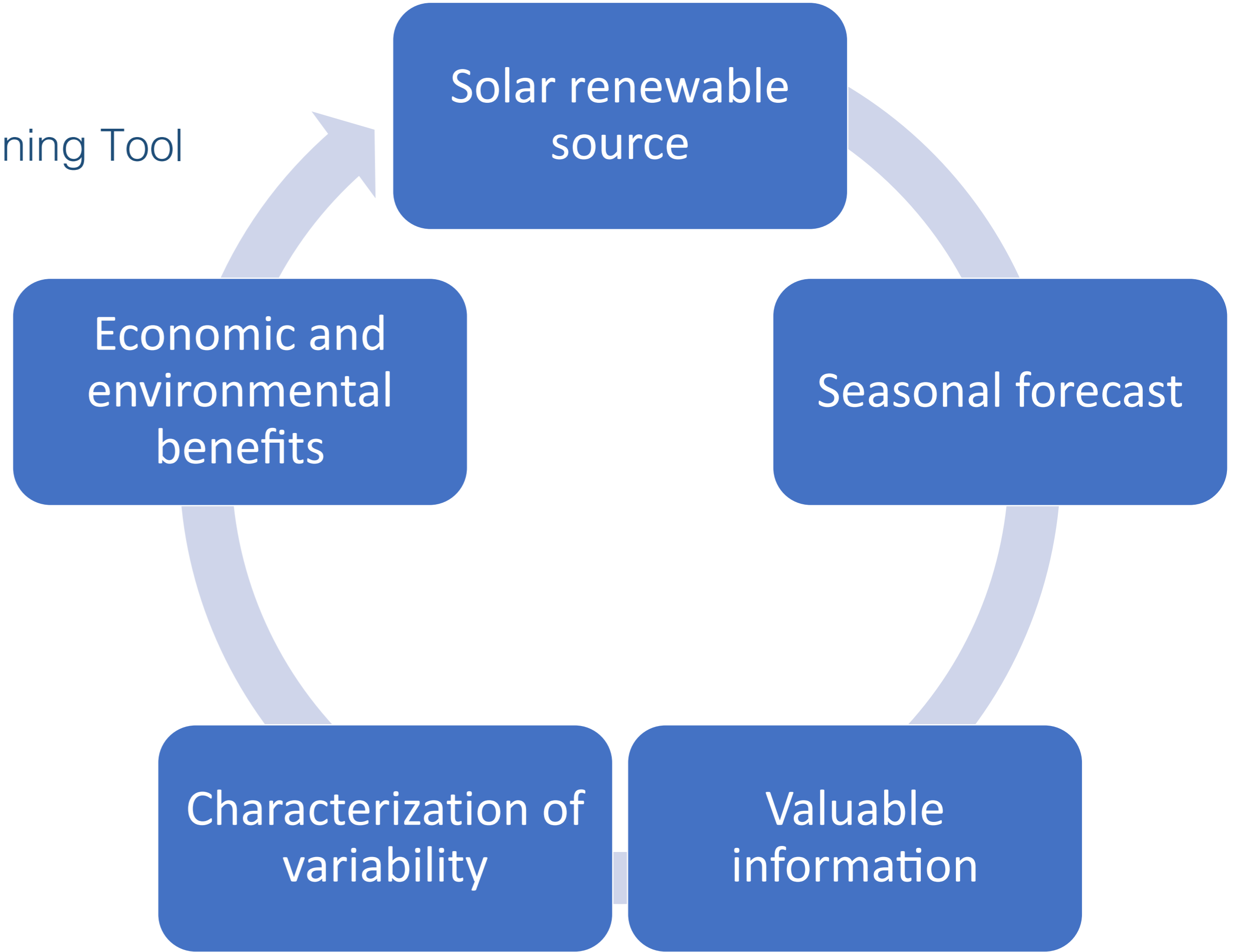




# Introduction

An Approach for the Solar Energy Assessment using Weather Medium-Range Forecasting  
Moreno-Garcia, Isabel M.

## SEAP Solar Energy Assessment and Planning Tool



- Introduction
- Methodology
  - SEAP service
  - Planning tool workflow
- Results
  - Data collection
  - Data processing & storage
  - Web application
- Conclusion