05-023

Analysis of the economic viability of new electricity supply models based on renewable energies in energy-intensive industries

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Energy-intensive industries - highly sensitive to the increase and volatility of the electricity price- are increasingly exposed to international competition. This fact is one of the main drivers of the ongoing process of relocation of this type of industry in some geographies. On the other hand, the greater requirements of economic efficiency, in addition to a high need for energy security and environmental sustainability, are driving a transformation process on the traditional model of electricity supply, increasing its degree of decentralization.

This paper aims to evaluate the suitability, in economic terms for almost a hundred countries, of the development of alternative energy supply models for the energy intensive manufacturing sector based on renewable energies. In the initial phase of the study, a comparison of electricity supply cost has been made between the power network extension model and the distributed generation model. In addition, a sensitivity of the result has been analyzed according to the variability of the location. Finally, the profitability associated to a distributed generation project has been analyzed compared to the retail market price, determining the degree of economic viability per geography.

Keywords: Distributed generation; Renewable energy; Industrial sector

Análisis de la viabilidad económica de nuevos modelos de suministro eléctrico basados en energías renovables en industrias intensivas en energía

Las industrias intensivas en energía -muy sensibles al incremento y volatilidad de su precio- se encuentran cada vez más expuestas a la competencia internacional. Esta situación es uno de los principales impulsores del proceso actual de deslocalización de la industria en algunos países. Por otro lado, los mayores requisitos de eficiencia económica, además de una alta necesidad de seguridad energética y sostenibilidad medioambiental, está impulsando un proceso de transformación en el tradicional modelo de suministro de electricidad aumentado su grado de descentralización.

Este artículo pretende evaluar la idoneidad, en términos económicos para casi un centenar de países, del desarrollo de modelos alternativos de suministro de energía para el sector manufacturero intensivo en energía basados en energías renovables. En la fase inicial del estudio, se ha realizado una comparación de los precios de aprovisionamiento de electricidad, entre el modelo de extensión de red y el de generación distribuida. A continuación, se ha analizado la sensibilidad del resultado en función de la variabilidad de la localización. Por último, se ha analizado la rentabilidad asociada a un proyecto de generación distribuida y se comparó con el precio de la oferta minorista, determinando el grado de viabilidad económica por geografía.

Palabras clave: *Generación Distribuida; Energía Renovable; Sector industrial*

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1. Introduction

The greater requirements of economic efficiency, energy security and sustainable development are driving a transformation in the current model of electricity supply increasing its degree of decentralization. During the past few years, a growing interest in some concepts associated with distributed generation has shown a significant increase (Erdinc, 2015). In particular, residential consumers are increasing the installation of simple systems known as "stand alone" while more complex solutions, distributed generation systems (DGS), are being developed for large consumers or clusters.

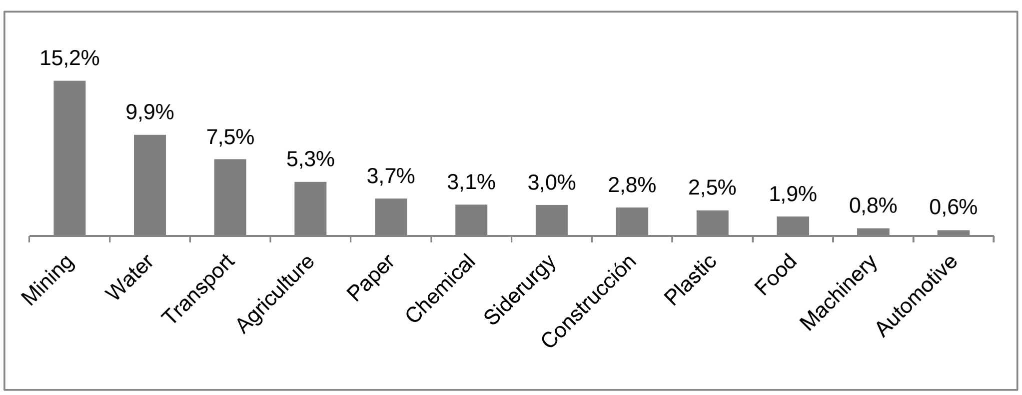
A DGS is, in a general definition, a system that groups one or more electricity generation elements and one or more consumers interconnected through control and management equipment at a local level through an internal distribution infrastructure that may or may not be connected to a transmission or distribution (T&D) network.

The decision to deploy a DGS in a particular location usually obeys two parameters: economic efficiency and the particular requirements of the promoter in terms of safety and sustainability.

It is possible to characterize three fundamental typologies of DGS depending on the type of consumer: isolated residential, urban (residential, institutional and tertiary sector) or associated with a productive activity (secondary or primary sector). The weight of the decision parameters varies according to the typology of DGS; in isolated areas the development impulse, in urban areas the security of supply and in productive activities (additionally to supply security) the economic efficiency. However, there may be particular considerations within the same typology of DGS due to the particular characteristics of the project, its proximity to the T&D network or, the capacity required, etc.

In particular, energy-intensive industries (highly sensitive to the increase and volatility of the electricity price) are increasingly exposed to international competition (Ecofys, 2015). This fact is one of the main drivers of the current process of relocation of this type of industry in some geographies.

Figure 1: Cost of energy over total OPEX by industry (%)

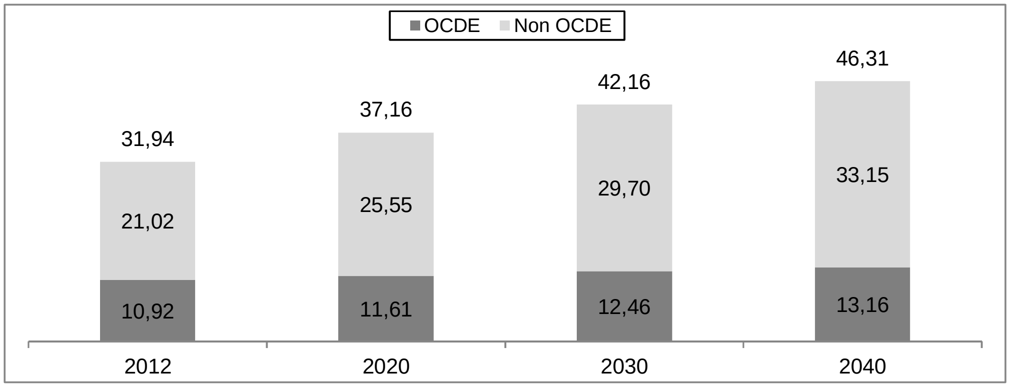


Source: Spanish Ministry of Industry and Energy, Goldman Sachs Global investment Research

In some industries (Figure 1), the energy cost can reach between 2% and 10% of total operating costs. Consequently, achieving a reduction in the energy cost of around 20% can lead to substantial improvements in the gross margin.

Industrial activities use more energy than any other sector, consuming about 54% of the total energy supplied in the world (IEA, 2016). In the future, it is expected (in spite of the improvements in energy efficiency) an increase in electricity consumption by the secondary sector (Figure 2). Therefore, it is of great interest to develop economically efficient solutions (Schulze, 2016), which improve security of supply and ensure environmental sustainability.

Figure 2: Industrial sector electricity consumption by region, 2012-40 (quadrillion Btu)



Source: International Energy Agency, International Energy Outlook 2016

There is currently consensus on the future growth of DGS deployment of close to a 20% annually (Navigant Research, 2016). However, today its deployment is at an intermediate stage of development. One fact that illustrates this situation is that among the most relevant agents in the industry there is no single and consistent definition of what is called distributed generation. The confusion in its definition, establishes a significant difficulty to mark a dividing line in terms of characterization and configuration.

The configuration of a DGS has a number of elements that do not differ from those of a centralized system, although with a potential greater penetration of non-conventional generation due to a more suitable dimension of the storage elements (Stadler, 2016). Therefore, the different configurations of the elements of a DGS depend fundamentally on:

- The degree of penetration of renewable generation (Conde, 2016) and the related need for back up.
- Its insulation or connection to the electrical T&D network (Anaya, 2015).

The level of technological maturity of a DGS, as an integrated system, is that of its weakest element (Patrao, 2016). In particular, the elements of generation, internal distribution and connection to the network as well as the operating equipment show a greater degree of technological maturity than the systems of storage and management of the demand.

However, the specific characteristics of the customer, the degree of penetration of unconventional technology and the connection to a T&D network establish the need for storage and demand management systems determining the degree of technological maturity of the DGS (Luo, 2015).

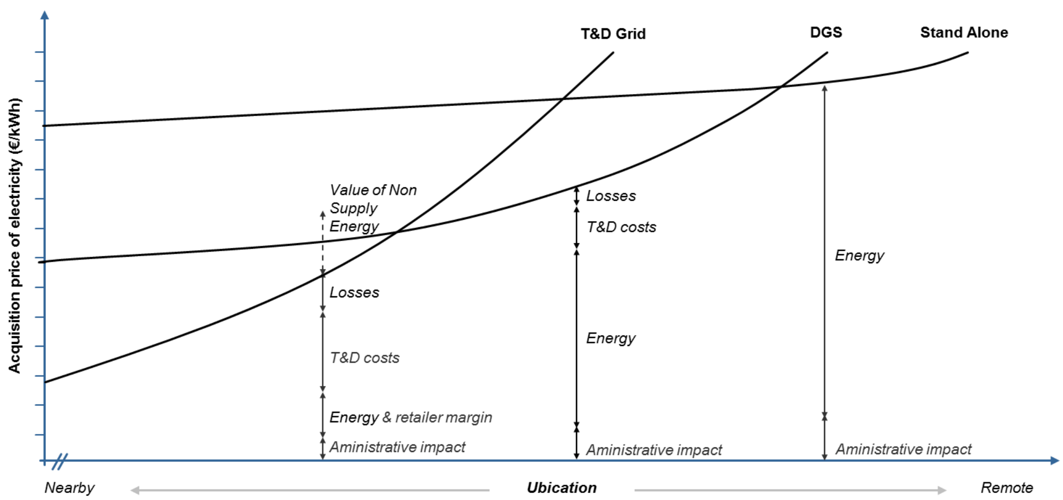
2. Objectives

In economic terms, the decision to develop a specific electrification model (Urtasun, 2015) against another is determined by:

- The location: electricity retail price, network extension cost, network losses, power outages, etc.
- The electricity supply: volume of demand to be covered, number of the supply points, dispersion of loads, etc.
- The location: obsolescence of the infrastructures, distance to the T&D network, complexity of the terrain, density of loads, etc.

A "niche" in which the distributed supply model can offer a acquisition cost lower than that associated with the centralized model through the network extension of T&D is possible to identify in some locations, for a type of supply and a specific location (Figure 3).

Figure 3: Identification of the "niche" for the deployment of an DGS



The purpose of this article is to provide the necessary tools to identify this "niche" of distributed generation systems in the energy-intensive industries, for this aim it is intended:

- Clarify the decision-making process and criteria to establish the most appropriate electricity supply model for any customer.
- Evaluate the suitability, in economic terms for the industry, for the development of alternative decentralized energy supply models based on renewable technologies.

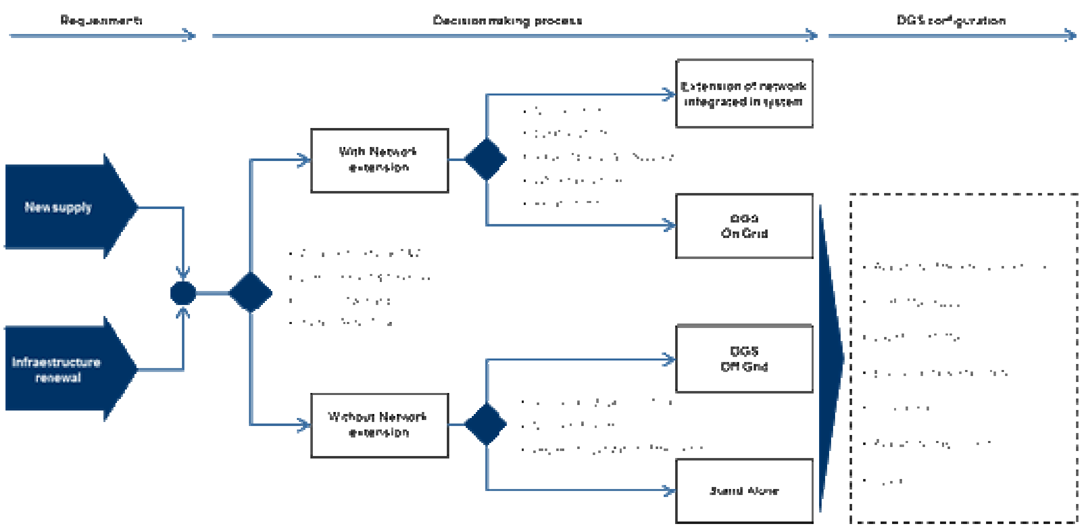
3. Methodology

Decision-making in the development of an electricity supply solution is a complex process in which the degree of integration in the T&D network must be determined and the degree of renewable penetration determined according to its location (Allan, 2015). For this objective, a decision-making process has been established among the different solutions (Figure 4).

- Firstly, a need to meet a specific energy demand should be identified: a new electricity supply or the renovation of obsolete or economically inefficient infrastructure.

- Secondly, it must be assessed whether the proposed solution must be made through the current electricity distribution system or deployed in isolation based on the distance to the grid, its losses, the demand to be covered and the retail price (Mitra, 2016).
    - If the consumer must be connected to the network, an assessed between to extend the current centralized network or develop an DGS On Grid should be made base on the quality and reliability of the network and the value of energy not supplied.
    - If the consumer should not be connected to the network, the typology of DGS Off Grid should be evaluated according to the number and dispersion of loads.
- Finally, in the case that the most economically efficient solution is a DGS, the configuration of the DGS should be determined by considering others variables such as the availability of renewable resource, the cost of procurement and logistic of fuel, as well as criteria of sustainability, availability of equipment , Physical space, etc.

Figure 4: Decision making process on the different power supply solutions



Once the process and the decision-making criteria have been clarified, an economic model has been constructed that bases its analysis on the comparison of the prices of electricity supply associated with each solution. This model allows, based on a series of parameters related to the supply and location to identify those geographies where its development is more profitable regarding its economic viability.

In the initial phase of the study, a comparison of electricity supply prices between the centralized network extension model and the distributed generation model was carried out. An indicator has been defined (IEEDGS) that will allow us to assess the economic efficiency of the DGS versus the solution based on the extension, over the lifetime of the project. If the value of the IEEDGS is positive, the electricity supply through the distributed generation system will be economically more efficient than the extension of the current T&D network.

$$IEEDGS = NEP - DGSP \quad (1)$$

$$NEP = RP/(1 - NL) + EC + CNSE \quad (2)$$

$$EC = (UEC \cdot DN) / CD \quad (3)$$

$$CNSE = SIF \cdot SID \cdot VNSE / CD \quad (4)$$

$$DGSP = LCOE + EC \quad (5)$$

$$LCOE = COL / EPOL \quad (6)$$

$$COL = \Sigma_{i=1;n} (CAPEX_i + OPEX_i / (1 + DR)^\wedge i) \quad (7)$$

$$EPOL = \Sigma_{i=1;n} (Energy_i / (1 + DR)^\wedge i) \quad (8)$$

IEEDGS: Economic efficiency of DGS Index ($/MWh)

- NEP: Network extension price ($/MWh)
  - RP: Retail price ($/MWh)
  - NL: Network losses (%)
  - EC: Extension cost ($/km)
    - UEC: Unitary extension cost ($/km)
    - DN: Distance to transmission and distribution network (km)
    - CD: Total demand over project lifetime (MWh)
  - CNSE: Cost of non-supply energy ($/MWh)
    - SIF: System average interruptions frequency (# - year)
    - SID: System average interruptions duration (h/#)
    - VNSE: Value of non-supply energy ($/MWh)
- DGSP: Distributed generation system price ($/MWh)
  - LCOE: Levelized cost of energy ($/MWh)
    - COL: Investments & expenses over project lifetime ($)
      - CAPEX: Capital expenses ($)
      - OPEX: Operation expenses ($-year)
      - DR: Discount rate (%)
      - N: Project life time (years)
    - EPOL: Energy produced over project lifetime (MWh)

Next, the sensitivity of the result was analyzed according to the variability of the location (Abu-Mouti, 2011). For this purpose, the distance between the supply and the T&D network where the price associated with the network extension is equal to the price of the DGS has been identified. In others words, the distance that makes zero the IEEDGS.

$$IEEDGS = NEP – DGSP = 0 \quad (9)$$

$$NEP = DGSP \quad (10)$$

Finally, the profitability associated to a distributed generation project according to the type of customer has been analyzed and has been compared with the retail offer price, determining the degree of economic viability per country and geography. For this purpose, the project IRR has been modeled based on the related cash flow:

$$PIRR = (-INV + \Sigma_{i=1;n}(CF_i))/\ \Sigma_{i=1;n}(i \cdot CF_i) \quad (11)$$

$$CF_i = INC_i - EXP_i \quad (12)$$

$$INC_i = (RINC_i + WINC_i)/(1 + DR)\text{^}i \quad (13)$$

$$RINC_i = ELS_i \cdot ARP \rightarrow when\ ARP<MRP \quad (14)$$

$$WINC_i = ELG_i \cdot WP \quad (15)$$

$$EXP_i = (CAPEX_i + OPEX_i + FUC_i + COMC_i + FINC_i)/(1 + DR)\text{^}i \quad (16)$$

$$COMC_i = MAC_i + COC_i + CCC_i \quad (17)$$

$$FINC_i = PC_i \cdot IR \quad (18)$$

PIRR: Project internal rate of return (%)

- INV: Investment ($)
- CF: Cash flow ($)
  - INC: Incomes in year i ($)
    - RINC: Retail incomes ($)
      - ELS: Electricity supplied to customer (MWh)
      - ARP: Agreed retail price ($/MWh)
      - MRP: Market retail price for industrial customers ($/MWh)
    - WINC: Wholesale incomes ($)
      - ELG: Electricity fed into the grid (MWh)
      - WP: Wholesale price ($/MWh)
    - DR: Discount rate (%)
  - EXP: Expenses in year i ($)
    - CAPEX: Capital expenses ($)
    - OPEX: Operation expenses ($ - year)
    - FUC: Fuel costs ($)
    - COMC: Commercial costs ($)
      - MAC: Marketing and acquisition costs ($)
      - COC: Commercial operation costs ($)
      - CCC: Customer care costs ($)
    - FINC: Financial costs ($)
      - PC: pending capital ($)
      - IR: interest rate (%)

4. Case study

A case study of an energy-intensive type industry with specific requirements in relation to its electricity supply has been assumed (Table 1).

Table 1. Case study

Parameter	Value	Unit
Customers	1	-
Supply points	10	-
Unitary capacity	1,000	kW
Total capacity	10	MW
Demand	40	GWh-y
Density of loads	0.7	Km2
Distance to T&D network	10	Km
Project useful life	30	Años

Note: in many of the analyzed markets consumers with annual demands greater than 100-150 GWh can be supplied directly in the wholesale market.

For the proposed case study, a solution of a distributed generation system has been designed (Table 2).

Table 2. DGS solution designed for the study case

Elements	Dimensión	Unidad	F. Carga	Unidad
Generation:				
Solar photovoltaic system	12,000	kW	30	%
Diesel engine	2,000	kW	80	%
Storage (2 cycles – day)				
Lithium-Ion batteries	1,800	kW		

Next, a sample of 93 countries has been taken according to their geographic location: Europe (31 countries), America (23), Africa (24) and Asia- Pacific (15). For each of the countries identified, the following information was obtained:

- Electricity retail price for industrial customer ($/MWh)
- Electricity wholesale price ($/MWh)
- Cost of the network extension for low and medium voltage ($/km)
- Losses in the transmission and distribution network (%)
- Number (#) and duration (hours) of supply outages
- Value of the Energy not supplied for an industrial customer ($/MWh)
- Cost of supply ($/Ton) and logistics ($/km-Ton) of fuels

Finally, for the different generation technologies, as well as for storage elements, internal distribution infrastructures and operating and management systems, the following information has been obtained:

- Initial and replacement investment CAPEX ($/MW)
- Operation and maintenance costs OPEX ($/MWh-year)
- Fuel cost ($/MWh)

5. Results

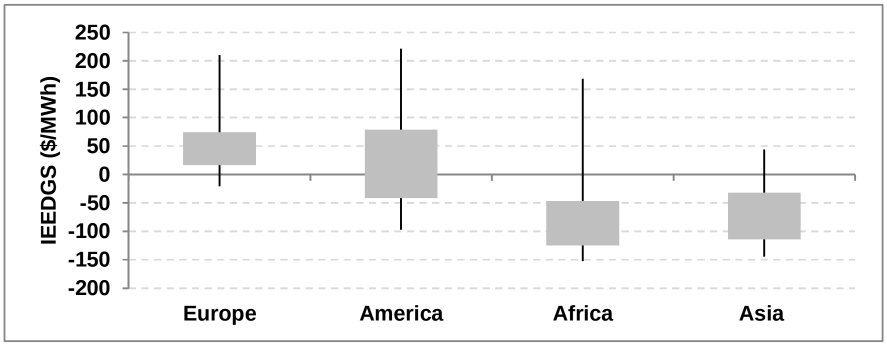
Considering the IEEDGS index, the electricity supply (for the case study analyzed) through a distributed generation system for an industrial consumer is economically more efficient than through an extension of the existing T&D network in 53% of the analyzed countries (Table 3).

Table 3. IEEDGS for each of the selected countries

Europe		America		Africa		Asia	
Country	IEEDGS ($/MWh)	Country	IEEDGS ($/MWh)	Country	IEEDGS ($/MWh)	Country	IEEDGS ($/MWh)
EU 1	210.2	AM 1	221.2	AF 1	168.6	AS 1	44.0
EU 2	154.5	AM 2	214.5	AF 2	75.3	AS 2	16.3
EU 3	127.4	AM 3	132.7	AF 3	68.7	AS 3	4.5
EU 4	124.3	AM 4	117.3	AF 4	62.9	AS 4	-10.2
EU 5	121.6	AM 5	86.5	AF 5	-18.4	AS 5	-53.3
EU 6	98.3	AM 6	86.4	AF 6	-36.9	AS 6	-61.9
EU 7	81.9	AM 7	71.9	AF 7	-50.0	AS 7	-62.9
EU 8	74.4	AM 8	54.6	AF 8	-65.1	AS 8	-65.7
EU 9	74.1	AM 9	46.6	AF 9	-75.1	AS 9	-91.7
EU 10	66.7	AM 10	38.6	AF 10	-75.6	AS 10	-101.4
EU 11	65.7	AM 11	35.5	AF 11	-94.8	AS 11	-110.2
EU 12	59.4	AM 12	33.3	AF 12	-110.0	AS 12	-117.6
EU 13	53.7	AM 13	11.1	AF 13	-110.0	AS 13	-129.0
EU 14	52.0	AM 14	7.7	AF 14	-113.7	AS 14	-130.7
EU 15	50.8	AM 15	-24.8	AF 15	-113.8	AS 15	-144.4
EU 16	43.7	AM 16	-36.6	AF 16	-116.3		
EU 17	39.7	AM 17	-37.7	AF 17	-123.6		
EU 18	39.6	AM 18	-45.2	AF 18	-123.8		
EU 19	38.7	AM 19	-57.2	AF 19	-128.4		
EU 20	36.6	AM 20	-60.0	AF 20	-131.8		
EU 21	30.5	AM 21	-65.7	AF 21	-134.9		
EU 22	24.9	AM 22	-82.1	AF 22	-142.9		
EU 23	20.2	AM 23	-97.3	AF 23	-147.9		
EU 24	13.5			AF 24	-152.7		
EU 25	11.7						
EU 26	6.2						
EU 27	5.4						
EU 28	2.2						
EU 29	-3.5						
EU 30	-6.4						
EU 31	-20.9						

However, considering the specific results according to the different geographies the IEEDGS varies substantially (Figure 5).

Figure 5. IEEDGS values for each of the geographies analyzed



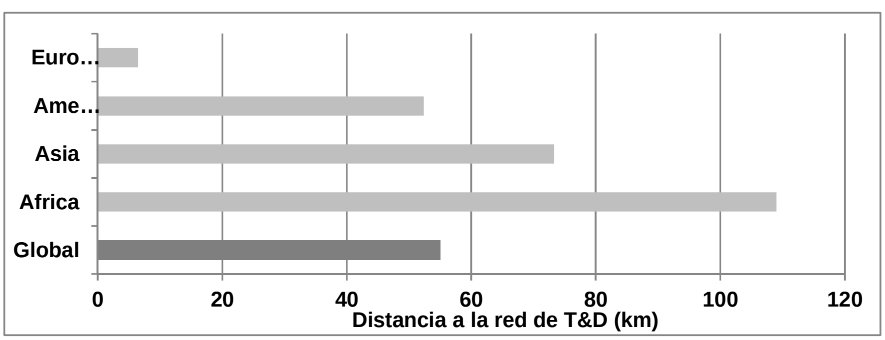
In particular, the following results could be highlighted:

- IEEDGS index shows positive values in: 90% of the European countries, 61% of the American countries, 17% of the African countries and 20% of the Asian countries.
- Average value for IEEDGS is: 54.7 $/MWh in Europe, 28.3 $/MWh in America, -62.1 $/MWh in Africa and -67.6 $/MWh in Asia.

The highest values in Europe and America compared to Africa and Asia are due to high retail prices of electricity for industrial customers in some countries, along with lower technological cost of distributed generation elements.

Additionally, the average distance by geography in which the value of IEEDGS is zero has been calculated. From this distance -always considering average values- where the electricity cost of the DGS is equal to the industrial retail price, the implementation of a DGS is more profitable than the network extension (Figure 6).

Figure 6. Average distance where IEEDGS is equal to zero according to geographies



Similarly, the profitability of a standard distributed generation project for an industrial consumer varies significantly depending on its location. For this exercise, it has been estimated that the distributed generation system is connected to the T&D network, establishing a bidirectional flow of electricity and, consequently, an increase in revenues from the excess of power generation and its value in the wholesale market of each country.

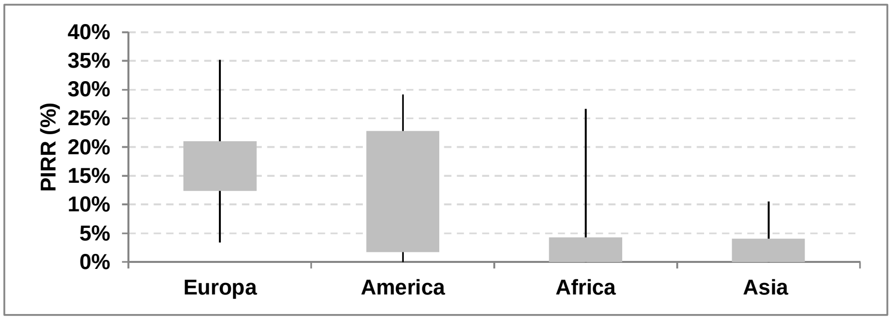
Consequently, in addition to the retail price that determines the highest sale price of the electricity from DGS, the wholesale price is one of the most relevant parameters to determine the economic viability.

The electricity supply (for the case study) through an on-grid distributed generation system for an industrial consumer is profitable in 68% of the countries analyzed (Table 4).

Table 4. Profitability of an DGS OnGrid for each of the selected countries

Europe		America		Africa		Asia	
Country	PIRR (%)	Country	PIRR (%)	Country	PIRR (%)	Country	PIRR (%)
EU 1	35.2%	AM 1	29.0%	AF 1	26.7%	AS 1	10.6%
EU 2	27.9%	AM 2	29.0%	AF 2	18.7%	AS 2	7.3%
EU 3	28.1%	AM 3	29.2%	AF 3	12.5%	AS 3	9.0%
EU 4	29.0%	AM 4	25.4%	AF 4	11.8%	AS 4	6.2%
EU 5	22.1%	AM 5	23.0%	AF 5	4.7%	AS 5	1.8%
EU 6	28.8%	AM 6	22.7%	AF 6	4.0%	AS 6	-
EU 7	23.7%	AM 7	22.2%	AF 7	3.8%	AS 7	1.6%
EU 8	19.9%	AM 8	20.5%	AF 8	4.2%	AS 8	-
EU 9	18.9%	AM 9	15.4%	AF 9	-	AS 9	-
EU 10	22.8%	AM 10	14.6%	AF 10	6.8%	AS 10	-
EU 11	16.8%	AM 11	14.9%	AF 11	-	AS 11	-
EU 12	18.9%	AM 12	11.6%	AF 12	-	AS 12	-
EU 13	18.1%	AM 13	23.0%	AF 13	-	AS 13	-
EU 14	17.0%	AM 14	11.7%	AF 14	-	AS 14	-
EU 15	20.0%	AM 15	-	AF 15	-	AS 15	-
EU 16	16.6%	AM 16	12.1%	AF 16	-		
EU 17	15.9%	AM 17	12.5%	AF 17	-		
EU 18	12.9%	AM 18	-	AF 18	-		
EU 19	12.8%	AM 19	-	AF 19	-		
EU 20	15.3%	AM 20	-	AF 20	-		
EU 21	17.1%	AM 21	3.5%	AF 21	-		
EU 22	12.4%	AM 22	-	AF 22	-		
EU 23	12.4%	AM 23	-	AF 23	-		
EU 24	11.9%			AF 24	-		
EU 25	10.2%						
EU 26	7.8%						
EU 27	7.9%						
EU 28	14.0%						
EU 29	9.0%						
EU 30	3.4%						
EU 31	11.5%						

Figure 7. PIRR values for each of the geographies analyzed



In particular, the following results could be highlighted (Figure 7):

- PIRR index shows positive values in: 100% of the European countries, 61% of the American countries, 17% of the African countries and 20% of the Asian countries.
- PIRR average value is 17.4% in Europe and 13.9% in the Americas. However, it should be noted that although the average profitability of a DGS project is lower in Africa and Asia, it is possible to identify opportunities with significant returns in some countries.

6. Conclusions

During the past few years, a shift in the power supply model is being identified towards more decentralized and renewable systems due to greater competitiveness and maturity of the related technology. Three criteria must be taken into account to identify which supply model is most appropriate: economic efficiency, security of supply and sustainability. However, in the particular case of the industrial sectors, security of supply and economic efficiency generally prevail. This article aims to clarify this decision process and provide the tools to identify the most economically efficient model of electricity supply to improve the competitiveness of the energy-intensive industries.

The results obtained allow us to assume that, under certain conditions, the decentralized supply model based on distributed renewable generation system (DGS) is more efficient and profitable than the centralized network extension one:

- A DGS is economically more efficient in 53% of the countries analyzed, in particular:
  - Europe: in 90% of the countries due a high retail prices, with an average reduction of 54.7 $/MWh (for 40 GWh-year would represent savings of ~ 2.2 M$-year).
  - America: in 61% of countries, with an average reduction from retail price of 28.3 $/MWh (for 40 GWh-year would represent savings of ~1.1 M$ -year).
  - In the case of Africa and Asia, where the industrial retail price is lower, the network extension model is more efficient in 82% of the countries. However, it is possible to identify specific countries where the DGS is the most interesting option.
- A DGS is economically more profitable in 68% of the countries analyzed:
  - Europe: in 100% of the countries, with an average investment return of 17.4%.
  - America: in 74% of the countries, with an average investment return of 13.9%.
  - Africa: in 38% of the countries, with an average investment return of 3.9%.
  - America: in 40% of the countries, with an average investment return of 2.4%.

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