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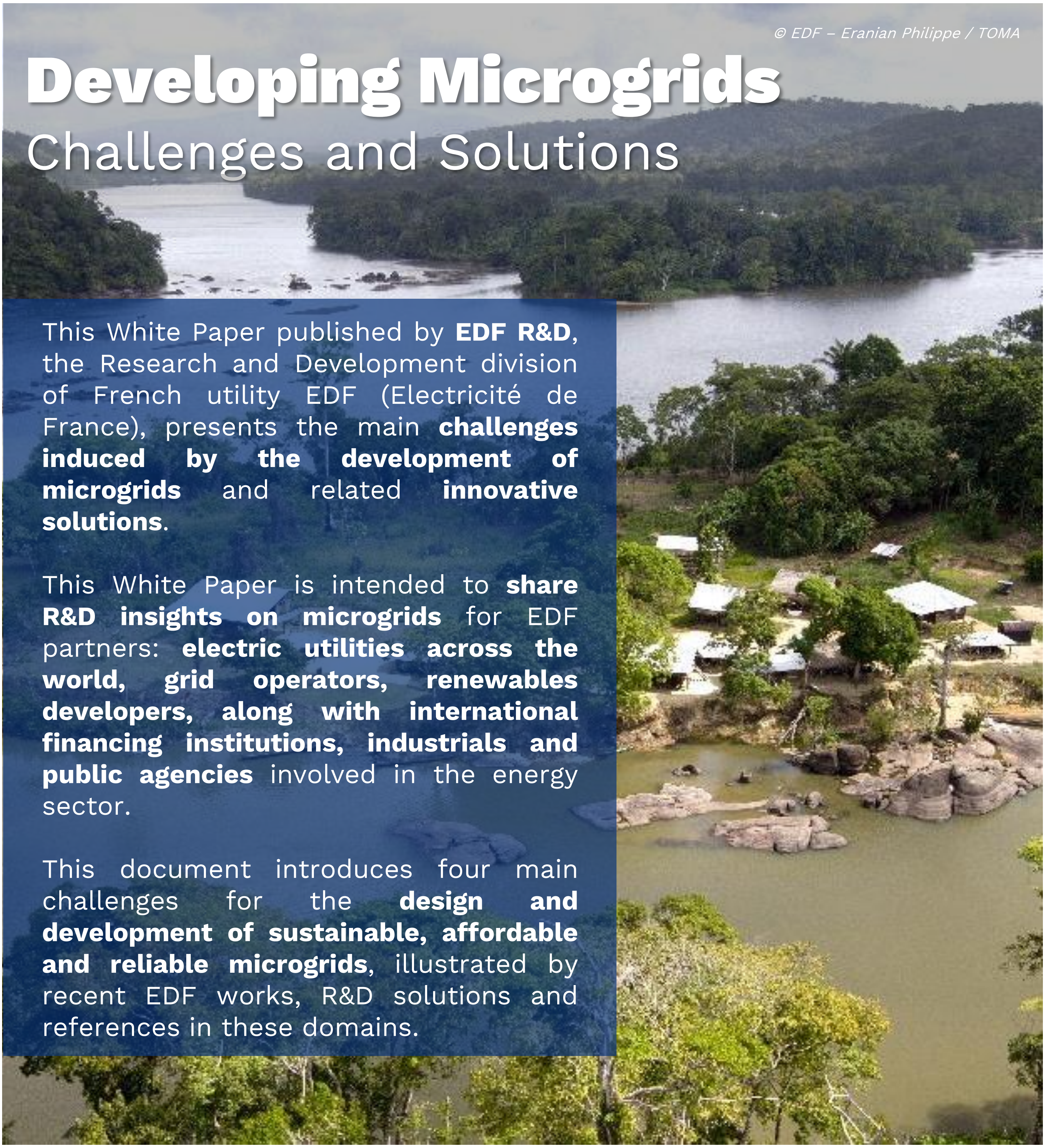
R&D WHITE PAPER



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Developing Microgrids

Challenges and Solutions

This White Paper published by **EDF R&D**, the Research and Development division of French utility EDF (Electricité de France), presents the main **challenges induced by the development of microgrids** and related **innovative solutions**.

This White Paper is intended to **share R&D insights on microgrids** for EDF partners: **electric utilities across the world, grid operators, renewables developers, along with international financing institutions, industrials and public agencies** involved in the energy sector.

This document introduces four main challenges for the **design and development of sustainable, affordable and reliable microgrids**, illustrated by recent EDF works, R&D solutions and references in these domains.

Designing efficient, reliable and low-carbon microgrids

In the current context of "energy transition" and the trend towards decentralization of energy systems, **microgrids** have emerged in the recent years as an additional solution to provide efficient, reliable, and low-carbon electricity supply. Their development however implies **major challenges** for power systems stakeholders.

Individual rural electrification	1 client	10-300 W	Non-critical loads
Collective rural electrification	100 to 10,000 clients	100 kW to 10 MW	Non-critical and critical loads
Commercial, Industrial, & Government	1 client	500 kW to 10 MW	Critical loads

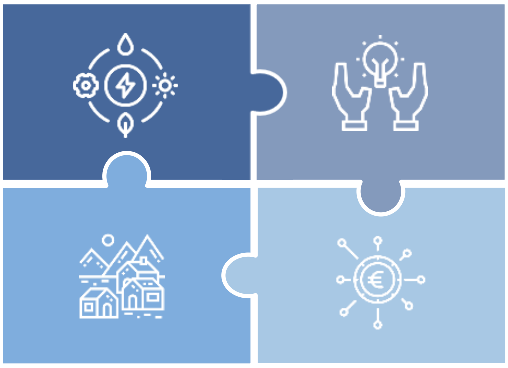
A wide variety of microgrids

Although there are several definitions, microgrids generally include **generation assets** (solar panels, wind turbines, biomass, diesel gensets...), **electric loads** of industrial, commercial and residential clients, **control & optimization systems**, and **Medium Voltage/Low Voltage grids.** Typically, microgrids are fully isolated power systems but they can also be connected to local distribution grids with islanding capabilities.

Microgrids may be small in size or installed capacity but they are not necessarily simple to design, implement, and operate. They basically are comprehensive power systems **facing most of larger systems' issues and needs**. Designing and developing microgrids therefore requires **specific skills** spanning across optimal design and engineering, procurement, construction and operational phases. Microgrids development goes through sound economic assessment, adapted financing schemes and specific organization with stakeholders and partners.
As microgrids are **not one-fits-all solutions**, their development therefore implies a **global approach**, covering technical, economic, regulatory, environmental and social dimensions. Implementing operational microgrids ultimately deals with addressing **four key objectives**:

DEVELOPING A SUSTAINABLE ENERGY MIX

PROMOTING ELECTRIFICATION AND ASSOCIATED USES



ANTICIPATING IMPACTS ON LOCAL COMMUNITIES

CREATING SOUND BUSINESS MODELS & FINANCING SCHEMES

A significant number of microgrids are being implemented around the world serving several types of customers (residential, commercial or isolated industrial sites). Technical challenges remain, particularly to achieve sustainable microgrids with significant shares of renewables while delivering electricity supply to the clients, meeting expectations in terms of reliability. Economic aspects are key to deliver electricity at a competitive price also taking into account the clients' willingness and ability to pay. Specific business models are being implemented to ensure that microgrids development will provide affordable electricity for the local clients and show sufficient profitability for investors and stakeholders in the long run.

Developing a sustainable energy mix

#1

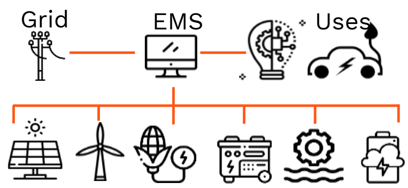
The main challenge is to design microgrids which can contribute to **energy transition and decarbonation objectives**. The electricity they provide should be **low-carbon** but also **affordable** when compared to traditional energy supply. Innovative methods may help to evaluate demand and generation needs in the planning phase, as well as operate the system efficiently in a sustainable way.

Existing solutions

Microgrids using renewable energies can be considered as an **additional solution for decarbonizing the power sector**. They may indeed allow to avoid investments in power plants using fossil fuels (gensets mostly) and drastically reduce emissions from fuel transportation.
In order to promote a sustainable energy mix, microgrids should be designed by **carefully assessing users needs and objectives**.

Local renewable energy resources should then be evaluated in order to assess and select the most appropriate generation assets, taking into account the local environment of the microgrid (economic development, geographic specificities, climatic conditions, etc.). **Solar panels** are usually the main energy source, thanks to their ease of installation and their decreasing costs. Various technological innovations have been developed to increase their efficiency, such as **double-sided solar panels** which produce on average 5% to 15% more energy. **Solar PV and storage containerized solutions** are emerging, allowing to cut down civil engineering costs. Solar energy can be supplemented with **wind**, **hydraulic**, or **bio-energies**, which are increasingly being considered as promising but could represent significant shares of CAPEX and OPEX. **Bio-fuel** derived from sugarcane or rapeseed requires few CAPEX but a higher level of OPEX, in contrast with **solid biomass** made from wood or waste with boilers. **Biogas** may also be used to generate energy from agricultural waste. The choice of these energies will take into account the ability to produce them locally in a sustainable way.

Storage systems will also contribute to optimize the energy mix and avoid energy losses, especially if coupled with PV (battery capacity could be significant in PV-only microgrids). If lithium batteries are predominant, technological innovations provide new opportunities such as zinc-air batteries or the use of second life EV batteries. Microgrids can offer **flexibility solutions**, the energy provided being either directly consumed, stored, or re-injected if connected to a larger grid.
In order to reach an optimal behavior, the energy provided by intermittent renewables needs to be **forecasted**, from a couple of minutes to several hours ahead. To do so, **innovative forecasting tools**, leveraging data from local weather stations and sensors, or meteorological databases are used.
Energy Management Systems (EMS) also constitute a key element for the optimal design, control and operation of microgrids. They can help maximize renewable energies in the mix considering the forecasted demand (load curve) and generation. EMS can be included in smart inverters for smaller systems or be an independent component having a key role for the overall microgrid control and optimization.



They shall also rely on communication **standards to ensure inter-operability** between microgrid equipment.

Besides Modbus or DNP3, **IEC 61850** is becoming a worldwide reference. Microgrid communication channels, software and hardware components should be carefully **secured** from a **cyber** perspective.

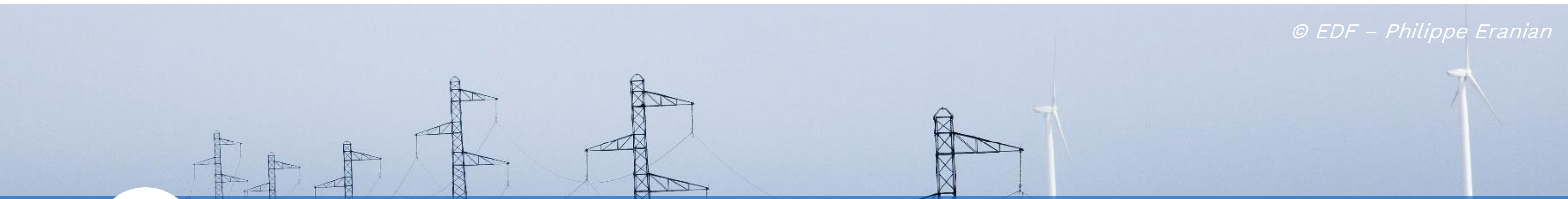
Energy transition in microgrids

Microgrids offer solutions to energy transition challenges for fully islanded systems including in developed countries. Several insular power systems are transitioning to become 100% renewable. That's for instance the case of Sein Island, off the coast of Brittany (France). Today, solar, wind and battery storage are drastically reducing the use of diesel gensets targeting a fully renewable system by 2030.

Sein island (Brittany, France)

LiteDERMS solution

In the frame of the MASERA microgrid demonstrator in Singapore, EDF R&D has developed a novel energy management system (EMS) called Lite-DERMS, which is a simple, affordable and evolutive control solution targeting microgrids in rural areas in particular. The solution leverages EDF R&D expertise in microgrid controls and software architecture. Its fast and easy commissioning was proven during on-site testing.



Promoting electrification and associated uses

#2

The challenge is to promote **low to zero carbon uses of electricity**, whether microgrids are implemented for industrial/commercial clients with high power quality requirements or for rural electrification projects supplying residential buildings. To do so, the main objective is to **identify and evaluate these uses** and their associated **demand curves**, in order to anticipate the evolution of the load both on the short and medium terms .

Existing solutions

Microgrids are often considered as **generation facilities**, for the most. However and besides MV/LV grids aspects, an essential component of microgrids is the **electricity demand** and **load curves**. Use cases will indeed be very different from an industrial site with high reliability requirements to a remote village with limited access to electricity.

The **electricity demand** and **associated loads**, whether they are critical or not, should be carefully evaluated. Tools based on a "**bottom-up approach**" can aggregate accurate load curves providing access to sufficient amount of data. **Site surveys** with interviews of users and local stakeholders may complete this data collection phase. **Metering and billing data** based on smart meters could greatly help. One key element is indeed to foresee the load evolution over time having direct impact on the microgrid sizing.

For small rural electrification projects, microgrids can address **basic uses** adapted for low consumption, such as TV, water pumping and cooking. **Energy-efficient appliances** could be installed, such as LED for lightning. For some projects, their marginal cost would be lower than retrofitting existing appliances. Coupled with small distributed energy resources generators, they can provide low-carbon electricity and contribute, in the medium to short term, to develop other uses.

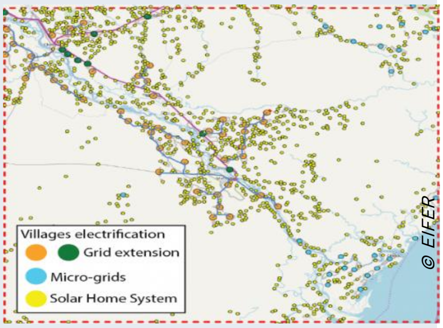
For industrial or commercial uses, such as military bases or mining facilities, implementing microgrids can offer **continuity and quality of supply** for **critical loads**, while decarbonizing the use of electricity and leading to economic savings.

Low-carbon energy generated locally could be used to support **other sustainable electricity uses**, especially for remote or isolated systems. For instance, **seawater desalination plants** are sometimes included in microgrids: they can be operated using renewable energies and provide clean water to regions where the resource is scarce, thus creating a "virtuous cycle". **Water pumps** may be installed for irrigation purposes, contributing to support local economic development. Such equipment may be connected to the microgrid or be self-powered by small solar panels.

New electricity applications appear to bring services to local communities. In this context, **micro-mobility**, like electric scooters, light trucks or vehicles with charging infrastructures, may be promoted to reduce fuel shipping to remote microgrids. EVs could also provide additional flexibility to support the operation of the microgrid. Other uses, like **cold storage** (fisheries for instance) may also optimize microgrid operations leveraging their intrinsic flexibility.

Design & study tools

To ensure optimal microgrid configuration, EDF R&D has developed a set of **design & study tools** adapted to all project development phases. These tools cover **generation mix, grid and loads components** and calculate technical and economic indicators. They can allow areas screening to come up with best electrification strategies. Some tools can also reach the **optimal sizing** of industrial hybrid microgrids (gensets and renewables).



Electrification strategies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Anticipating impacts on local communities

#3 The challenge is to **take into account and anticipate the externalities** on communities where microgrids are to be implemented. It requires to perform **in-depth analysis** of local situations and conditions, including **social and environmental aspects** of microgrids, in addition to technical and economic dimensions.

Existing solutions

Microgrids can have several **societal** and **environmental impacts** on local communities. Those impacts need to be carefully assessed according to local situations, in order for such projects to be sustainable and successful. As renewable energy sources become increasingly more competitive, they can provide an efficient access to electricity and thus facilitate local social and economic development. The main challenge is indeed to provide **affordable solutions** for microgrids users depending on their profile and need, also taking into account their willingness and ability to pay.

As previously indicated, the choice of generation solutions should be made by considering multiple conditions, including their social and environmental impacts. The objective of such analysis is to look for **synergies** between generation assets, electricity uses, and the long-term development of the community where a microgrid is to be deployed. For instance, crops could be used for producing **biomass energy**, farming, and creating fertilizer. However, such a solution requires sufficient (and significant) agricultural space. EDF R&D has developed digital tools to assess trade-offs between using crops for food or energy generation. **Agrivoltaics** innovative solutions may also be implemented to reconcile these two dimensions. They generate solar energy on agricultural spaces, and prevent drought and water evaporation for farms.

To support economic and social development, microgrids require **specific local skills**. Communities should be able to rely on local resources to operate and maintain the microgrid, especially for isolated systems. Microgrids projects shall include **capacity building**, mainly **on-site training of local operators**. However, EDF R&D is convinced that technical solutions should not only be reliable and affordable, but also easy to implement, operate and maintain (PV panel cleaning, manual restart, EMS configuration). They can therefore contribute to creating **local and sustainable jobs**.

More generally, local populations should be guided to ensure they take active ownership of the solutions and their uses, as well as become actors of the energy transition. In this context, **energy-efficient equipment** may be supplied for rural electrification projects, such as refrigerators, fans, or LED lights. Microgrids shall be considered as **"collective" projects**. Finally, the implementation of microgrids requires a close **cooperation with local authorities and populations**. Having a local presence and knowledge may not only help to obtain the required administrative approvals (safety, protection from electrical risks, building permits, operations licenses, etc.), but also to involve all stakeholders in a collective project.

In the same way as power grids are designed using a long-term approach, the planning, implementation, and operations of microgrids should not be driven by short-term results alone.

Hybrid renewable generation in microgrids

EDF is developing electrification projects for isolated villages and islands based on hybrid renewables leveraging the complementarity of bio-energies and solar generation. Biomass supply highly relies on local resources including agro-waste. These solutions allow continuous and reliable electricity supply, leading to the development of commercial activities fostering economic development with positive aspects on jobs creation.

Agrivoltaics


Agrivoltaics demonstrator (EDF Lab Les Renardières)
© EDF – Jobard Rodolphe

Agrivoltaics associates crop growing and photovoltaic production on the same surface. To ensure agricultural performance and farmers operations (tractors), PV panels are widely spaced and put at a certain height. With dynamic agrivoltaism, panels orientation allows shading or direct sun exposure of the crops. This shading effect can be beneficial to certain crops, sensitive to direct sun. Optimal choice of crops and panels orientation are demonstrated at EDF R&D.

#4

Creating sound business models & financing schemes

The challenge is to reach a certain level of **efficiency** in the development and operations of microgrids. It implies that the **costs should be acceptable for all of the different stakeholders** (grid users and local communities, microgrid operator, financial institutions...), throughout the **life cycle** of the microgrid. Models should therefore be **adaptable** and **replicable**, in order to secure and rationalize their industrialization.

Existing solutions

In order to effectively contribute to economic development and energy transition objectives, microgrids which include low-carbon generation solutions should guarantee **affordable prices** of electricity. Those should be **competitive** compared to traditional installations.

Therefore, all microgrid **costs should be evaluated** as accurately as possible, taking into account upfront investments, operations and maintenance costs, as well as training of local actors. They should be compared to what the users of the microgrid would be **willing to pay** and the **level of risk** taken by the project developer(s) and financer(s). Tariffs and grid connection costs should be as competitive as possible to ensure a large number of users. It is essential to develop a **commercial approach** and to plan **communication actions** towards customers.

Besides, **additional financing schemes** may need to be sought. They may take different forms. Local or national authorities could allocate **grants and subsidies**, as well as International Financing Institutions. **Green funds** may also be used to implement sustainable microgrids (with specialized financial institutions, carbon credits...). New financing schemes are also emerging to support their development. Access to capital and trust between funder, builder, operator and users remains the main challenge. A **portfolio approach**, i.e. investing on several microgrid projects, may therefore be used to ensure economies of scale and attract investors, and ultimately meet banks' expected financing volume. **Innovative financing schemes** such as **crowdfunding** or **microcredits** may also help secure their financing.

A platform to attract investments in electrification

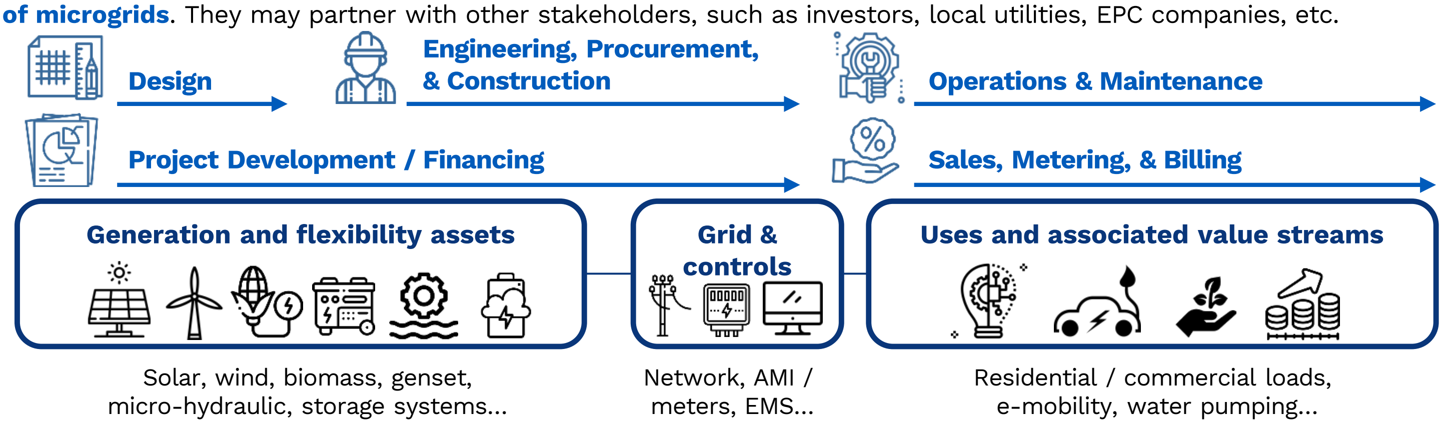
EDF R&D is investigating a financing solution based on two innovative concepts:

Crowdfunding, to allow financial, corporate and private actors to invest and earn a return.
Blockchain, to ensure a transparent and proper use of funds and payments with a high level of security and trust.

This solution, which could be particularly adapted for electrification projects in developing countries, would allow to involve private and public actors to foster the development of efficient microgrids.

Developing a microgrid constitutes a complex project, requiring different **roles** and associated activities, from their design to their maintenance. These roles may be performed by **several actors** (utilities, network operators, electricity producers / suppliers, engineering and construction contractors, hardware manufacturers, software editors, financial institutions...), leading to a **variety of models and combinations**.

Utilities with proven experience in both technical (design, engineering, operations and maintenance) and business (sales, metering, billing...) dimensions, like EDF, are **legitimate** to ensure **end-to-end development and operations of microgrids**. They may partner with other stakeholders, such as investors, local utilities, EPC companies, etc.



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Several areas of research are open to customers willing to **benefit from EDF R&D analysis, expertise or lab testing**. EDF R&D services span across three major domains: **Smart Home, Regions and Companies and Low Carbon Generation**.

The **Institute for Technology Transfer (ITech)** is a training organization to share practices, expertise, and innovations based on EDF R&D activities.

Various training courses are available on **renewable integration, smart grid solutions, microgrids, grid integration, energy storage, control and communication technologies…** Training is provided by EDF R&D leading experts in these key domains.

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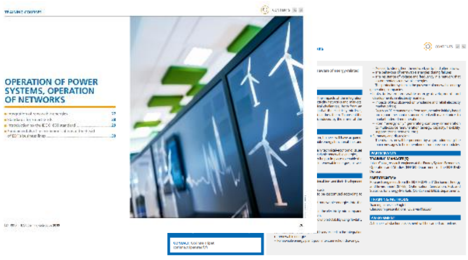

EDF R&D: DARE TO LOOK TOWARDS THE FUTURE AND INNOVATE AT PRESENT

EDF R&D carries out **research for all EDF Group entities**, helping them improve performance and prepare the future integrating innovative technologies and solutions.

EDF R&D has **three Labs in France and six abroad** (China, Germany, Italy, Singapore, UK, USA) and an office in Brussels.

OUR 4 SCIENTIFIC PRIORITIES

1. DECARBONISING OUR CLIENTS' USES
2. STRENGTHENING THE PERFORMANCE OF GENERATION ASSETS
3. INVENTING TOMORROW'S ENERGY SYSTEMS
4. ACCELERATING DIGITAL TRANSFORMATION

EDF R&D facilities in Saclay, one of EDF's research labs.

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