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Deliverable D2.5: "DRES2Market economic assessment methodology to evaluate the proposed solution to enhance renewable energy penetration in the energy and ancillary services markets: evaluation, criteria, assessment procedures and KPIs"

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Work Package 2: Proposing technical solutions and market approaches to enable RES penetration

DRES2Market: Technical, business, and regulatory approaches to enhance the renewable energy capabilities to take part actively in the electricity and ancillary services markets

Horizon 2020-LC – SC3 – 2020 -RES-IA-CSA

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Executive Summary

This document is part of the Work Package 2 of the DRES2Market project. It is the deliverable 2.5 "DRES2Market economic assessment methodology to evaluate the proposed solution to enhance renewable energy penetration in the energy and ancillary services markets: evaluation, criteria, assessment procedures and KPIs".

The aim of this document is to validate the performance of the most promising solutions and approaches proposed with a set of key performance indicators (KPIs) established according to economic, technical, social, and environmental criteria.

The deliverable is part of the work that must be done in Work Package 2, which focuses on proposing technical solutions and market approaches to enable RES Penetration. The first part of the Work Package has identified technical and regulatory solutions to enhance the participation of distributes renewable energy facilities in energy and ancillary services markets. The analysis to identify the most promising solutions have been based on the renewable production and storage, such as PV technologies, onshore wind, and storage systems. The demand side management, mainly focused on smart EV charging and power to heat and power to gas, has been studied and the control and management for grid and DER operators were also analysed.

The document addressed the development of the methodologies and Key Performance Indicators (KPIs) for design, testing and validation of the DRES2Market solutions.

The main conclusion of this deliverable is that the impact of some of the indicators identified that will be tested in cases studied proposed, which will be stimulated in the Work Package 3 where the most promising solutions for large penetration of RES in the electricity markets and in the supply of ancillary services will be analysed, compared, and also will help to produce the guidelines for the large penetration of RES in electricity and ancillary services markets that will be explained in Work Package 4.

Introduction

This deliverable collects the main existing Key Performance Indicators that are relevant for the evaluation of the solutions and approaches identified for the large penetration of RES in electricity and ancillary services markets. The data collected is based on literature review.

As a result of this analysis, this deliverable proposed a comprehensive set of methodologies and a full list of preliminary KPIs. It provides a quantifiable approach to measure, test, design and validate the identified equipment, devices, and procedures to enable the active participation of variable renewable energy and the regulatory frameworks, market rules and grid codes for the large penetration of renewable energy.

The present deliverable is organized according to the following plan: a brief description of the solutions and approaches identified, follow by the evaluation of KPIs according to economic, technical, social, environmental and regulatory criteria and the selected ones to be implemented.

1. Review of the solutions and approaches proposed.

During the first stage of the Work Package 2, the DRES2Market Partners have identified technical and regulatory solutions, to enhance the participation of distributed renewable energy in energy and ancillary services markets.

The solutions identified have been divided in four categories, which are the following:

A. Renewable production and storage: Some of the areas analysed in this part of project has focused on:
   a. PV technologies and the importance as a market driven by an increasing demand in renewable energy, analysing PV modules, PV systems, PV system types, LCOE of PV systems and the environmental impacts of the PV systems.
   b. Onshore wind is another approach that has been studied. The revision has focused on the main turbine manufactures, efficiency, capacity factors and average wind power generation. Also, the importance of operation and maintenance costs, reliability of wind turbines technologies and control strategies and maximum power point trackers have been analysed.
   c. Electrochemical storage systems: the different storage solutions were evaluated to determine their main characteristics regarding lead acid and carbon batteries, lithium ion and all solid lithium batteries, nickel redox vanadium and sodium ion batteries, etc. all of this types of electrochemical storage systems are characterised about their potential use, energy storage capacity, round trip cycle, response time, depth discharge, degradation, number of cycles, and investment and maintenance cost.

   d. Pumped storage hydropower and their importance in controlling the necessity of renewable energy accumulation. During this chapter, the pump storage hydropower capacities in Europe have been analysed and the different types of pumped storage hydropower plants.

e. Thermal storage systems: this type of technology that stock thermal energy in the same fluid used to collect it has been studied and a comparison among technologies were done to obtain the best conclusion and identify the main solutions for renewable energy integration and participation.
f. Converters and their contribution to distributed generation: the current, additional, and new features for PV inverters have been analysed.

B. Demand side management: the aspects analysed during the stage have been the following:
   a. Smart EV charging: a determining aspect to contribute to the demand side management such as the Electric vehicle, battery size, charging power and level, infrastructure, cost, and number of charging points.
   b. Power to heat and Power to gas: power to heat mainly focused on their applications and the advantage for the residential sector and power to gas hopping for green Hydrogen's ability to store energy and their applications and perspectives as distributed energy storage.
   c. Other demand side management such as prosumers, households, commercial, industrial, communities and blockchain.

C. Control and Management focus on measuring the actual performance of renewable energies and establishing the corrective actions to increase the use of them. The main aspects analyse had been:
   a. Control and management for DER operator; related to the forecast technologies and methods mainly wind and solar generation forecasting and energy management systems and their optimization techniques and strategies for distributed generation grids.
   b. Control and management for grid operators: involved to grid connection and protections solutions and power control.
D. DER integration in the main EU countries: regulatory aspects applied in the EU countries and the renewable energies grid integration percentages.
   a. EU countries with large integration of DER renewable: countries like Spain, Denmark and Portugal have been identified among the ones with a larger integration of renewable in Europe, each country has been revied in terms of regulatory framework renewable installation and recent auctions approved.
   b. EU countries with medium integration of DER renewables. France and Greece are some of the countries that have not reached yet a high integration. The characteristics of these countries have been identified and analysed.
   c. EU Countries with low integration of DER renewables. Some of the EU countries included in this group are Poland and Czech Republic.
   d. Demand response in USA: as an example of a program to reduce electricity usage during periods of high-power prices or when the reliability of the electric grid is

threatened. In exchange, end energy users are compensated for decreasing their electricity use.

2. KIPs for testing, validating, and measuring the solutions and approach identified for DER integration

2.1 Economic KPIs

Electricity market prices and cost of the ancillary services, economic flows among the different players, rated of returns of the solution, estimation of the total costs of the systems are some of the key performance indicators identified.

1. *Technological learning rates*

Technological learning rates which help to assess the maturity of a technology. Learning rates are furthermore one of the most important inputs to energy models for the generation of future cost scenarios.

Literature & Data
(Statista, 2021)(The Oxford Institute for Energy Studies, 2021):

2. *Herfindahl-Hirschmann Index* (OSMOSE, 2021)

Herfindahl-Hirschmann Index describe the market concentration in the energy/electricity sector. It is a concentration-based index. It is computed as the sum of the squares of each participant market share.

$$R_H = \sum_f \alpha_f^2$$

Where αf represents company f 's market share.

An RH below 0.01 (or 100) indicates a highly competitive industry, Mergers and acquisitions with an increase of 100 points or less will usually not have any anti-competitive effects and will require no further analysis.

An RH below 0.15 (or 1,500) indicates an unconcentrated industry. Mergers and acquisitions between 100 and 1500 points are unlikely to have anti-competitive effects and will most likely not need further analysis.

An RH between 0.15 to 0.25 (or 1,500 to 2,500) indicates moderate concentration. Mergers and acquisitions that result in moderate market concentration from HHI increases will raise anti-competitive concerns and will require further analysis.

An RH above 0.25 (above 2,500) indicates high concentration. Mergers and acquisitions with HHI scores of 2500 or above will be considered anti-competitive and an in-depth analysis produced, if the scores are well above 2500 they are considered to enhance market power they may only be allowed to progress when significant evidence is shown that the merger or acquisition will not increase market power.

Example of application in Denmark (Energinet, 2020)

3. *Reduced cost of network losses*

Distribution losses can be extremely costly and represent billions of euros of annual waste in distribution grids from electricity that was produced but never used and invoiced. Minimised these losses are critical to increase grid efficiency and improve DER management.

Saving = Electricity generation from solution (kWh)• average in transmission and distribution (%) • average cost of electricity production(€/kWh)

4. *Investment cost* (OSMOSE, 2021)

Total capital cost of infrastructures or other equipment (€). Investment costs correspond to the sum of every investment made in infrastructure and installation relative to the supply chain of the power system (i.e., generation, the grid, communication infrastructure, among other).

5. *Operating Cost (€)*(OSMOSE, 2021)The operating costs are composed by the fuel costs, fixed and variable O&M cost and CO2 costs.

6. *Integration Cost (€)*(OSMOSE, 2021)

- Balancing costs: the costs to balance the renewable deviation from the day-schedule. It represents the forecast error costs due to the variability of the renewable, i.e., the price spread between day-ahead and real-time prices.

- Grid-related costs: the marginal costs of transmission constraints and losses reflected by the locational prices.

- Profile costs: costs due to a lack of temporal coincidence of renewable generation and load, i.e., when the renewable produce at times of low electricity prices. The profiles costs are due to the flexibility effect and the utilization effect. The former represents the increase of the power plant constraints and cycling to follow the steep gradients of the residual load. The latter represents the decrease of the load factor which reflects an increase in cost per MWh.

7. *Congestion management Cost (€)* (OSMOSE, 2021)

Cost overruns due to network infeasibilities (€) comprise re-dispatch costs, counter-trading costs and any other action needed to manage network infeasibilities. They indicate the costs of network bottlenecks and other physical constraints.

8. *Net Present value (NPV)*

The difference between the present value of cash inflows and the present value of cash outflows.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$$

C_t = net cash inflow during period t_1

C_0= the total initial investment cost

r = the discount rate

9. *Internal rate of return (IRR)*

This rate measures the profitability of potential investment and given expected future cash flow.

$$0 = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0$$

C_t = net cash inflow during period t_1

C_0= the total initial investment cost

IRR = the internal rate return

t = the number of time periods

10. *Payback time*

It is the time required to recover the cost of the investment.

$$PB = \frac{C_0}{C_t}$$

C_0 =Initial cost (€)

C_t= Cash flows per each period t (€/t)

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11. *Levelized Cost of Electricity (LCOE)*

This indicator measures the average net present cost of electricity generation for a generating plant over its lifetime.

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

LCOE = Levelized cost of electricity in Euro/KWh

I_o = Investment expenditures in Euro

A_t = Annual total costs in Euro in year t

$M_{t,el}$ = Produced quantity of electricity in the respective year in kWh

i = Real interest rate

n = Economic operational lifetime in years

t = Year of lifetime (1,2…. n)

12. *Imbalance cost ratio*(OSMOSE, 2021)

Ratio of price to the sensitivity of system balancing costs with respect to changes in agent's imbalance due to regulatory framework. It quantifies the efficiency of imbalance settlements.

This KPI can be computed as the ratio of the unit price paid for imbalances to the sensitivity of the system balancing costs. The difference in price paid by an agent should reflect the sensitivity of system balancing costs with respect to an increase in the imbalance by the agent. This will be a measure of the efficiency of imbalance settlement designs.

13. *Occurrence of negative prices* (OSMOSE, 2021)

Occurrence of negative prices (Symbolizing possible market failures) can be computed as the number of hours with negative prices over a given period. Negative prices are the evidence of an inefficient market reaction to a given perturbation or the lack of completeness of the market itself.

14. *Market curve evolution in one year with the DRES2Market solution*

where the average price is the demand-weighted average price in the current hour t.

$$\frac{\text{energy consumed with DRES2Market solution}_{\text{average price}}}{\text{energy consumed without solution}_{\text{average price}}} = \frac{E_{D2MS}}{E_{WS}}$$

15. *Volatility of the market curve in one year (σ)*

Measure the degree of variation of the market curve in one year.

$$\sigma_{D2MS} = \sqrt{\frac{\sum_{t=1}^{N}\left(E_{D2MS_t} - \overline{E_{D2MS}}\right)^2}{N-1}} \qquad \sigma_{WS} = \sqrt{\frac{\sum_{t=1}^{N}\left(E_{WS_t} - \overline{E_{WS}}\right)^2}{N-1}}$$

t = Current hour

N = Total number of hours in one year

E_{D2MSt} = Average price of energy consumed with DRES2Market solution in the hour t

E_{D2MS} =Average in one year

E_{WSt} = Average price of energy consumed without solution in hour t

E_{WS} =Average in one year

The energy consumed with DRES2Market solution would be simulated in different scenarios, including the extremes in a one-year exercise. It might also be very interesting to establish a classification by time groups such as peak hours, valley hours, solar hours, non – solar hours, weekend hours, working hours and others.

16. *Renewable energy cleared – offered in the market*

The indicator measures the total volume of renewable energy cleared of the total volume of renewable energy offered in the markets.

$$\sum_{T}\sum_{I}\sum_{M}\frac{E_{cleared_{i,t,m}}}{E_{offered_{i,t,m}}}$$

$E_{cleared\ I,t,m}$ = Volume of cleared energy by the I renewable resource at time t (MWh)

$E_{offered\ I,t,m}$ = Volume of offered energy by the I renewable resource at time t (MWh)

I = Set of renewable resources

T = Examined periods

M* = Electricity market of ancillary services (ex. Daily, XBid, Local, aFFR, mFRR)

* This indicator can be evaluated separately, for each market and for each technology

17. Competitiveness of renewable in the markets

This indicator measures the degree of competitiveness of a renewable technology in the market.

$$\sum_{T}\sum_{I}\frac{E_{cleared,i,t,m}}{E_{cleared(conv\&renew)t,m}}$$

$E_{cleared\ I,t,m}$ = Volume of cleared energy by the I renewable resource at time t (MWh)

$E_{cleared\ (conv\&renew)t,m}$ = Volume of bided energy (conventional and renewable) at time (MWh)

I = Set of renewable resources

T = Examined periods

M* = Electricity market of ancillary services (ex. Daily, XBid, Local, aFFR)

* This indicator can be evaluated separately, for each market and for each technology

18. Effect of renewable energy in the interconnection

It measures the volume of renewable energy cleared compared to the volume of renewable energy offered when interconnection is full, what it means there is splitting and when it is not.

if splitting (Yes), $\sum_I \sum_T \frac{E_{cleared_{i,t,daily}}}{E_{offered_{i,t,daily}}}$

if splitting (No), $\sum_I \sum_T \frac{E_{cleared_{i,t,daily}}}{E_{offered_{i,t,daily}}}$

$E_{cleared\ I,t,daily}$ = Volume of cleared energy by the I renewable resource at time t (MWh) in daily market

$E_{offered\ I,t,daily}$ = Volume of offered energy by the I renewable resource at time t (MWh) in daily market

$E_{cleared\ (conv\&renew)t,m}$ =examined periods

I = Set of renewable resources

* Splitting: Periods when interconnection is full and there is different price with the contiguous country

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19. Market volatility

Define the electricity markets liquidity based on the daily market. Comparing the market price with the daily price for each t.

$$\sum_{T} Price_{m,t} - Price_{daily,t}$$

$Price_{m,t}$ = Market m price at time t

$Price_{daily,t}$ = Daily market price at time t

T = Examined periods

M = Electricity market or ancillary service (ex. Daily, XBID, local, aFFR…)

20. Market liquidity

This indicator measures the electricity liquidity based on the daily market.

$$\sum_{T} \frac{n_{Bids,t,m}}{n_{Bids,t,daily}}$$

$n_{Bids,t,m}$ = Number of offered transactions in the market m at time t

$n_{Bids,t,daily}$ = Number of offered transactions in the daily market at time t

T = Examined period

M = Electricity market or ancillary service (ex. Daily, XBID, local, aFFR…)

21. Market depth

It analyses the electricity market depth based on the daily market.

$$\sum_{T} \frac{n_{Agents,t,m}}{n_{Agents,t,daily}}$$

$n_{Agents,t,m}$ = Number of agents participating in the market m at time t

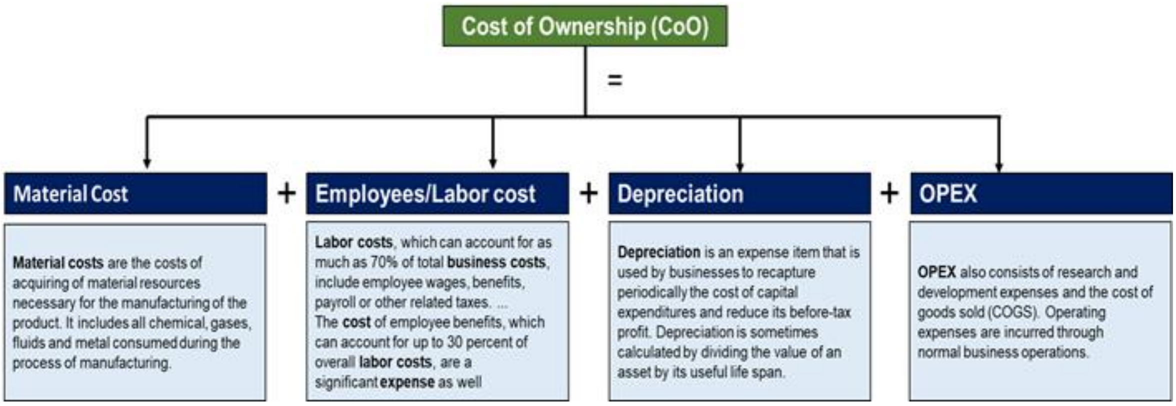
$n_{Agents,t,daily}$ =Number of agents participating in the daily at time t

T = Examined period

M = Electricity market or ancillary service (ex. Daily, XBID, local, aFFR…)

22. Cost of ownership (CoO)

The life cycle cost (LCC) of a product is defined by the estimation of its Cost of Ownership (CoO), which represent the cost of production and calculated based on the material cost, the staffing cost, the CAPEX and the OPEX cost. In the PV field, it about the cost of PV modules and expressed on €/WP. This indicator depends on the type of PV technology.



23. EBITDA

Ebitda indicator is about earnings before interest, taxes, depreciation, and amortization.

$$EBITDA = Net\ Income + Interest + D + A$$

D = Depreciation

A = Amortization

24. LCC (Life Cycle Cost)

This is a method for assessing the total cost (direct, indirect, variable and fixed) of all the investment.

$$LCC = CAPEX + \sum_{1}^{n} \frac{OPEX}{(1+r)^n}$$

n = Life time of PV module (or other DER component)

CAPEX: Cost of PV module & balance of system (or for other DER system)

OPEX = O&M + Insurance + land rent + distribution cost + monitoring

2.2 Technical KIPs

The impact of renewable energy on frequency, voltage control, losses, and other technical aspects can determine a greater or lesser penetration of these energies in the European electrical system and their participation on the electricity market.

The Key Performance Indicators that will be used to measure the technical acceptance of renewable will be the following:

1. *Renewable share*

1.1 Market shares of renewable (%) (OSMOSE, 2021): shares of energy produced by renewable on total supply.

1.2 Total traded volume of renewable over a given period (MWh) (OSMOSE, 2021). A way to measure renewable market participation over a period, the renewable penetration into the market.

1.3 Installed capacity of renewable (MW) and share of renewable at the distribution level (DER) (OSMOSE, 2021).

1.4 Market share of distributed energy resources (DER) (%) (OSMOSE, 2021). It captures trend towards decentralisation on the supply side. It may point to possible grid management challenges at medium and low voltage networks. The total shares of renewables for the entire grid should be obtained, and then their voltage level on the grid should be identified by assessing the market shares of Distributed Energy Resources

1.5 Amount of load capacity participating in Demand Response (DR) programs (Estimation of the participation of DR in the market) (OSMOSE, 2021)

1.6 Renewable that provide flexibility (MW) that can participate in ancillary services and the % and MWh of renewable that provide flexibility.

2. *Renewable* Curtailment

2.1 Renewable curtailment in MWh and subsequently cost to the sytem (€)

2.2 Curtailment of DER (MWh and %) (OSMOSE, 2021). Optimisation of the system with respect to the decentralisation of supply. Curtaiment of DER shall be computed to assess to what extent the grid is well optimized for distributed energy resources. The more MWh from DER are curtailed, the less adapted the system is to accommodate decentralized produced energy.

3. *Renewable share (%) at peak demand hours.*

4. *Flexible generation capacity installed (MW)*

Flexible generation capacity installed in MW and share (%) of flexible generation capacity sources by category compared to total installed capacity in the system.

5. *Degree of self – sufficiency*

This indicator measures the degree of PV self-sufficiency that a country has reached.

$$self\text{-}-sufficiency = \frac{PV\ own\ consumption}{total\ electricity\ consumption}$$

It can be calculated for storage too.

6. *Reduction peak demand ration*

Percentage relation of the resulting demanded energy (residual load) in the peak hours of the day between PV and Wind solution and the reference scenario.

$$Reduction\ peak\ demand\ (\%) = \frac{Peak\ demand_{solution}\,[kWh]}{Peak\ demand_{bs}\,[kWh]}$$

7. *Energy exchange with the grid*

To evaluate loss in transmission and distribution system., The energy exchange with the grid is evaluated in both directions for feed -in and consumption.

$$\Delta_{feed} = \frac{W_{feed,solution}}{W_{feed,bs}} \qquad \Delta_{cons} = \frac{W_{cons,solution}}{W_{cons,bs}}$$

8. *Hosting capacity of solar PV, wind and hydro power.*

It is amount of new PV, wind and hydro power production or consumption that can be connected to the grid without endangering the reliability or voltage quantity for other customers.

$$Hosting\ capacity = \frac{Solar\ PV_{solution} - Solar\ PV_{bs}}{Solar\ PV_{solution}}$$

Solar PV_{bs} = PV in baseline scenario
Same for wind and hydro.

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9. *Increase voltage quality performance*

Reduction in the variations with respect to the reference distribution voltage of the country, enhanced due to the ability of distributed energy when facing voltage system variations.

$$\Delta V\ (V) = \sqrt{\frac{1}{n}\sum_{n=1}^{N}\left(V_{RMS\_n} - V_{RMS\_ref}\right)^2}$$

10. *Duration of overvoltage in the grid*

Overvoltage in the grid occurs when the voltage connected exceeds the country standards. Measures the duration of this event it is important to determine the possible damage of the grid.

$$t_{Vmax} = \Delta t(\sum violation\ occurs)$$

11. *Duration of undervoltage in the grid*

Undervoltage in the grid can cause a problem in the grid, this KPI will also be measured to determine the duration of this event in the grid.

$$t_{Vmin} = \Delta t(\sum violation\ occurs)$$

12. *Time of certain voltage variation*

Average amount of time in which, the main voltage of a certain grid varies from the reference distribution voltage of each country, with respect to the variation limits for the chosen period.

$$t_{\Delta V} = \frac{\sum tperiod_{Vn \neq Vref}}{tperiod_{total}}$$

13. *Decrease/Increase frequency quality performance (NADIR)*

Reduction and Increase in the variations with respect to the reference distribution frequency of the country, enhanced due to the ability of distributed energy when facing frequency system variations.

$$\Delta f = \sqrt{\frac{1}{n}\sum_{n=1}^{N}\left(f_n - f_{ref}\right)^2}$$

14. *Time of a certain frequency variation*

Average amount of time in which, the main frequency of a certain grid varies from the reference distribution frequency of each country, with respect to the variation limits for a chosen period of time.

$$t_{\Delta f} = \frac{\sum tperiod_{fn \neq fref}}{tperiod_{\ total}}$$

15. *Increase in coordinated operation between TSOs and DSO*

$$Communication = \frac{nº\ smart\ metering_{solution} - nº\ smart\ metering_{bs}}{nº\ smart\ metering_{solution}}$$

16. *Average outage duration for each customer served (SAIDI)*

Referred to as the system average interruption duration index, It is the average period duration in which each consumer supply is interrupted.

$$SAIDI = \frac{\sum U_i * N_i}{N_T} = \frac{sum\ of\ all\ customer\ interruption\ durations}{total\ number\ of\ customers\ served}$$

17. *Average number of interruptions in the supply of a customer (SAIFI)*

Also named as the System Average Interruption Frequency Index, it is the average amount of interruptions each consumer would experience.

$$SAIFI = \frac{\sum N_i}{N_T} = \frac{total\ number\ of\ customer\ interruptions}{total\ number\ of\ customers\ served}$$

The SAIFI is measured in units of time, minutes, or hours, over the course of a year.

18. *CAIDI: Customer average interruption duration index*

It is the average duration of the interruption that any customer would experience. CAIDI is measured in units of time, often minutes or hours.

$$CAIDI = \frac{SAIDI}{SAIFI} = \frac{total\ duration\ of\ customer\ interruptions}{total\ number\ of\ customer\ interruptions}$$

19. *CTAIDI: Customer total average interruption duration index.*

It is the average total duration of interruption for customers who had at least one interruption during the period of analysis. CTAIDI is measured in units of time, such as minutes and hours.

$$CTAIDI = \frac{total\ duration\ of\ customer\ interruptions}{total\ number\ of\ customers\ interrupted}$$

20. *CAIFI: Customer average interruption frequency index*

Designed to show trends in customers interrupted and helps to show the number of customers affected out of the whole customer base.

$$CAIFI = \frac{total\ number\ of\ customer\ interruptions}{total\ number\ of\ customers\ interrupted}$$

21. *MAFI: Momentary Average Interruption Frequency Index*

$$MAIFI = \frac{\sum ID_i * N_i}{N_T}$$

22. *ASAI: Average Service Availability Index*

$$ASAI = \frac{N_T * 8760 - \sum r_i * N_i}{N_T * 8760} = 1 - \frac{SAIDI}{8760} = \frac{customer\ hours\ service\ availability}{customer\ hours\ service\ demand}$$

23. *CEMI: Customer Experiencing Multiple Interruptions*

$$CEMI = \frac{total\ number\ of\ customers\ in\ the\ system\ experiencing\ more\ than\ n\ outages}{total\ number\ of\ customers\ in\ the\ system}$$

24. *Increased efficiency in preventive control and emergency control*

$$Reaction\ capacity = \left(\frac{(SAIDI \cdot SAIFI)_{bs}}{(SAIDI \cdot SAIFI)_{solution}} - 1\right) \cdot 100$$

25. *Coordinated restoration after emergency*

$$Restoration\ reaction\ time = \frac{Restoration\ time_{PV\ solution}}{Restoration\ time_{bs}}$$

26. *Increased demand side participation*

$$Demand\ side\ participation = \frac{nº\ EMS_{solution} - nº\ EMS_{bs}}{nº\ EMS_{bs}}$$

27. *Actual availability of network capacity*

$$Availability = \frac{Total\ capacity\ of\ the\ grid\,[MW] - \sum Capacity\ of\ solutions\ installed\ [MW]}{Total\ capacity\ of\ the\ grid\,[MW]}$$

28. *Insufficient Ramp Resources Expectation (IRRE)* (OSMOSE, 2021)

Expected number of times in each period that a system will not be able to meet changes in net load. It can be computed as the cumulative probability that the flexibility will not be enough to overcome the ramps. It offers a high-level insight into the flexibility of a system

29. *Expected Energy Not Served (EENS)* (OSMOSE, 2021)

Represents a metric which could be used to measure security of supply as well as to set a reliability standard in the electricity market.

30. *FREQUENCY*

30.1 RoCoF – Rate of Change of Frequency

$$RoCoF_{max} = \frac{df}{dt_{max}} = \frac{\Delta P_{Imbalance}}{P_{Load}} * \frac{f_0}{T_N}$$

30.2 System Inertia

$$H_{sys} = \frac{\sum H_i * S_i}{\sum S_i}$$

(Includes Synthetic inertia)

30.3 Frequency droop

$$K_D = \frac{\omega_g - \omega^*}{p_m - p_0}$$

31. *POWER*

31.1 PTSI – Power Transfer Stability Index

$$PTSI = \frac{2 * S_r * Z * (1 + \cos(\theta - \varphi))}{U_2^2}$$

2.3 Environmental KPIs

These Key Performance Indicators measure the impact of fossil fuels consumption and the effects of greenhouse emissions and on water, resources, and land use.

1. *Quantified reduction of carbon emissions*

$$avoided\ CO_2\ emissions = Solar\ PV\ energy\ [kWh] \cdot emission\ factor\ [{}^{CO_2}/_{kWh}]$$

- It is calculated the CO2 equivalent (taking into account CO2, NO2, CH4 emissions).
- As defined in the formula, energy (kWh) can be calculated also for the rest of variable renewables technologies in addition to Solar PV.
- The emission factor must be the country mix fossil emission factor as renewable displace fossil energy generation.

2. *Material footprint of energy technologies and amount of critical materials needed* (Sonnberger, 2020)

3. *EU Critical Materials List, now the fourth: in 2020, a fourth list of 30 CRMs (critical raw materials)*(European Union, 2021)

4. *Water demand of energy technologies* (Mekonnen et al., 2015):

5. *Land-use of energy technologies* (Trainor et al., 2016):

6. *Quantified energy stored for a battery during its life regarding energy used for fabrication*

This indicator does not consider a variation of capacity during the life of the battery on the numerator, and it does not take into account losses (efficiency) in the denominator.

$$\text{ESOI} = \frac{\text{Energy stored}}{\text{Embodied energy}} = \frac{(\text{capacity})\lambda\eta D}{(\text{capacity})\varepsilon_{\text{gate}}} = \frac{\lambda\eta D}{\varepsilon_{\text{gate}}} \quad (2)$$

with λ cycle life, η the efficiency and D the DOD
with εgate the embodied energy cradle to gate (materials sourcing, manufacturing, ...)

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Another indicator related to the quantity of energy store for a battery can be used

$$ESOI'' = \frac{E_{delivered}}{E_{transport} + E_{cooling} + E_{loss}} \quad \text{with} \quad E_{loss} = E_{delivered}\left(\frac{1}{\eta} - 1\right)$$

7. *Fossil energy saved during reference period*

$$FEsaved = \frac{RE}{RE + FE} \cdot 100$$

FE: consumption of fossil energy during reference period, KWh

RE: Renewable energy (solar and wind) supplied to the process during the same reference period, kWh

Fesaved: fossil energy saved during reference period, %

8. *Visual Impact*

This is a very subjective KPIs, interesting to measure…. It can be rated on an arbitrary scale (low impact) to 4 (high impact).

This indicator could be a composite one taking into account degree of visibility, aesthetic, integration in the landscape and existing buildings, etc with ponderation factors.

9. *Energy returns on*

This indicator measures the amount of usable delivered from a particular energy resource to the amount of exergy used to obtain that energy resource.

$$EROI = \frac{Eused}{ERused}$$

EROI = Energy Return on Energy

Eused = Usable energy MWh

Erused = Energy used to obtain that energy resource

10. *EPBT (Energy PayBack Time) in years*

EPBT is defined as the period required for a renewable energy system to generate the same amount of energy (either primary or kWh equivalent) that was used to produce the system itself. It is close to EROI.

$$EPBT = \frac{Cumulative\ Energy\ Demand}{Annual\ Energy\ Production}$$

Cumulative Energy Demand =Total energy used for DER system fabrication, installation, and commissioning.

Annual Energy Production = Annual production in energy of DER system.

11. *CED (Cumulative Energy Demand) in MJ*

Cumulative energy gives a value of the total energy used by the DER system for its complete life from material extraction to End of Life consideration.

$$CED = E_{mat} + E_{manuf} + E_{transp} + E_{inst} + E_{EOL}$$

Emat = The primary energy demand to produce materials that constitute PV (or DER) system

Emanut = The primary energy demand to manufacture PV or (DER) system

Etransp = The primary energy demand to transport materials and system

Einst = The primary energy demand to install the system

EEOL = The primary energy demand for end-of-life management

12. *GHG emission rate (Greenhouse Gas emission rate)*

This rate is the greenhouse gas emitted from the unit of electricity produced by the FIPS (CO-eq/kWh).

$$GHG_{em_{rate}} = \frac{GHG_{em_{total}}}{E_{LCA_{output}}}$$

GHGemtotal = The total greenhouse gas emitted during the life cycle FIS (Co2-eq)

ELCAoutput = The total electricity produced by the FIS during itslife cycle (kWh)

13. *Capacity factor of the adopted solution or facility*

This rate is the average energy production of a facility per its potential production at full power.

$$CF = \frac{Av\ Energy\ produced}{Energy\ at\ full\ power}$$

- This indicator evaluates the efficiency of the adopted solution: New turbines are more efficient and therefore have higher CF
- Hybrid solutions increase the CF of the facility

2.4 Social KPIs

Social impact of renewable energy is a very important indicator to measure. Aspects such as employee's acceptance, guarantees of the quality of the environment, work conditions and respect for the human right is a key issue to evaluate.

Following it is described the main KPIs related to the DRES2Market solutions identified:

1. *Health Costs saved*

$$Health\ costs\ saved\ \left[\frac{\$}{Avoided\ Fosil\ MWh}\right] = \left(\left(\frac{tNOx}{Coal\ MWh} * \frac{€}{tNOx} + \frac{tSO2}{Coal\ MWh} * \frac{\$}{tSO2} + \frac{tPM}{Coal\ MWh} * \frac{\$}{tPM}\right) * \%\ Coal\ Country\ Fosil\ Energy\ Mix\right) + \left(\left(\frac{tNOx}{Fuel\ MWh} * \frac{€}{tNOx} + \frac{tSO2}{Fuel\ MWh} * \frac{\$}{tSO2} + \frac{tPM}{Fuel\ MWh} * \frac{\$}{tPM}\right) * \%\ Fuel\ Country\ Fosil\ Energy\ Mix\right) + \left(\left(\frac{tNOx}{Natural\ Gas\ MWh} * \frac{€}{tNOx} + \frac{tSO2}{Natural\ Gas\ MWh} * \frac{\$}{tSO2} + \frac{tPM}{Natural\ Gas\ MWh} * \frac{\$}{tPM}\right) * \%\ Natural\ Gas\ Country\ Fosil\ Energy\ Mix\right)$$

2. Water saved

$$Water\ saved\ \left[\frac{m^3}{Avoided\ no\ RE\ MWh}\right] = \left(\frac{1{,}9m^3}{Coal\ MWh} * \%\ Coal\ Country\ no\ RE\ Energy\ Mix\right) + \left(\frac{0{,}757m^3}{Fuel\ MWh} * \%\ Fuel\ Country\ no\ RE\ Energy\ Mix\right) + \left(\frac{0{,}7m^3}{Natural\ Gas\ MWh} * \%\ Natural\ Gas\ Country\ no\ RE\ Energy\ Mix\right) + \left(\frac{2{,}7m^3}{Nuclear\ MWh} * \%\ Nuclear\ Country\ no\ RE\ Energy\ Mix\right)$$

3. *Direct, indirect, and induced increase of GDP / number of jobs created per renewable MW installed*

- *Direct, Indirect and Induced increase of GDP*

The estimation of the social-economic impact of investments is focused in the way to show the GDP's increase.

The investment (CAPEX & OPEX) is faced through an Input-Output table of the country, giving as result how invest is shared along different economic sectors. The input-Output table is like a matrix that provides a summary of economic transactions among productive industries (rows) and final users (columns).

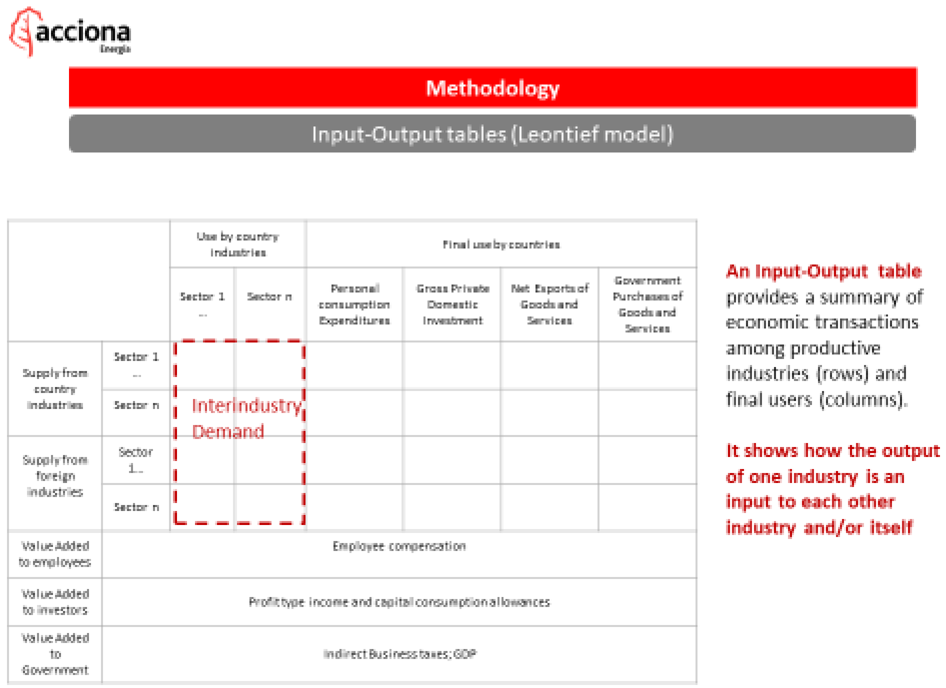
Going through the Input-Output table 3 times, we get direct results (first), indirect (second) and induced ones (third)

- *Direct, Indirect and Induced job generation*

The Input-Output tables also provide the number of jobs generated from the investment. They have some factor relating GDP increase calculated with jobs created.

- *Some equivalences*

Equivalences from these results are calculated relating with M€ invested; MW installed; or GWh produced.



4. *Energy improvement*

This rate indicates the energy produced by the new solution per energy produced by the previous one.

$$Energy\ improvement\ (\%) = \frac{Energy\ produced\ by\ the\ new\ solution}{Energy\ produced\ by\ the\ original\ one} * 100$$

Increasing the energy production in an existing facility by repowering or/and by hybrid solutions reduces the number of facilities and landscape saturation risk. The increased affection is produced in an area where there is already an acceptance fo the population and has an evaluation of the social and environmental impact.

5. *Energy poverty* (European Commission, 2021)

Indicators & Data | EU Energy Poverty Observatory

Energy poverty is a multi-dimensional concept that is not easily captured by a single indicator. Our approach to measuring energy poverty has been to use a suite of indicators, which should be viewed and used in combination. Each indicator captures a slightly different aspect of the phenomenon. Our intention is that these indicators should be used to give a snapshot of energy

www.energypoverty.eu

-> arrears on utility bills

-> low absolute energy expenditure

-> high share of energy expenditure in income

-> inability to keep home adequately warm

6. *Energy justice* (Reinhard & Minna, 2018)

Indicators that express access of households to the energy grid, experience of blackouts per household, access of households to mobile phones and internet (as prerequisite to engage in the markets for example). Time per household spend to secure access to energy services.

7. *Energy improvement* (Gasser, 2020)

Energy diversity & security from national perspective

2.5 Regulatory KPIs

In the Deliverable 2.1 of the project, the DRES2Market members have analysed the legislative rules that applied to some countries of the EU with large, medium, and low penetration of renewable energies. The regulatory KPIs will be used to analyse and to evaluate the regulatory flexibility and adaptation to increase the use of renewable energy and their integration.

1. *Reduction in time to connect new user*

Average period of time, expressed in days, needed for getting the required permission to connect a new prosumer into the grid.

$$Av\ time\ [days] = \frac{\frac{\sum t_{permission}}{Total\ nº\ of\ prosumers}_{bs} - \left(\frac{\sum t_{permission}}{Total\ nº\ of\ prosumers}\right)_{solution}}{\left(\frac{\sum t_{permission}}{Total\ nº\ of\ prosumers}\right)_{bs}}$$

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2. *Increase in coordinated operation between TSOs and DSOs*

This indicator measures the improved communication between TSO and DSO, due to the installation of advance metering equipment related to prosumer's installation.

$$Communication = \frac{nº\ smart\ metering_{solution} - nº\ smart\ metering_{bs}}{nº\ smart\ metering_{solution}}$$

3. *Legal support of renewable energy in the EU legal framework*

The extent to which renewable energy regulation is suitable at EU level in %.

4. *Public authorities support*

Each EU country can be tested, reviewing the positive and negative aspects such as:

- *Positive impact*: Facilitate to promote RE, contribution to funding, grants and tax reductions.
- *Negative impact*: Special requirements beyond legislation, special permits, high taxes.

5. *Feed in tariff EU policies and capacity mechanisms both are schemes that impacts on the renewable integration, how this affect can be discussed on the next work packages*

6. *Reduction in time for repowering and hybrid solutions*

Reduction in time for grid connection, administrative and environmental permits for repowering and hybrid solutions, especially when the maximum power to deliver to the grid is not exceeded.

$$Average\ time\ (days) = \frac{Average\ tyme_{new} fality - \ Average\ time\_solution}{verage\ tyme_{new} fality}$$

3. Conclusion

This document presents an overview of the common methodologies and Key Performance Indicator for design, testing and validation of the solutions and approaches identifies in previous stage, which will be tested in Work Package 3 of the DRES2Market project.

The measurement framework defined in the document, is evaluating the various aspects that affects renewable energies addressed by DRES2Market proposed approached, related with:

- Economic life cycle cost and value
- Technical standards: energy security
- Social aspects: advantage and disadvantage, energy security, energy democracy (poverty, justice, participation)
- Environmental impacts: positive and negative, including water, land-use, material resources, chemical leakage, and visual impact
- Regulatory development to promote and integrate renewable energies and to ensure energy justice

The selection of the Key Performance Indicators described is very wide. All those parameters have been analysed, to identify which are the most reliable indicators that should be taken into consideration, however not all of them will be tested in all the case studies and environments proposed in Work Package 3. For each case study will be selected those ones that suit better with the solution evaluated.

During the following weeks, the DRES2Market partners will adapt the indicators that are more suitable, to the solutions studied, to get the right conclusion for the identification of the RES integration.

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