# Impacts of small units for electricity generation

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**Abstract**
This paper gives an overview of all positive and negative impacts of the shift from large to small installations for electricity generation, as seen from the viewpoint of the different stakeholders. The impacts are summarized in the form of an impact matrix related the impacts to the stakeholders. The impact matrix is an appropriate tool for finding situations in which the introduction of small generation has positive impacts for most of the stakeholders involved.

**Keywords:** Electric power generation; renewable energy; electric power systems; combined heat and power generation.

## 1. Introduction

The availability of reliable and cheap electrical energy is an essential condition for the way-of-life in large parts of the world. In industrial countries the vast majority of electrical energy is generated in large power stations using hydropower, nuclear power or fossil fuel as a source of primary energy. Recently has seen a shift towards the generation of electricity by smaller generator units. Wind power is the most visible exponent of this, but also solar power, combined-heat-and-power and small hydro, are examples of these so-called "distributed energy resources" (DER). Although environmental concerns are often cited as the reason for installation of small units, there are other driving forces as well.

## 2. Large versus small generation

Most electric power is generated in large installations, with sizes between 100 MW and more than several 1000 MW, often located relatively far away from the customers. Different sources of primary energy are used for electricity generation in large power stations; with fossil fuel (gas, oil, coal), hydropower and nuclear power forming the vast majority. The electricity is next transported to the end-users through the power transmission and distribution system.

Recently has seen an increased interest in power generation by means of smaller units, from several MW down to less than 1 kW (the power consumption of one household is in the range between 1 and 10 kW). These small units are referred to as "distributed generation" or "distributed energy resources", contrary to the term "centralized generation" used for the large units. The fraction of energy produced by distributed generation is, with some exceptions, not more than a few percent of the total production. However a significant increase is expected and/or deemed necessary by many. Environmental and energy-political arguments are often used, but also local cost savings and reliability improvements are mentioned as an argument. We will come back to this in more detail further down in this paper.

Distributed energy resources come in different forms. Wind and solar-power installations are probably the most visible examples. Especially wind power is expected to grow significantly in the future. However the biggest fraction with the highest growth potential is formed in some countries by so-called combined-heat-and-power (CHP) installations. CHP installations are in use in industrial installations where a high electricity demand goes together with a large heat demand. Examples are the pulp-and-paper industry and the petrochemical industry. The size of these installations ranges from a few MW up to a few hundred MW. A future growth segment is the use of CHP installations for smaller industries, for office buildings, for district heating and even for individual households. The heat will in those cases mainly be used for space heating.

This list is not exclusive and other applications will certainly be found. For example, Distributed Energy Sources may reveal of interest in some specific cases such as:

- The metropolitan areas where the DSO has little remaining capacity and very high cost of reinforcement of the power network
- The regions where the actual electricity price is sufficiently high for DER to become economically feasible
- The rural or isolated areas where the high cost of transmission lines makes the initial investment and the operation costs not attractive
- For consumers with high power reliability or quality demands DER may serve as a reliable backup source when the public supply is temporarily not available or not sufficiently reliable or when the electricity price is temporarily too high.
- For the increased use of renewables, where policy makers intend to favour increased security of electricity supply.

The introduction of distributed energy resources will have a wide range of impacts, including impacts on health and lifestyle. A thorough understanding of all the driving forces is needed to allow an increase of the amount of distributed energy resources. In the same way, the negative impacts have to be known in order to allow any, technical and non-technical, barriers against the introduction of distributed energy resources to be removed.

## 3. The Stakeholders

The following stakeholders will be impacted by the shift from large (centralized) to small (distributed) generation.

**END USER:** the consumer of the electrical energy and often a separate energy source (like gas) for room and water heating. The end user may invest in small generation and sell electricity either to an aggregator or directly to the DSO or a centralized generator company.

**AGGREGATOR**: any marketer, broker, public agency, city, county, or special district which combines the loads of multiple end users in facilitating the sale (“supply aggregator”) and purchase (“load aggregator”) of electricity, transmission, and other services on behalf of these customers. The aggregator manages the commercial balances of small consumers and/or local producers and partakes in the markets by buying/trading electricity on their behalf. The aggregator may even become the contact point for the distribution and transmission-system operators.

**TSO - TRANSMISSION SYSTEM OPERATOR**: the entity that is responsible for the transport of electricity in large amounts over long distances (typically nation-wide) on the high-voltage interconnected systems.

**DSO - DISTRIBUTION SYSTEM OPERATOR**: the entity that is responsible for the transport of electricity on the medium-voltage and low-voltage interconnected systems, from the transmission system to the end-users. The costs of DSO and TSO are charged to the end-users, typically in the form of a fixed connection fee and an amount per transported kWh.

**ISO - INDEPENDENT SYSTEM OPERATOR:** entity that controls the whole system: "transmission network + distribution network + generators" to ensure a reliable power supply to the consumers. In many countries this role is played by the TSO.

**MANUFACTURER**: manufactures and sells small-generation equipment.

**FOSSIL FUEL SUPPLIER:** transports and sells fossil fuel. Depending on the regulation, these transport and sales may be the responsibility of independent entities.

**CENTRALIZED GENERATOR**: the entity that owns large (centralized) generation facilities and sells the electricity to end-users, either through bilateral contracts or on the electricity market.

**REGULATOR:** ensures that the system and market operate according to the rules, guaranteeing non-discriminatory access to the network, and giving support and incentive to the research, development and demonstration of the new technologies and promote the new policies.

**POLICY MAKER:** elaborates the laws and directives for a fair game in the context of a liberalised energy market.

**FINANCIAL INVESTOR:** invests in small generation units to make profit.

# 4. Impacts on the Stakeholders

The impacts brought by Distributed Energy Resources (DER) deployment are 22 and can be "clustered" as follows:

- Main impacts to the end consumer (5)
- Impacts related to Power Quality (3)
- Economic impacts (1)
- Main impacts for grid operators (7)
- Societal impacts (6)

## 4.1. Main impacts to the end consumer

Savings on electricity bills. The difference between the cost of buying electricity from the grid and the cost of generating electricity on site is an important incentive for the end-user. When the surplus amount can be sold back to the grid, the savings will be even bigger and may result in a net profit.

Savings on heating bills. Combined heat and power is the recovery of electricity generation from waste heat to meet heating/cooling needs. The total energy consumption for heating and electricity will be less for the end-user than when using separate installations. Although there is no limit on the size of CHP installations they are most efficient at a small to medium scale due to the inefficiency of transporting heat over long distances.

Consumer electricity cost protection. Onsite power generation allows the end-user to become less dependent on short and long-term variations in the costs of electricity. At the short time-scale the end user has the option of choosing between locally generated electricity of electricity bought on the market.

Power reliability variation. The presence of a local power source allows for a reduction of the number and duration of supply interruptions as experienced by the consumer.

Consumer behaviour change. DER can meet some subjective and ethical needs expressed by the end users, as energetic independence and environment protection. DER can thus allow the consumer to decide on its consumption sources and behaviour.

DER can meet the requirements of end users seeking for energy independence, and a better control on their own consumption thanks to a direct monitoring of their load, providing them the opportunity to measure the effects of changing the energy consumption behaviours. Environmental protection and clean power use (green electricity certificates)

## 4.2. Impacts related to Power Quality

Power quality - enhanced risk of damage. An increased (uncontrolled) penetration of DER will most likely lead to an increase of the number and severity of voltage disturbances. This in turn will lead to further reduction in lifetime, more erroneous tripping and more equipment damage with the consumer.

Power quality - voltage disturbances / voltage support to the grid. The connection of a DER unit to the grid modifies the voltage along the grid. This must be handled by the TSO/ISO. Difficulties to maintain voltage stability in the transmission system increase as the penetration of DER increases.

Power quality - improved meeting of customer expectations. By controlling the power output and current waveform of DER units, an improved power quality and reliability can be achieved for some customers or possibly even for the whole grid. The introduction of DER will thus allow a customization of the offer regarding voltage quality to the consumer.

## 4.3. Economic impacts

Economic flows. An increase in electricity generation close to the customer will lead to a reduced production in large installations and reduced power flows through the transmission and distribution networks. The reduced production and power flow will have an immediate impact on the income of those companies. The ISO will have to set new rules for the price setting of DSO and TSO.

However, the deployment of DER will lead to an increase in sales for technologies associated with small generation and its grid connection and in sales for primary energy sources.

## 4.4. Main impacts for grid operators

Distribution capacity deferral. Already small amounts of DER, if suitably located, will enable a reduction of overloads on distribution systems. This allows the DSO to defer investments to mitigate these overloads. Even random growth of DER (i.e. driven purely by the end user) may alleviate overloads.

Transmission capacity deferral. Larger amounts of DER will have a mitigating effect on transmission-system loading, this allowing a deferral of investments in the transmission system.

Generation capacity deferral and stranded assets. A growth in DER will lead to a reduction in the central power demand. For central generators, this demand reduction may have positive (capacity deferral) or negative (stranded assets) effects, considering either a short-term or a long-term perspective.

Reduction of demand peak load. An overload situation at transmission or distribution level can be alleviated by the DSO or TSO "buying" capacity from DER units. This will reduce the need for planned interruptions and increase the reliability of the supply.

Reduced resistive loss of the grid. Generating the electricity close to the end-user (as is the case with DER) reduces the electricity losses associated with the power transport.

Improved planning of normal grid operation. Assuming the DSO and TSO have some kind of control over the DER units, these can be used as an additional tool for improved network operation. The control over the smallest units will likely take place via an aggregator. Alternatively, the DSO or TSO may own and operate DER units themselves.

Improved management of contingency events. DER units may even be of assistance to the DSO or TSO during system emergencies. This however requires an automatic system that is able (and allowed) to intervene in the operation of the DER unit. This requires major investments on both sides of the meter and contractual agreement.

### 4.5. Societal impacts

Energy savings at national level. The higher efficiency of combined-heat-and-power, renewable energy sources and the reduction of losses, lead to energy savings at a national level.

Environment and health issues. Fuel-based electricity generation (CHP) leads to additional indoor and outdoor emissions. The transport of the fuel may have adverse environmental impact. Different levels of noise and visual impact are associated with the various technologies.

Grid electricity demand / price elasticity. The widespread use of generation by the end-user increases the electricity demand elasticity, which may bring about a reduction of electricity prices to the benefit of all consumers.

Land use and population resistance. Local generation of electricity gives consumers a large choice of location for their activities and can encourage urban sprawl, with negative effects on the environment. Certain technologies such as PV or wind power require much more space to generate a given amount of energy. The installation of DER units in specific locations may bring less or more resistance from the population than with central plants

Diversification of energy supply. Large deployment of DER means a diversification of energy supply sources. This lowers dependency towards suppliers and thus increases negotiation margins.

Increased profitability of DER markets. Small generation may be considered as an investment inducing future cash flows and profits to recover the initial investment.

## 5. The Impact Matrix

The current deregulation of the electricity markets, coupled with the deployment of distributed generation, has made these markets more complex:

- Deregulation has brought many new actors in the game;
- The increasing use of distributed energy resources has dramatically changed the relations between the electricity actors: the relation is evolving from a simple, one-way flow (from the utility to the end customer), to numerous, and complex interactions (many actors generate, consume, buy, and sell electricity).

This new complexity of the electricity markets allows for a more diversified offer in energy, i.e. more choice and more autonomy for the end consumer; but it also leads to less visibility on the market.

The Impact Matrix is a tool that helps appraising the impacts brought by distributed energy resources in a systemic way, i.e. by taking account of all interactions between the different stakeholders.

Indeed, each of the impacts mentioned above can affect the various stakeholders in a different way (weak, strong, major, no impact): enabling the deployment of distributed energy resources means to seek for win-win-win situations, where:

- the consumer wins;
- the grid actors win;
- the society as a whole wins.

Moreover, the impacts of distributed energy resources get stronger as the penetration level of small generation increases. These impacts must thus be studied under two extreme scenarios of DER penetration level (low/ high penetration rate).

The matrix below summarizes the intensity of the different DER impacts under a high penetration scenario. The colours and letters refer to the level of impact: major (M); strong (S) or weak (W). For the white cells the impact is nil or negligible.

| IMPACTS | End user | Aggregator | Manufacturer | Fossil fuel provider | DSO | TSO | ISO | Centralized generator | Regulator | Policy maker | Financial investor |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Savings on energy bills | M | M | | | | | | | | | S |
| Improved energy use efficiency | M | S | | | | | | | | | |
| Consumer electricity cost protection | M | M | | | | | | | | | W |
| Power reliability variation | M | M | | | | | S | S | M | M | |
| Power quality - Enhanced risk of DER equipment damage | M | M | M | | | | S | | | | M |
| Power quality – improved meeting of customer expectations | M | M | | | M | M | S | | | | |
| Consumer behaviour change | M | M | | | | | | | | | S |
| Economic flows | | | M | M | M | M | S | M | | | |
| Distribution capacity deferral | | | | | M | | | | | | |
| Transmission capacity deferral | | | | | | M | | | | | |
| Generation capacity deferral | | | | | | | | S | | | |
| Power quality - Voltage disturbances along the grid | | | | | M | M | M | | | | |
| Grid congestion relief | | | | | M | M | M | | | | |
| Reduced resistive loss of the grid | | | | | M | M | | | | | |
| Improved planning of normal grid operations | | | | | S | S | M | S | | | |
| Improved management of contingency events | | | | | S | S | M | | | | |
| Energy savings | | | | | | | | | | M | |
| Environmental /health issues | M | | | | | | | | M | M | |
| Elasticity of grid electricity demand /price | M | M | | | | | | | S | S | |
| Land use/population resistance | | | | | | | | | W | S | |
| Diversification of supply | | | | | | | | | | S | |
| Increased profitability of DER markets | | | | | | | | | | | M |

## 6. Conclusions

The shift from large (centralized) generation to small (distributed) generation has a range of impacts for a range of stakeholders. If a number of stakeholders are significantly adversely affected, this will lead to serious barriers against the widespread introduction of small generation. The integrated EU-DEEP project aims at finding business opportunities were the introduction of small generation will provide a win-win situation for all stakeholders involved. The impact matrix is an appropriate tool for finding such a win-win situation.


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