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CONTENTS

CHAPTER 1

ACRONYMS, ABBREVIATIONS, DEFINITIONS AND DATA

1.1. Acronyms and abbreviations

ade	Average Daily Energy
adl	Average Daily Load
ASqD, σ	Average Square Deviation, also called standard dispersion
CPV	Concentrated Photovoltaic
Cbat	Battery capacity
DEG	Distributed Energy Generation,
DER	Distributed Energy Resources
DES	Distributed Energy Storage
DSES	Distributed Solar Energy with Storage
DNI	Direct Normal Irradiation
EE	Electrical Energy
EV	Electrical Vehicle
FIT	Feed in Tariff
FPGA	Field Programmable Gate Array
FSCR	Photovoltaic cell with Storage and Connected to Reticulation
FSI	PV energy cell with storage for isolated locations
GC	Green Certificate
GHI	Global Horizontal Irradiation
GIS	Geographic Information System
GPP	Gas Power Plant
H2S	Hydrogen to Storage
HE	Harvest Energy
HEP	Hydroelectric Plant
HEPP	Hydroelectric Plant with Pumping
Hh, hh	Households
IEA	International Energy Agency

iEC, iES	intelligent Energy Cell, intelligent Energy System
IRENA	International Renewable Agency
IRR	Internal Return Rate
HV, MV, LV	High Voltage, Medium Voltage, Low Voltage
K_{rigid}	Power system inertia, a coefficient of inflexibility
K_{ves}	The ratio between the sum of the wind gradients and the sum of PV gradients exceeding a certain threshold
K_{fl}	The ratio between the deviation of all hourly demand, (σ(σ)) and the yearly average of all hourly demands
LCOE	Levelized Cost of Energy over 20 years
ME	Missing Energy
MPPT	Maximum Power Point Tracking
η	Efficiency, yield
NPV	Net Present Value
NPP	Nuclear Power Plant
PERC	Passivized Emitter Rear Contact (a PV panel technology)
PV	photovoltaic
PoO	Put on Operation
PLC	Programmable Logic Controller
Pprag,	Value of power gradient over which TSO intervenes for balancing
PWM	Pulse Width Modulation
RoI	Return of Investment
S2H	Solar to Hydrogen concept
sEC	smart Energy Cell
SEN	The Romanian National Power System
STC	Standard Test Conditions for PV panels
RES	Renewable Energy Source
TEP	Tonne of oil equivalent 41,868 MJ = 11.63 MWh
THD	Total Harmonic Distortion [%]
Trf	Transformer
TSO	Transmission System Operator
V2G	Vehicle to Generation
WT	Wind Turbine

1.2. Definitions

Available Power, **AP**, is the long-term gross maximum power given by a generator group, considering the relevant electrical and mechanical safety conditions.
Battery capacity, **Cbat**, is the product of the C5h battery parameter and the nominal value of the battery's voltage.
Cold month, **cold season** do not refer to any climatic notion; they depend on three characteristics {location, PV energy cell, load} and include the months when *ade* < *adl*. For example, March can be regarded as a cold month or a warm one, depending on the place and load of a given PV energy cell.
Warm month or **warm season** refer to the opposite.
Consumption paradigm is specific to solar-based energy and refers to the consumption profile that must be adapted or not to the solar "bell" curve.
Photovoltaic panel efficiency is calculated according to the relationship between the quantity of generated electric energy and the level of irradiation on the module's total surface, considering the STC conditions. The STC conditions require a 25 °C module temperature and an irradiation degree of 1,000 W/m^2 perpendicular to the panel.
EEG: The German Law on Renewable Energy Promotion.
FIT (Feed in Tariff) is an incentive paid by domestic electricity consumers, rather than industrial ones, to support renewable energy. Such schemes are promoted by most European countries.
Surcharge: a tax included in a domestic consumer's electricity bill to promote green energy. It is distributed among green energy producers through FIT schemes.
$FSCR_{1st}$ is a residential PV energy cell with a storage facility that is connected to the grid and only borrows energy from it. Physically, it is like an off-grid cell.
$FSCR_{2nd}$ is a residential PV energy cell with a storage facility that connected to the grid. It is *simultaneously on and off-grid* and exchanges, in both directions, energy with the grid.
Hybrid renewable cell: an energy cell made up of generators using at least two renewable energy sources.
iEC: an energy cell with storage facilities that can exchange energy with other iEC or other energy systems and can function autonomously, making decisions on its own.
iES: an energy system made up of both traditional generators, networks, storage facilities, more and more intelligent consumers (each with their own DNA), and of iECs. The control needed within such an iES is reduced.

Irradiation: refers to solar rays, including global horizontal irradiation (GHI), direct normal irradiation (DNI), global normal irradiation (GNI), global irradiation at the optimal angle, diffuse irradiation (DI), absorbed radiation, and reflected radiation etc. Solar radiation is measured in kWh/m^2 or Wh/m^2 referring to one unit of time (day, year) that must be established.

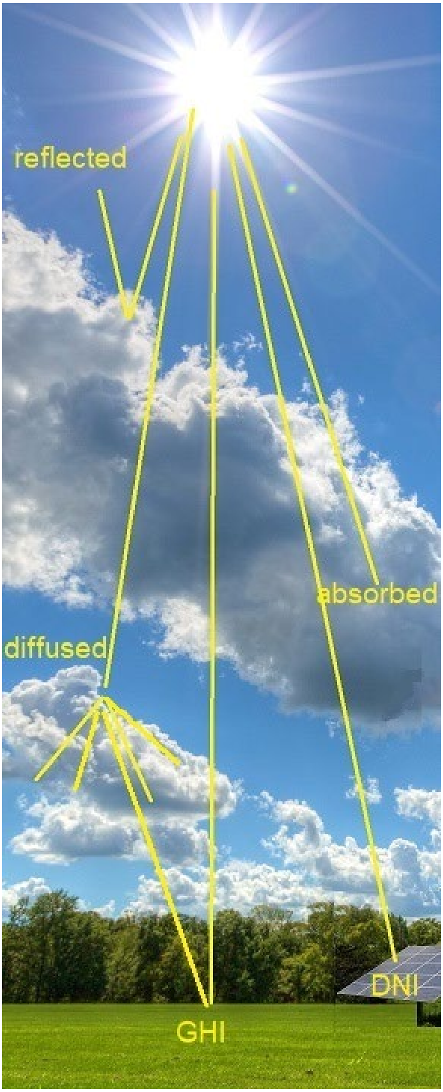

Fig. 1-1: Types of solar irradiation

Diffuse Irradiation, **DI**, describes sunlight that has been scattered by particles in the atmosphere, but that has still made it to the surface of the Earth.

Global Horizontal Irradiation, **GHI**, is the total quantity of shortwave radiation (from *red* to *violet* and *ultraviolet*) received from the Sun on a horizontal surface on the ground. GHI includes two components: DNI and DI.

Direct Normal Irradiation, **DNI**, is the normal (perpendicular) beam radiation on a surface.

The annual average daily radiation is a scalar value that includes the average of the sum of all radiation within a year.

The monthly average daily radiation is a scalar value that includes the average of the sum of all radiations within a month.

The annual average hourly radiation is a 1 x 24 vector that includes the hourly averages of all daily radiation in one year.

One-year hourly radiation refers to a 365 x 24 matrix that includes the total radiation for all the hours within one year.

Observation of solar radiation refers to annual or monthly solar radiation; the daily or hourly averages made strictly considering solar radiation on a fixed surface, with 0 azimuth and with a tilt equal to the annual average optimum angle; this is the so-called global irradiation at the optimal angle.
Kogaion: software application developed by the author for the analysis of wind resources and the design of wind and PV farms.
Koson: software application developed by the author for the design of PV energy cells, their financial analysis, and their evaluation from the point of view of energy fluxes, as well as for the study of certain new aspects.
$\mathbf{K_{ves}}$ refers to a coefficient of the vulnerability of wind versus solar, defined as the ratio between the sum of all the wind gradients and the sum of all the photovoltaic gradients that both exceed a threshold for a given time period; the threshold is considered by the dispatcher as the adjusted moment of intervention using the tertiary power reserve.
$\mathbf{K_{fl}}$ is a flattening coefficient defined as the ratio between the deviation of all hourly demands and the yearly average demand.
$\mathbf{K_{rigid}}$ is a coefficient of inflexibility and of the stiffness of a power system defined as the sum of the product between the weight of generators and the generator start times. $1/\mathbf{K_{rigid}}$ represents the flexibility and the resilience of the power system.
LCOE is the ratio between all lifetime costs (investment, maintenance & operation) and the sum of lifetime electrical energy produced.
Peak power or installed capacity is the installed nominal power of the generator. The measurement units are followed by the p index: kWp, MWp, GWp.
Perovskite is any material with the same type of crystalline structure as calcium titanite oxide ($CaTiO_3$).
Power permanent reduction, **PPR**, is the difference between power plant-installed power and their available power, if this power reduction cannot be eliminated sooner than one year.
A prosumer is a person who produces and consumes energy.
PV energy cell, in a broad/large sense, has a trinity of characteristics {location, PV energy cell itself, load}. A **PV energy cell** itself is the functional ensemble of PV panels, inverters, chargers and batteries that convert solar energy into electrical energy.
PV junction cell is a silicon junction diode that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon.
Rated power of a PV plant is the maximum DC power of the PV module matrix under STC, i.e. the multiplication of the surface of the standard solar radiation modules (1,000 W/m^2) by the modules' nominal efficiency.

RET: the HV and MV electrical network.
RTS: the rapid tertiary stock is the power stock ensured by generator groups qualified to meet demand in a maximum fifteen minutes.
Specific yield of a PV plant is the ratio between AC electrical generation and DC installed power for one year. The specific yield of a PV plant depends on the operating conditions over the reference year, including: solar radiation, radiation spectral deviation, temperature, shadow, snow covering, inverter and transformer losses, and power outages.
Specific yield of a PV conversion is the ratio between the energy (Wh) produced by 1 Wp in one year and the GHI (as a yearly mean value expressed in Wh/sqm/yr), as an annualised average per sqm. The specific yield of a PV conversion depends on PV cell efficiency in a given location.
sEC: is the link between the existing renewable cells and future iECs, which must have storage facilities and exchange energy with the grid. In sEC, the inverter or the bidirectional inverter/charger coordinates the whole cell.
SEN: includes all the capacities of electrical energy production, transportation, distribution and usage in Romania, regardless of the owner and/or manager of the respective capacity. These capacities are interconnected and have a common and continuous operating structure for electrical energy production and consumption.
TSO: transmission system operator in UE (Transelectrica: Romanian TSO; ELIA: Belgian TSO; National Grid: UK TSO).
Uncollected energies are energies that could have been collected by PV panels in cases where off-grid PV energy cells cannot consume or store energy.
V2G: refers to the concept of an electric car fleet as a resource for the public power grid during peak times.
Net present value: is the difference between the current value of the cash input and the updated value of the cash output for a certain period of time.

1.3. Data

The data on energy systems in Romania, Germany, Belgium and the UK was obtained from the national TSOs in these countries:

- Transelectrica: Romania [http://www.transelectrica.ro/web/tel/home],
- ISE Fraunhofer: Germany [https://www.energy-charts.de/index.htm],
- ELIA: Belgium [http://www.elia.be/],
- NationalGrid: UK [https://www.nationalgrid.com/].

ISE Fraunhofer provided data as graphs, which were sufficient to draw a number of conclusions. The data provided by Transelectrica allowed for detailed time series observation. The time series on consumption and production, according to fuel category, were provided for different time intervals: Transelectrica used intervals of 590 sec.; ELIA used intervals of 15 min.; and the National Grid set the interval at 30 min. As a consequence, more detailed comparative studies could not be made because the possible results would have been inaccurate.

Three sources were used for solar irradiation data: PVGIS, *Surface Meteorology and Solar Energy NASA* and SOLARGIS.

The consumption parameters were elicited so that we could observe the effect of integrating residential PV energy cells on a large scale in the national power systems of Romania, Belgium and the UK. Because of the different time sampling periods, we could only make a general study of the power system in the Romanian system (Chap. 8). Even so, we were able to observe a substantial meteorological difference in solar and wind energy conversion between Romania and the UK. As such, comparison of the effects of PV and wind energy should be made only by taking into account geographical context.

1.4. The book's purpose

Considering that the power of the Sun's radiation falling on the Earth's surface is tens of thousands of times greater than the power needed by mankind; at the beginning of this millennium the problem of how best to use solar energy arises: how can this energy be harnessed? The best way is clearly to harness solar energy in as close proximity to the consumer as possible. This is how one understands concepts such as: distributed solar energy with storage; seasonal storage with active heat pumps; smart energy cells; intelligent energy cells; and various newer concepts. Intelligent energy cells are certainly part of the future; they are also central to the concept of a DNA machine. Starting from these concepts, one proceeds to practical entities like FSCR cells and the new triple function inverter/charger. In addition, this approach to harnessing solar energy through millions of geographically distributed photovoltaic cells implies their successful integration with contemporary power systems.

Keeping all these elements in mind, one must take into consideration small PV energy cells for residential areas with storage elements that are only connected to LV distribution grids. A new type of simultaneous on/off-grid PV energy cell with a ground-breaking triple function inverter is advocated for; this should encompass on-grid, off-grid, and an accumulator-grid charger. New renewable cells with new inverter/chargers are part of future machines with their own DNA [1].

An important condition is any power system's capacity to receive connection from a large quantity of small PV energy cells while maintaining network stability. The sum of these residential installations could result in a large amount of installed power in terms of GWp, leading to the "industrialization" of the energy sector. Moreover, such an "industrialization" cannot be limited by governmental budgets. This suggested industrialization needs to be based on citizen interest and the personal decision to invest in it.

A private citizen's motivation to invest in PV energy is the price paid for kWh to the distribution grid (see table 8-8); this is a lot higher than the normal cost per kWh produced by PV energy cells during their lifespan (LCOE). In the modelled examples of small PV energy cells in this book, the LCOE, without FIT, is between 0.09 and 0,04 euro/kWh, i.e. much lower than the price on public grids.

This difference is set to increase as the grid kWh price becomes higher and the component prices decrease, reducing the LCOE. The recovery time of investment could be between 5 and 10 years in the case of normal PV installations without little inventiveness in their structure. With a little innovation, the recovery time could decrease by at least two years. A future intelligent simultaneous on/off-grid inverter/charger could substantially increase the PV energy cell's efficiency, reducing further the investment recovery time.

For these models to be successful, attitudes related to the sizing of the storage capacity in a residential PV cell need to be changed. The phenomenon of uncollected PV potential intrinsic to off-grid PV cells and first generation FSCR cells is highlighted in this book and then the correct solution is proposed for using the full potential of a given PV cell.

The advantages of large-scale integration of distributed small residential photovoltaic sources into the power system need to be highlighted. As demonstrated in this book, the advantages of large-scale integration of small photovoltaic cells, spread out geographically, both for prosumers and power systems, include: i) flattening of consumer demand; ii) undercharging of components that make up the power system; iii) freeing up the active reserve transfer of some generators; and iv) broadening the daily curve of photovoltaic production.

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[1] Octavian Căpățînă, *One Holistic Vision of the Future Energy Systems*, IJEE, April 2013, Vol. 3 Issue 2, pp. 34-40

[2] ***, PVGIS, https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html

CHAPTER 2

TENDENCIES AND NEW CONCEPTS IN ENERGY

2.1. Tendencies

The total solar radiation power that reaches the Earth's surface is over 120,000 TW. In 2005, the average power of global consumption was estimated at 13 TW [1].

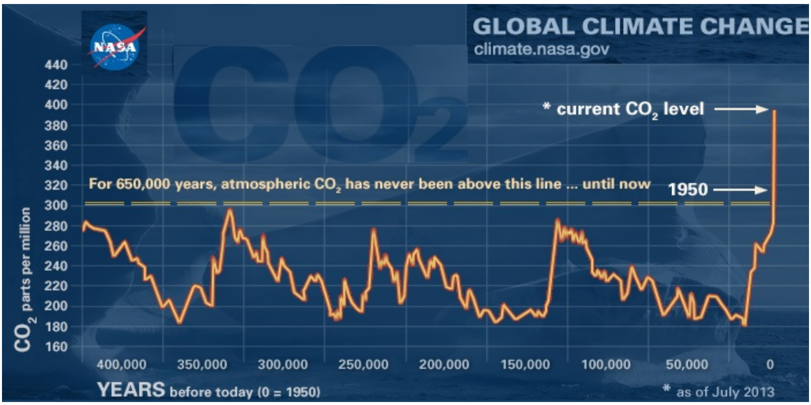

Fig. 2-1: CO_2 in the atmosphere over the last 400,000 years

According to IEA projections, in 2030 RES will reach 15 % in India, 16 % in China, 18 % in the US and 27 % in the EU. Renewable energy must gain ground on fossil sources and although the predictions are positive, they are already outdated since the stimulating factors increase every day. As European hydrographic potential comes to be exploited to its full (in terms of both economic and ecological costs) the increase of energy potential through renewable sources will be made through wind, solar energy, and biomass. Recently, Australian researchers have suggested a new approach for harnessing hydropower potential. They have identified more than half a million locations throughout the world that could be suitable for approximately 1,000 TW of hydro-pumped storage capacity [2].

In 2017, PV saw the highest percentage increase in the energy sector with 29 %, compared to 2016 [3], and 31 % in 2018 compared to 2017 [4].

All of us need to rethink energy systems. We inherited today's energy system from Nicola Tesla—a system that came into prominence before the DC energy system. Energy systems have continuously modernised, but they have remained locked in the same structural paradigm for the last hundred years. Nowadays, new forms of renewable energy conversion are appearing, people are increasingly acknowledging the destructive effects of pollution, and computers, communications, informatics and artificial intelligence are becoming commonplace; the energy system cannot be left outside this deeper process of transformation. Important changes are coming from everywhere, with new concepts and new conversion technologies all coming from unprecedented ITC innovation.

In the USA, a country that is currently opposed to addressing climate change, a 2019 report by the US Energy Information Administration shows that renewable electricity generation amounted to 742 TWh in 2018, which is double that of 2008 when 382 TWh were produced. Over this decade, wind and solar combined have made up 90 % of that increase in renewables: wind energies rose from 220 to 275 TWh and PV from 2 to 55 TWh [1].

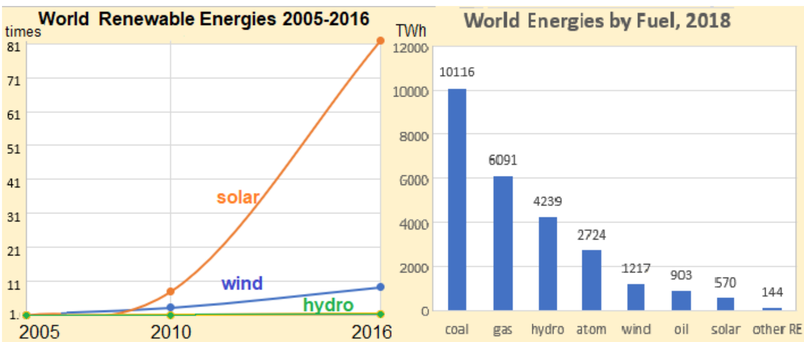

Fig. 2-2: World RE evolution (after IEA [1])

Solar now generates 2.3 % of the US electricity mix, with 6.9 % from hydropower and 6.5 % from wind. New offshore and onshore wind projects have push capacity to 94 GW, which is nearly four times that of 2008. Solar power has multiplied by more than 50 times to 51 GW of installed capacity [5]. Globally, PV increased 82 times between 2005 and 2016, but we should note that of total electrical energy generation, PV amounted to 2.15 %.

Recently, a European thinktank cast doubt on the idea that coal is the cheapest available source of energy. Today, almost 80 % (84 % lignite and 76 % hard coal) of the European Union's coal power plants are operating at a loss [22]. As can be seen, nothing will stand in the way of solar energy except the inertia of the power system, for which there are growing storage solutions.

Tendencies in Electrical Energy Consumption

Before discussing the real goal of large-scale PV integration, one has to follow the evolution of electricity demand. Electricity consumption in EU households has tended to increase along with total energy consumption: in 2000 it represented 21 %; by 2015 it had reached 25 % [6]. A turnaround in global tendencies cannot be predicted since there are no sound indicators in this respect. It is true that we can notice a decrease in consumption in highly developed countries (such as the UK and Belgium, which have a very high consumption level anyway) due to newer and more efficient A, A+, and A++ appliance technologies. At a global level, however, it is predicted that the need for electricity will double by 2040 [3].

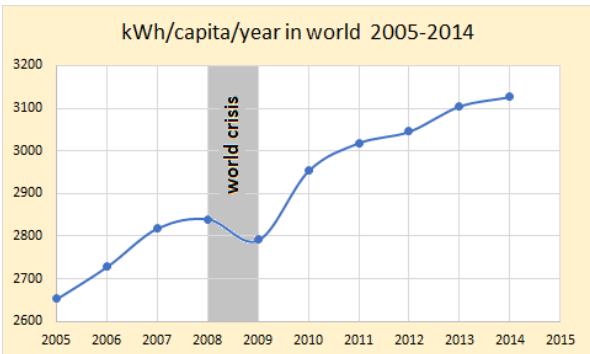

Fig. 2-3: Global trend of consumption per capita

2.2. Old and new concepts

We may note that a new world of electrical energy is appearing. This is a world in which: i) energy demand is doubling very rapidly (it will double between 2014 and 2020 according to the IEA). ii) The decarbonisation of energy production is accelerating (World Energy Outlook, 2012). iii) The decentralization of energy production is being achieved through the exploitation of renewable energies. This is particularly with PV energy, which is relatively uniformly distributed in the environment, and simultaneous on/off-grid energy cells based on renewable energies are appearing. iv) Innovative local storage systems (batteries, capacitors, hydrogen generation, compressed air, and pumping etc.) are in full development because making use of the huge potential of renewable energy depends on developing effective storage. v) The new concepts of *intelligent energy cells* and *intelligent energy systems and subsystems* capable of being on/off-grid are appearing. vi) Finally, intelligent consumers and new paradigms of consumption are appearing [7]. This intelligent development is also being driven by the accelerating digitization of technology and power engineering.

Some relevant ideas and concepts include: enernet; smart grids; zero net energy buildings; near zero energy buildings; intelligent buildings; distributed energy generation; distributed energy resources; clean energy; net metering; microgrid resilience; energy efficiency securitization; intelligent efficiency; grid edge modernization; and electricity prosumer. The diversity of these concepts is proof that we are in the process of searching for a new direction and perspective on energy systems [21].

2.2.1. Enernet and smart grid

A few years ago, the idea of the *smart grid*, as a common space for information and energy, developed from Bob Metcalfe's suggestion of the *enernet.* During those years, the so-called visionaries in the domain talked solely of the *smart grid*. In the end, this concept was reduced to telemetering and the only achievement was the installation of clever counters and their remote reading using the grid as a communication environment. This tendency is a positive element that has been extended and maintained. Despite its conceptual emptiness, the *enernet* can, and still does, generate ideas. In 2009, Bob Metcalfe spoke at the *GreenNet* Conference in San Francisco, saying:

> "The same type of innovation and entrepreneurship that built the Internet should be applied to building a smart grid for a 'squanderable abundance' of cheap and clean energy. … The Enernet needs to have an architecture, probably needs some layers, standards, and storage. ... The Internet has lots of storage here and there; the current grid doesn't have much storage at all" [8].

It may be the case that Bob Metcalfe, who appeared to support the enernet's storage component due to its resemblance to the *Internet*, believed the contrary. Erik Palm noted that [8]:

> "While some scientists, and even CEOs of oil companies, talk about peaking energy supplies, Metcalfe thinks we shouldn't build the smart grid with a focus on conserving energy. Instead, we should build the Enernet for much more energy."

This inconsistency is inherent to the process of innovation and the clarification of such concepts. Today, and especially tomorrow, more and more energy will rely on renewable sources. The major disadvantage of renewable energies is their natural fluctuation and intermittence; these are significant drawbacks, but they can be partially solved by storage. This aspect is analysed in detail in this book from the point of view of residential PV cells.

2.2.2. Microgrids

Today, the smart grid has been forgotten and everyone speaks only of the microgrid. A microgrid is *an energy system with generators and consumers locally interconnected within certain physical limits*. This is an unimportant and limited meaning that comes from the past and has no future. The microgrid gives a new name to an old concept; many of the islands of yesterday's world had, and still have, an energy system with locally interconnected consumers and generators within certain physical limits. Therefore, even if we do not realise the much more generous concept of the *intelligent energy cell* (iEC), as part of an iES, the main features of the *microgrid* include: 1) the existence of storage facilities and 2) a capacity to connect/disconnect to/from a larger energy grid, working on or off-grid. An off-grid microgrid is a particular example of a future energy cell. We prefer the term *energy cell* to the terms *picogrid*, *nanogrid* or microgrid due to its general meaning; in any case, the terminology is not as important as its structure and functionality. It is not just the off-grid characteristic of an energy subsystem with locally connected consumers and generators within certain physical limits that defines the energy cell of the future, but its capacity to connect/disconnect to/from a larger grid based on storage facilities, resources and load. Thus, the definition of *energy cells* includes not only generators and consumers, but also storage units, which are essential for ensuring their efficiency. Another feature of future *energy cells* will be the optimization of functionality of their components. A future definition of an energy cell would be: "an energy subsystem with generators, consumers and storage facilities locally interconnected that could function both off-grid and connected to other energy subsystems or systems."

François Borghese from Schneider Electric [9] has established the microgrid limit at 100 kWp. This is a reasonable value; but there is a difference between a 100 kWp microgrid and 3kWp/hh—a difference that should be emphasised. A picogrid, destined for household use, would be rated up to 3 x 5 kWp; a nanogrid, for small workshops, boarding houses etc., would be up to 3 x 33 kWp. Finally, those that exceed 100 kWp (3 x 33 kWp) should be termed microgrids. However, it is not the dimensions of the grid that are essential, but its structure and function and this is why we prefer the general term *cell*.

The two large concepts that follow the *enernet* are the smart grid and the microgrid. These do not exclude each other, but solve certain requirements in a future *energy system*. Anya Kamenetz, a futurologist, also has a vision of the future, which she presents in her article *Why the Microgrid Could Be the Answer to Our Energy Crisis* [10]:

> "But if many of us see this moment as a defining one, a key opportunity to reassess how we create and use energy across the country, the federal government seems content to leave the owners of the old energy world in charge of designing the new one. Big utilities are pushing hard to do what they do best—getting the government to subsidize construction of multi-billion-dollar, far-flung, supersize solar and wind farms covering millions of acres, all connected via outsize transmission lines.… There's nothing especially efficient or high tech about heavy-duty aluminium-steel cables; 'line loss'—the power lost during transmission—runs as high as 10 % on our overloaded grid. The power lines take years to propose, approve, and complete.… The evidence is growing that privately owned, consumer-driven, small-scale, geographically distributed renewables could deliver a 100 % green-energy future faster and cheaper than big power projects alone. Companies like GE and IBM are talking in terms of up to half of American homes generating their own electricity, renewably, within a decade. But distributed power—call it the 'microgrid'—poses an existential threat to the business model the utilities have happily depended on for more than a century."

2.2.3. Towards 100 % renewable & recyclable energy

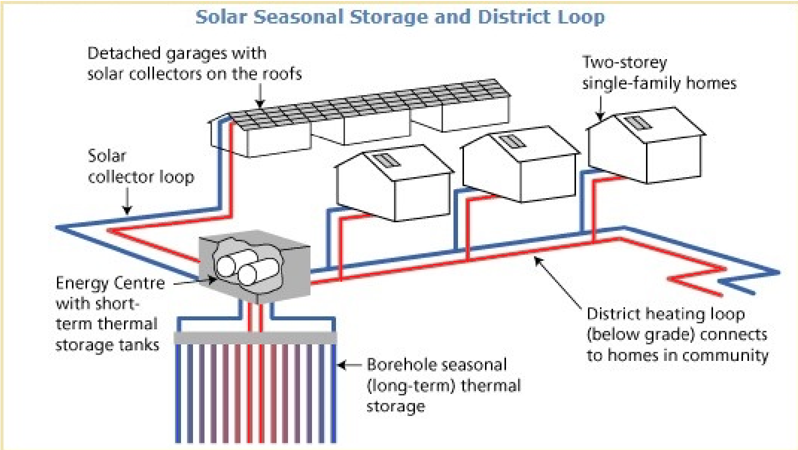

Fig. 2-4: The Okotoks, CA, solar seasonal storage for buildings (image reproduced with permission of https://www.dlsc.ca/how.htm)

Mark Jacobson of Stanford University believes that a straight line of development to a world fully fuelled by nature—solar, wind and water—implies, in fact, very little technology. He thinks that electrification and satisfying electricity demand with renewables and low-cost storage is a novel idea. According to him, the solution should be:

> "Storing heat in underground rocks, making mounds of ice at night, when electricity is cheaper, and melting it for air conditioning during the day. Building wind turbines on and offshore" [11].

During the summer, solar energy heats the water through thermal conversion and this heated water is then pumped underground to heat rocks. The underground rocks remain warm because they are well insulated. In the cold season, this process can be run in reverse to heat buildings, as described in Figure 2-4 [12]. An observation can be made in relation to Jacobson's scenario: in a world with 0 % fossil energy usage, energy at night is no longer cheaper; on the contrary. However, storing heat in water, in salts, and in underground rocks makes sense and these seasonal stores could be very powerful.

The idea of seasonal storage is a very important step towards a fully *renewable & recyclable world.* One issue to resolve is long-term and seasonal storage. In other words, the real novelty lies in joining renewable

	SOLAR	WIND	BIOGAS	HYDRO
Pro	• Location independent • Low maintenance cost • Reduce carbon foot print	• Reduce carbon foot print	• Reduction in soil/water pollution • Byproduct - Fertilizer	• with dam and pumping very useful for demand balance
Con	• Reliance on sun • Requires energy storage	• Location dependent • Reliance on wind • Requires energy storage • Threat to wildlife • Noise pollution	• Location dependent • Integration cost • Fuel treatment • Requires suitable biomass • Requires space	• Location dependent • Reliance on rainfall • Huge investment • Unfriendly to nature

Fig. 2-5: Advantages and disadvantages of renewable sources

sources with seasonal storage. An excellent experiment on long-term thermal storage (Figure 2-4), with solar energy, at Okotoks, Canada, has been running for more than 12 years already [12].

Renewable energies are diverse and each has advantages and disadvantages. Figure 2-5 compares the four most important renewable sources.

In [13], the authors write of *100 % renewable & recyclable energy*, but their agreements are unconvincing. The future of renewable generation needs to be integrated with the concept of moving *towards 100 % renewable & recyclable energy*, as presented in Figure 2-6. In this figure, blue represents sources, orange represents storage, and red represents consumers. As one can imagine, a system based mainly on renewable resources cannot exist without storage because of their innate intermittency and fluctuation. This storage comes in different forms: hydro-potential, compressed air, batteries, condensers, melted salts, and hydrogen etc. Some renewable technologies implicitly include an intermediary storage form, such as: biomass, biogas, waste, geothermal, and hydropower plants with storage water. Power plants based on these resources, which are themselves stored, can be combined with generation from run-of-the-river (ROR), tidal, solar, and wind power. The coordination of renewable resources together with storage systems will increase their percentage in future power systems and ensure a reduced carbon footprint. Energy storage lasting for hours and days has been solved, but the solution for achieving *100 % renewable & recyclable energy* has not yet been found. The long-term storage of energy and seasonal storage are now the main problems to be solved. Other views on the matter of electricity have come from the UK. According to Julian Leslie, the head of the UK TSO, the UK power system hopes to be *zero-*

carbon capable. In 2018, the UK's network operator aimed to become independent of fossil fuel generation and by 2025 the grid should phase out coal. In terms of the 2025 zero-Carbon aspiration [14]:

> "It may just be for half an hour; it may just be for an hour. Then gradually, in the years that follow, that time period will grow and grow."

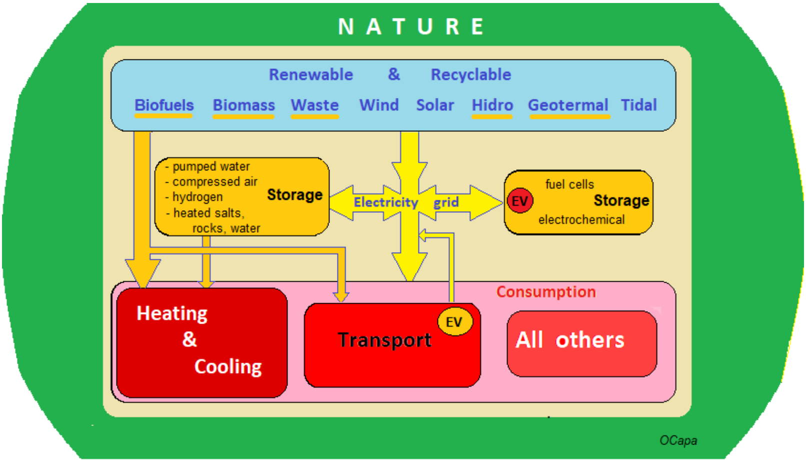

Fig. 2-6: Towards 100 % renewable and recyclable energy

Julian Leslie believes that to keep the system balanced, the network may need to use other technologies, such as flywheels and supercharged capacitors. Large natural gas power plants or hydropower plants give the network more inertia, because they have heavy spinning turbines; while wind and solar generators reduce grid stability as they are dependent on weather conditions [14]. As such, the UK solution to achieving the *zero-carbon-aspiration* in electricity production, includes both short-term and very short-term storage!

Finally, there are two relevant phases to this process: one that refers solely to the electricity power system and one that looks at complete energy consumption. These processes can run simultaneously.

2.2.4. Bidirectional inverters and V2G

In the future, fleets of electric cars will be comparable to a fraction of a national energy system! For example, the Tesla-S electric car has a battery with a capacity of 85 kWh. In the case of a fleet of approximately 2.5 million cars in Romania, the vehicles have stored energy of more than 200 GWh—currently in Romania consumption is 164 GWh/day. Moreover, due to the geographically uniform distribution of the source, this hypothetically stored energy will require no investment in network lines, other than maintaining existing ones. As such, it is a mistake to have non-storage residential PV cells without taking into account electric appliances with storage; a mistake that will later involve rectification costs. What seemed a futuristic idea for in 2012 [15], is now matter-of-course. One speaks nowadays of the V2G paradigm: i.e. support of the grid by an electric car fleet during peak periods [16]. This requires a new component, the simultaneous charger/inverter (Figure2-7).

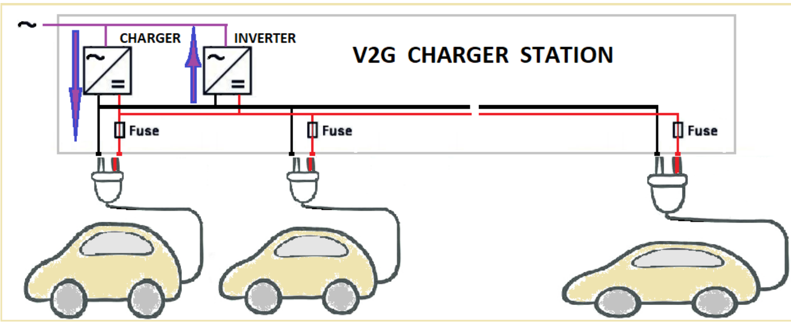

Fig. 2-7: Bidirectional inverter (inverter/charger) and V2G concept

2.2.5. S2H (solar to hydrogen) and H2Store: the green hydrogen option

The electrolysis of green hydrogen is powered by renewable energy with zero carbon emissions. It is seen by some scientists as a basis for energy transition, either in terms of transport or as long-term energy storage. However, renewable energy electrolysis is still costly compared to the same process when powered by fossil fuels. As such, the development of green hydrogen technology rests on continuing decreases in renewable energy prices.

Australian scientists have developed many technologies related to green hydrogen. Professor K-Fr. Aguey-Zinsou of the University of New South Wales (UNSW) believes that this technology can offer seven times more energy density in the form of so-called hydrogen batteries. The new technology will take energy generated through PV panels and store the energy as hydrogen in a very dense form; a major advantage of hydrogen batteries is that they are safer than the lithium-ion batteries used today. Advantages of today's lithium-ion batteries are their longer lifespan and higher energy density. The UNSW team hopes to have a 5 kW home storage system ready for the market by late 2020. Furthermore, the UNSW team is working on a large-scale storage system for solar and wind farms that will include storage vessels suitable for hydrogen used in large marine transport applications [17].

Belgian scientists at Leuven University have developed a solar hydrogen panel capable of producing 250 litres of hydrogen per day. It converts water vapour from the air using energy from sunlight, directly into hydrogen gas, with an efficiency of 15 %. The Leuven team believes that their technology (some patents are pending) will produce hydrogen more efficiently than conventional methods. Twenty panels of this kind could power and heat a well-insulated house during the winter [18].

2.2.6. Machines with DNA, iEC and iES

Clearly, we are heading towards an era in which machines in all sectors will become more and more intelligent and autonomous. Their behaviour will be encrypted within themselves, like DNA in living cells. Serious efforts on developing autonomous machinery are being made in the domains of auto-vehicles and drones, etc.

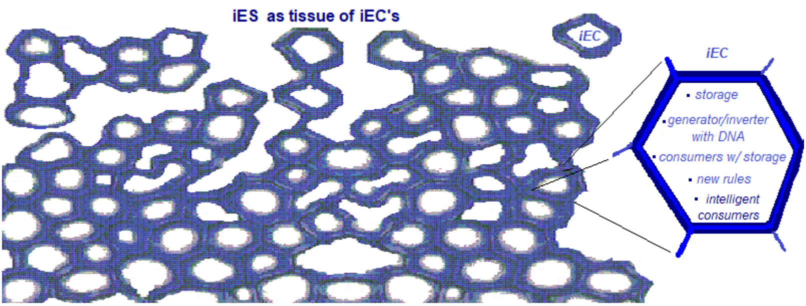

Fig. 2-8: Analogy between bio-cells and future iES systems formed from iEC

This tendency is also found in the energy sector [15]. The analogy between future iES, as a group of iECs, with what we know from cellular biology can be seen in Figure 2-8. For example, a liver cell knows what it has to do without any coordination; its behaviour is encoded within its own DNA. A future energy cell (Figure 2-9) will obligatorily include storage facilities and a grid connection so as to be able to fulfil its primary task. Autonomy requires energy and so storage is compulsory.

The storage elements (electro-chemical battery, compressed air, water pumping, hydrogen, salt-rocks, or combustion cells, etc.) will have an essential role in the future and will operate in a duality—they can be both source and load.

If the sources are renewable, one has renewable energy cells. Since the Sun is by far the most significant energy source, PV energy cells will comprise the most widely spread distributed energy resource (DER).

Fig. 2-9: Renewable energy cell

Based on our predictions, residential PV energy cells will dominate household supply. In terms of autonomy, a particularity in the energy domain requires, besides storage, interconnection with external sources. An inverter of residential PV energy cells has to efficiently supply local consumers and exchange energy with the exterior environment. Energy cells with a double-function inverter, an inverter/charger, which can optimize the energy fluxes, is called an sEC (Figure 2-7). The inverter, the most complex component of the energy cell, will take over the entire cell. The optimizational element, the controller, can be a PLC, a microprocessor or an FPGA. If the controller also has current, voltage, frequency, and phase sensors, then it can be programmed to reach maximum energy efficiency and function autonomously, connected to other cells, or connected to the grid. By analogy with a living cell, such a controller, which manages the entire energy cell in terms of local load fulfilment, can be considered to stand for the *energy cell's* DNA [15]. Several such fitted energy cells can interconnect with one another through their "own will" becoming a nanogrid, a microgrid, or part of a larger grid, and can then share or supply energy.

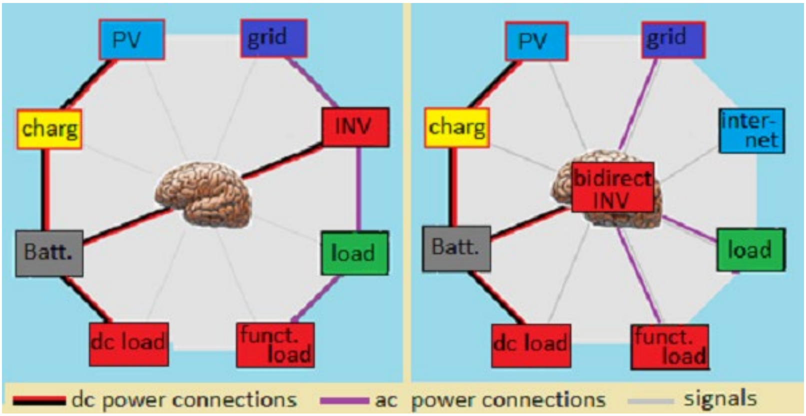

Fig. 2-10: Evolution towards a residential *intelligent energy cell* [19]

Such a spontaneous dynamic association of energy cells will be achieved by the action of their "DNA." These energy cells will form an "energy tissue" that if it fails to function as expected will be eliminated from an iES. Reciprocity will also be valid, i.e. a healthy iEC will disconnect itself from an unhealthy tissue or iES. The existence of intelligent consumers (washing machines, hot water tanks, or electrical vehicles, etc.), which will themselves know when to connect/disconnect or give energy, will not diminish the coordinating role of the inverter, having a general view of the entire cell.

2.2.7. Distributed energy storage (DES) and active heat pumps

The financial problem of storing fluctuating and intermittent energies is a general one that preoccupies scientists and, no doubt, they will find better and better solutions. The so-called democratic nature of solar energy also has a climatic characteristic: it has a seasonal character. As a consequence, its usage on a large scale is conditioned by the nature of the long-term storage. Seasonal, long-term storage requires 5-7 months of storage capacity. In the case of seasonal storage, we cannot use things like hydro accumulations or compressed air in mines; we have to find others ways.

For example, in Romania, which has a significant hydropower sector (32 % of the installed power produces 24 % of EE from about 10 hydrographic basins), the hydrographic basin of Someșul Cald is entirely used in a cascade and produces approximately 510 GWh per annum, representing 0.8 % of total of electrical energy, i.e. 0.14 % of total primary energy consumed. The main power plant in Mărișel (Someșul Cald hydrographic basin) has a 200 million cubic metre water reservoir with a fall of 400 m. This means that, to ensure total consumption of primary energy, we should have 700 such hydrographic basins with reservoirs, and not 10. Even if hydro-resources did not see significant annual variability, long-term storage through hydro accumulations is impossible. This variability in the case of Someșul Cald refers to an interval of 10 years, with a maximum production of 745 GWh and a minimum of 345 GWh. Switzerland, with an even more important hydrographic network, sees 40 % of its needed primary energy produced in the country, while the rest is imported. Of internal production, 56 % is generated by hydro energy (30 % from hydro dams and 26 % from river flows). The result is that hydro dam energy underpins 12 % of primary energy consumption in Switzerland. In both cases, Romania and Switzerland, the assumption has been that hydro resources are being optimally exploited.

Seasonal storage can be achieved thermally (salts, rock) or even chemically (hydrogen). Let us assume one has collectors and convertors of solar energy, dimensioned in such a way that in the warm season one collects double that needed for a suburban household (Okotoks [13]), in a city, or in a broader region. How can seasonal excess energy be stored? In an infinitely large store or in dozens of very large stores? The most likely is in hundreds of thousands of small stores, distributed around places where the energy is consumed. Such distributed energy sources (DES) avoid transportation by energy agent to the storage point and reconverted energy transportation to distant consumers. In the future, PV and thermo-solar roofs and boreholes will be used for seasonal thermal storage (Figure 2-4). Here, we touch on the last concept in this book—*active heat pumps*—which are the focus of the Okotoks experiment.