Dino Esposito | Simone Massaro

CONTROLLING THE UNCONTROLLABLE

Inside the True Nature of Renewable Energy

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BAX ENERGY

I would like nuclear fusion to become a practical power source.
It would provide an inexhaustible supply of energy, without pollution or global warming.

Stephen Hawking

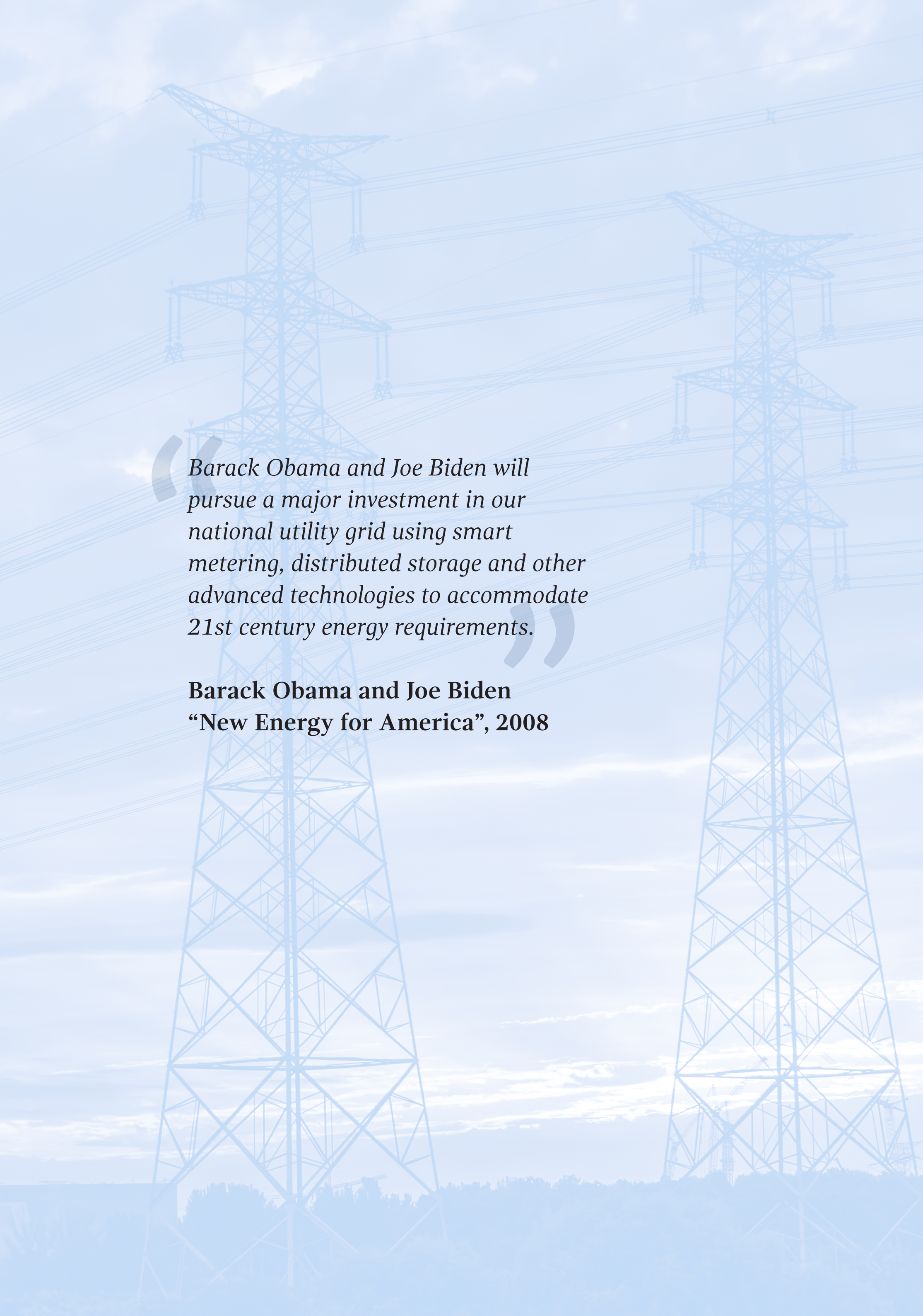
INTRODUCTION

"Controlling the Uncontrollable" is an evocative title used many times in many different contexts and may summon multifaceted thoughts ranging from philosophy to neurology, touching on emotions and temper and ultimately landing to nature and its forces.

In this book, the term "uncontrollable" just refers to the fundamental elements of mother nature that provide the foundation of renewable energy. Too often only the upsides of renewable energy are considered and the positive impact they have on public health, global warming and environment.

However, dealing with renewable energy is not free of issues with the major challenge just sitting in our ability to control the uncontrollable and take advantage of the forces of nature to produce and distribute energy.

This book is about the industry's efforts to monitor the production of energy from renewable sources. Sources geographically distributed by design and uncontrollable by nature.



> *Barack Obama and Joe Biden will pursue a major investment in our national utility grid using smart metering, distributed storage and other advanced technologies to accommodate 21st century energy requirements.*
>
> **Barack Obama and Joe Biden**
> **“New Energy for America”, 2008**

New York. September 12, 2008.

It was a warm Friday evening when a selected group of bankers silently shuffled into the Federal Reserve’s building in downtown Manhattan. They had to make a decision and didn’t know they were just about to face the perfect devil’s alternative.

Whatever they could decide—or could not decide—would have changed the course of history. With the Lehman Brothers case in their capable hands, at a minimum they would risk to push the whole financial system into the depths of a worldwide crisis. And, worse yet, not just the financial system.

A few weeks later, however, the energy program of President Barack Obama gave fresh hope for a new deal and energy was a core part of it.

This is where this journey begins.

Part I

RENEWABLE ENERGY

Today, we are the world's largest corporate buyer of renewable power, with commitments reaching 2.6 GW of wind and solar energy. That's bigger than many large utilities and more than twice as much as the 1.21 GW it took to send Marty McFly back in time.

Urs Hölzle
Senior VP of
Technical Infrastructure, Google

A BRIEF HISTORY OF ENERGY PRODUCTION

Until the industrial revolution started roaring in the second half of the 18th century, mankind never experienced the need of large amounts of energy. Until then, wood and horses were more than enough for heating, work and travel.

Around 1781, James Watt—an instrument maker at the University of Glasgow—successfully turned the same prototype of a steam engine, that Thomas Newcomen developed a few decades before, into a usable product. It was the decisive event that gave the industrial revolution the boost it needed to change forever the face of the world.

In fact, it was immediately clear to anybody that one of those sci-fi machines could really do the work of several horses and even at a lower cost.

It was just the beginning and electricity was the next step.

ELECTRICITY EVERYBODY?

About a century later, Thomas Edison founded the Edison Electric Light Company—the parent of modern electric utilities giving the spark to cheap and commoditized electricity.

“After the electric light goes into general use,” declared Edison to the New York Herald the 4th of January 1880, “none but the extravagant will still burn tallow candles.”

The subsequent high demand for electricity made building increasingly larger power plants a true necessity. It took a few months to have the world’s first hydroelectric power plant inaugurated in Wisconsin, north of Milwaukee, on the fast-flowing waters of the Fox river.

Bigger and bigger coal plants and hydroelectric dams showed up all over the world and electricity started traveling fast over power lines for thousands of miles across cities and rural areas.

In everyday life and business, the consumption of energy grew at a bold pace as the cost of producing it declined steadily. For decades nobody ever felt the need of preserving energy or even monitoring the production process for whatever reason. As of the 1940s, the world was full of fossil power plants fueled by coal and natural gas. A few, and mostly experimental, geothermal stations also existed at the time in Japan and California but until the late 1950s industrial-scale production of geothermal electricity was only taking place in Italy, in the surroundings of Larderello, Tuscany.

The next figure shows the timeline of power plants as they appeared in history.

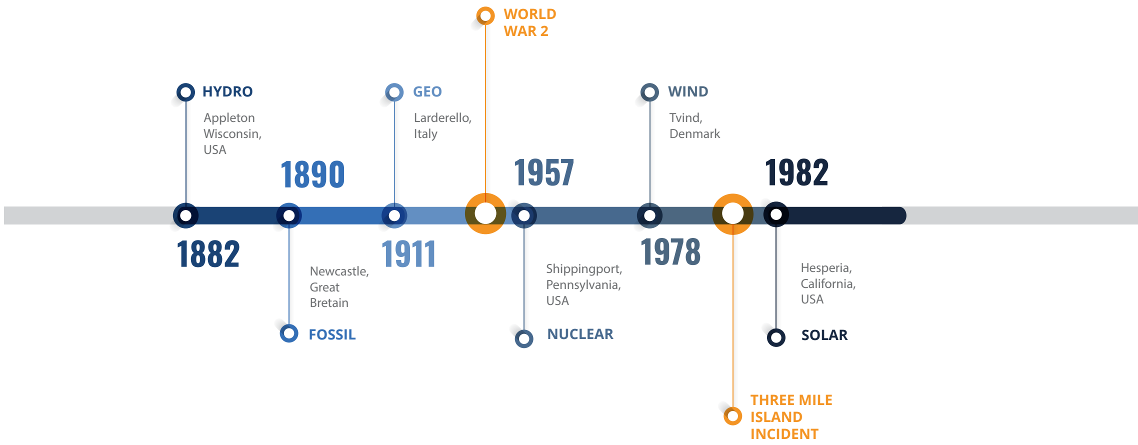


FIGURE 1-1. History of power plants

The relevant development in physics observed in the first three decades of the 1900s introduced a new player in the global arena of energy production—the atom. However, the atomic research being actively done in the 1930s was redirected to military use during the second world war and only in the 1950s the U.S. government took the decision of converting it back to civilian purposes.

United States, Japan, major European countries such as France, Germany, United Kingdom, as well as the Soviet Union, accelerated nuclear energy programs and many plants popped up all over the territory.

What for quite some time appeared an unstoppable growth started to back off in the 1980s due to a couple of key events.

- Demand of energy suddenly slowed down in 1973 because of oil crisis in mid-east. Facts led the U.S. President Jimmy Carter to a nation-wide conservation plan effectively summarized in the slogan Don't be fuelish.

- In March 1979, one of the reactors operating in the Three Mile Island nuclear plant (Pennsylvania) suffered a partial meltdown and released radioactive material into the environment.

Three Mile Island was the most significant nuclear accident that ever happened in the United States and it was classified 5 out of the 7-point international nuclear scale. It was unanimously considered the signal that opened the floodgates of a generalized anti-nuclear sentiment in the public opinion in the US and worldwide. The rather popular "No Nukes" movement took life right after the accident and contributed to raise people's awareness about the dangers of nuclear energy.

The accident drew a line under the world's warm hope of having found an unlimited source of energy and delivered a clear and unequivocal message. As a result, building nuclear plants turned out to be an extremely challenging feat as governments issued stricter regulations which brought to delays and cost overruns without really averting any potentially devastating accidents.

Where else to turn then to keep cultivating the evergreen dream of free and unlimited energy?

BACK TO RENEWABLE SOURCES

As of 1980, well over 90% of the energy produced in the world was coming from fossil power plants.

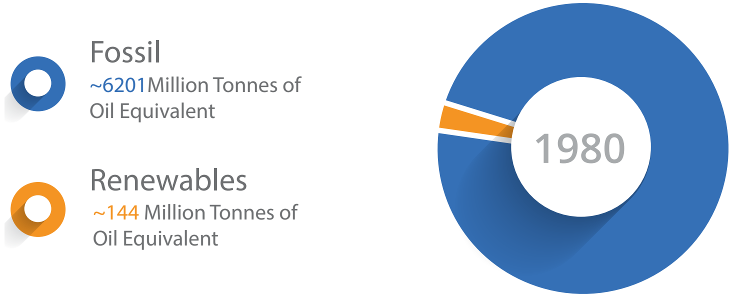


FIGURE 1-2. Fossil vs. Renewables as of 1980

As the breakdown in the figure below shows, coal, oil and natural gas were by far the primary sources of energy. All of them are non-renewable sources.

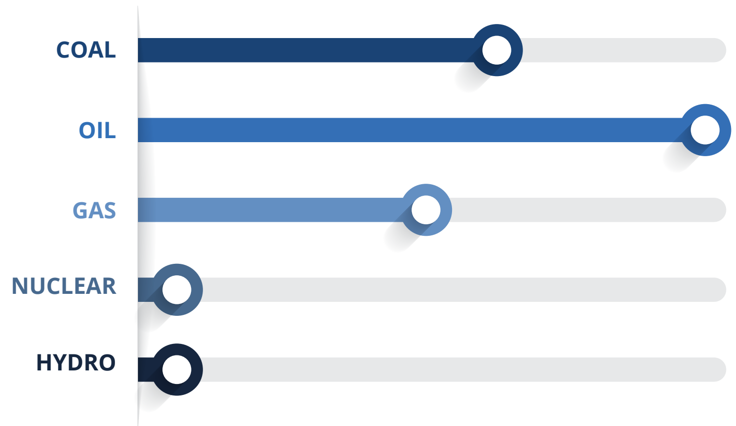


FIGURE 1-3. Breakdown of energy production as of 1980

It is interesting to note that the 1980s marked a massive return of interest for energy obtained from renewable sources. Curiously, until the start of the industrial revolution in the mid of the 19th century all energy consumed came from renewable sources, including water, wood, biomass and, to some extent, wind. Then the amount of coal discovered under the British soil, and relatively low costs of extraction compared to building dams, gave the spark to a new economy.

In the 1980s, the world realized to thrive on top of energy generated from wildly abundant but limited resources. Worse yet, it was resources that could be found only in a relatively small number of countries. Such a concentration of oil, natural gas, and coal in a few limited geographical areas leads to periodic peaks in the cost of energy and often lays the grounds for some political turbulence.

It was about time to find a new turning point.

In the end, it was a returning turning point: clean and renewable energy. And everybody thought that life would be much easier with renewable energy to sustain us.

NOTE

It is crucial to distinguish between the simpler act of leveraging the forces of nature like wind and sun and operating energy produced from those same forces.

In other words, one thing is using the force of the wind to operate a local windmill; quite another it is capturing the

wind into energy and feeding it to the national power grid for thousands of households to use even at considerable distances.

The overall notion of “energy” is quite different today and this different notion is just one of the points that make implementing renewable energy more challenging than commonly reckoned.

QUICK FACTS

- Steam machines powered the industrial revolution and common availability of electricity changed the face of the world.
- After the failure of the atoms, only wind and sun could be seriously investigated for cheap and unlimited energy beyond oil and coal.
- Using the force of wind to generate the energy necessary to operate a standalone windmill is different from producing and sharing energy.

NEXT UP

The bright side of renewable energy makes it great for humans and the environment. It has a dark side too that makes its intensive use and production quite challenging for the industry.

> *I like to think of ideas as potential energy. They're really wonderful, but nothing will happen until we risk putting them into action .*

Mae Jamison
Physician and NASA astronaut, first African American woman to travel in space aboard the Space Shuttle Endeavour on September 12, 1992

THE DARK SIDE OF RENEWABLE ENERGY

Energy is defined renewable when it comes from resources that constantly regenerate themselves through natural processes. Typical examples of renewable resources that can be used to produce energy are water, wind and sunshine.

None of those is expected to stop anytime soon.

Moreover, if the day will ever come that water, wind and sunshine exhaust, then the entire mankind will exhaust as well. Hence, it can be assumed without loss of generality that renewable resources are unlimited resources that will last for at least a few more million years, estimates say.

Energy obtained from renewable sources presents three major upsides:

- It reduces pollution, the root cause of world's global warming;
- It softens the dramatic impact of many serious threats related to public health;
- It can make every nation independent from the energy point of view;

Pollution is the primary downside deriving from intensive use of conventional, mostly fossil-based, sources. Pollution brings up a number of hidden costs related to global warming, climate change and, in particular, public health.
Furthermore, renewable sources are much more widespread than fossil sources (i.e., oil, gas) and have the potential to bring electricity, and therefore, prosperity, all over the globe including the poorest areas. There are strong reasons, both ecological and economic, that lead to a growingly intensive use of energy produced from renewable sources.

According to the annual report of the U.S. Energy Information Administration (EIA) for 2017, the global amount of energy produced from renewable sources and natural gas will steadily grow in the next two decades. As the figure shows, energy from renewables is expected to double within 2040. No other source of energy will experience a similar rate of growth.

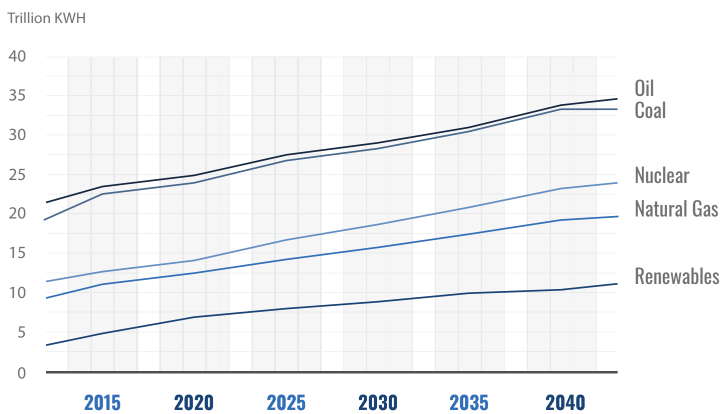


FIGURE 2-1. Production of energy (source EIA)

The long-term prospect of energy production above also matches nicely the projection of energy consumption worldwide that appears in the figure below.

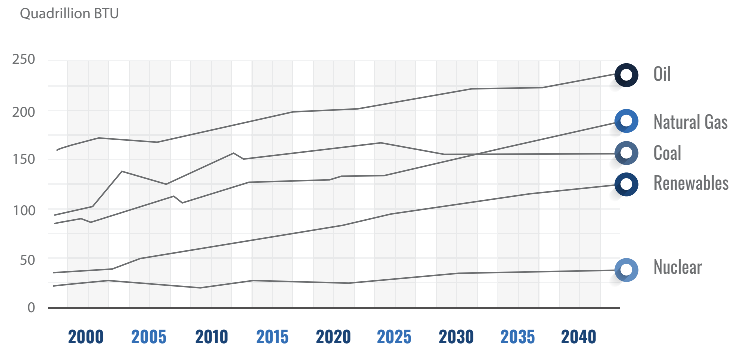


FIGURE 2-2. Energy consumption (source EIA)

Today, the quantity of energy derived from renewable sources is nearly 20% of the total and is expected to grow up to 40% in the next two decades.

It's definitely a fascinating outlook, but it poses a non-trivial issue. How do we control all the energy that may be produced by the uncontrollable forces of nature?

To understand why intensive production of energy from renewable sources is a serious challenge for nations to tackle, let's embark on a quick tour of how power plants are planned, built and operated.

THE NEED OF CONTROL

For years, all power plants have been sized and built to match the demand of energy expected to come from a given area. All the energy produced out of coal, oil, atomic, geothermal, hydro or natural gas power plants is fed to the nearest branch of the national or regional grid and from there delivered to households via power lines.

A number of patterns have been identified over the years to guarantee a constant inflow of energy that could balance demand and prevent both excess and shortage of energy. It is then safe to say that even a basic, down-to-earth grid fueled by conventional power plants can blissfully survive relatively small fluctuations of production and consumption.

A conventional power plant is designed to maintain the level of production relatively constant. A conventional power plant usually either works at full speed or is offline for some reason. Once connected to the power grid, its contribution of energy never changes dramatically and suddenly. In this regard, being down for maintenance is not an event that causes major hiccups of energy provision as long as it is a scheduled activity planned ahead of time. A power plant that goes suddenly down, instead, raises a serious issue for the connected homes which would remain without electricity.

Fortunately, this is no longer a problem.

Originally, power plants used to supply energy to specific local areas via a large number of nearby substations.

A substation is the part of a power plant located near the actual delivery points such as homes, factories, and offices. In a substation, the electricity transmitted from source is optimized for actual delivery. Serving as a proxy, the substation transforms the high voltage of transmitted energy (typically, several thousands of volts) into the much lower voltage suited for households (typically, 220 volts).

NOTE

Electricity can be transmitted over vast distances from remote power plants to the heart of our cities. Unfortunately, sending energy over the wire—even high-quality copper wires—burns energy and the longer the wire, the more energy is lost due to the resistance opposed by conducting materials.
To reduce loss, transformers are used to increase the voltage of transmitted energy. A high voltage, in fact, reduces the amount of current that flows over the wires and subsequently reduces the waste.

It turned out that a regional power network based on substations has many points of failure as each substation is connected to a single power plant.

To remedy the problem and make the network more resilient, utilities linked multiple power plants together to form a larger and more interconnected network—the power grid—where load balancing of electricity is managed by a centralized process. The process has a broader view of consumers' demand and can match it to production more effectively.

With the smarter power grids introduced around the 2000s, the risk of blackouts was significantly reduced and the long-time problem of ensuring grid balance was put aside.
However, the bold advent of renewables radically changed such an idyllic scenario.

UNCONTROLLABLE SOURCES

Nobody can stop the wind, cold the sun or plug a geyser. This means that a power plant based on any type of renewable resource, whether wind, sun, or geothermal heat, is not controllable straight at the source. Hence, any power plants that operate any renewable (uncontrollable) resource can potentially feed to the grid an unpredictable amount of energy at any time.

At the beginning of the millennium, the amount of energy coming from renewable sources that was regularly fed to the world grid topped at 2% of the total.
It was not too much and, more importantly, it was not too much to compromise the stability of the grid.

As long as the amount of energy produced from renewable sources remains well below an average 10% of the total, the grid can easily compensate any fluctuations of the production and consumption numbers thus ensuring a perfect balance of energy.

But with renewable energy production today steadily marching towards 20% of the world total, sudden and unpredictable changes in the amount of power released to the grid will put balance at serious risk.

One day there might be violent winds and then calm skies for the following days. Or there might be clouds and rain for weeks and then a month of sunshine. Or the other way around. All these factors may significantly affect the amount of energy delivered to the grid. How do you control the uncontrollable? And how do you forecast what will happen tomorrow?

In Europe, energy from renewable sources grows continually year after year. In 2016, the European Union scored an average 17% consumption of renewable energy. The share is slated to grow up to 20% by 2020 and up to 32% by 2030. Noticeably, about 40% of the countries already reached the target set for 2020.

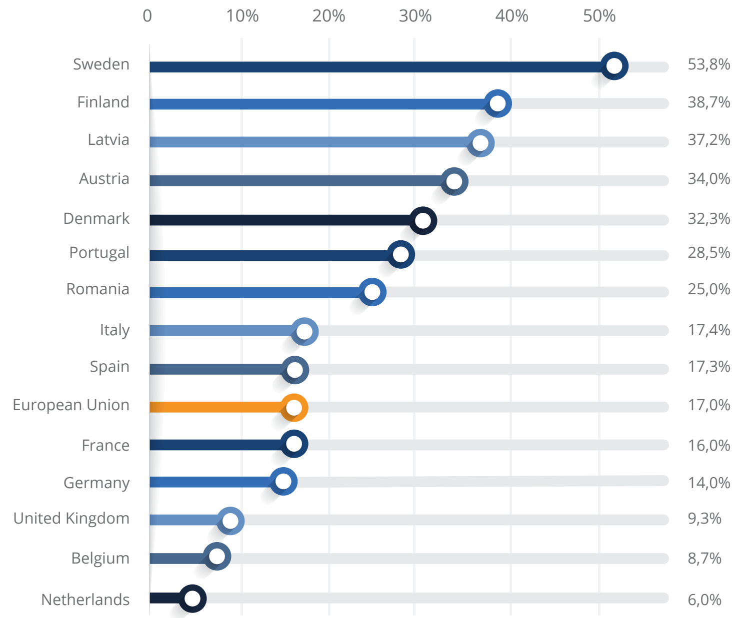


FIGURE 2-3. Consumption of renewable energy as of 2016 in some EU countries. (Source Eurostat)

As emphatic as it may sound, renewable energy destabilized a settled down domain and disrupted existing rules and principles. Historically, the production of conventional plants is tailor-made to the needs of the geographical area they serve.

At the same time, conventional power plants, such as coal or nuclear power plants, are quite expensive to shut down and not designed to work at a reduced production rate. Most of them either work or not and once offline they release zero electricity to the grid even though in some cases some plants may be kept in warm reserve and produce some energy at a very low rate.

In brief, dealing with an excess of energy is a wicked problem with many possible solutions being currently researched and actively experimented. To date, there are two, non-exclusive, approaches to control the uncontrollable.

- Storing the energy in excess, somehow and somewhere
- Limiting over-supply of energy to the extent that is reasonably possible

Production of energy from renewable sources is expected to nearly double in the next 20 years all over the world. It's great news for the environment but also a crucial challenge for the industry. Today's 20% share of energy produced from uncontrollable resources is a thorny problem for the stability of the grid and it will exponentially sharpen in 20 years.

Therefore, control is required and can only come via tailor-made, and especially smart, software.

In this context, an extremely popular buzzword like digital transformation, all of a sudden, acquires relevance and substance. Software intelligence, and digital transformation of processes, is required to transition the entire domain of energy back again into a settled down state.

CONSERVATION OF ENERGY

Pumping more electricity than the grid can handle may ultimately cause an overload and the failure of the grid. Not pumping enough energy, though, may likely cause blackouts.

One way to smooth the impact of uncontrollable fluctuations is storing any energy in excess for later. This can be achieved storing energy in batteries or, wherever it is feasible, via pumped hydroelectric storage (PHS).

PHS is today the most battle-field tested form of energy storage and it has been doing its job for well over a century. At its core, a PHS station consists of downhill and uphill reservoirs connected to form a closed loop. Energy in excess is used to upload water from the downhill reservoir to the uphill one.

The trick is that much of the energy consumed in the upload can be restored at any later time by simply reflowing the water down the hill. Ultimately, PHS implements storage by turning concrete energy into potential energy. Albeit working and consolidated, PHS has a deep social and environmental impact. For this reason, batteries appear as a more enticing option.

At the current stage of technology, batteries seem to work well only on a small scale, but prices to sustain are high and projected to be even higher as the scale grows to the level of utilities.

A lot of startups, though, are digging out hard to find a convenient way to battery storage that is scalable enough and efficient. So, we can perhaps expect to see a rather different landscape in just a year or two.

(We'll cover energy storage more in detail later in the book.)

NOTE

The overarching purpose of batteries is packing as much energy as possible into as less space as it is physically possible. A key factor to enabling higher density energy storage is changing the raw material that makes up the anode of the battery. Currently, the research is oriented to lithium-metal. In August 2018, Pellion Technologies, a Massachusetts-based fast-growing startup, announced the commercial availability of lithium-metal based batteries with a capacity twice as much as conventional batteries.

Another approach to control the amount of energy that renewable power plants contribute to the grid consists in applying some degree of control over the production. Transmission system operators (TSO), in fact, may order to start, stop, or reduce solar and wind farms when too much, or too little, energy is going to be released to the grid.

In this regard, power forecasting is key and it is also sometimes used in conjunction with energy storage.

Particularly relevant for wind and solar farms, power forecasting refers to calculating an estimate of the power that the plant is expected to produce in a short range of time.

Reliable power forecasts help TSO to buy the right amount of power for the grid so that the available energy always balances the actual demand. Reliable power forecasts can be obtained in a few different ways but always crunching the content of a few different data sets:

- Historical data
- Hi-res weather forecasts
- Maintenance plans

The production of a renewable farm tends to be nearly the same as the last measured value in history. As naïve as it may sound, empirical data prove that renewable source power plants tend to produce nearly the same amount of energy at the same given time of the year. Therefore, observing what happened in the past at a given time helps getting a good estimate of what might happen in the future.

Overall, power forecasting is a smarter approach than battery storage as it addresses the problem of unbalanced grids at the root by trying to guess how much wind or solar energy is being produced the next days.

Power forecasting is a popular and successful branch of artificial intelligence that not just reduces the risks of grid failures but also opens up a whole new world of business opportunities for utility companies. An accurate estimation of the power being produced would in fact let companies predict the wholesale prices of electricity and then arrange more effective strategies in energy trading.

(We'll cover energy trading in later in the book.)

QUICK FACTS

- Energy in the power grid must be balanced at any time to prevent surplus and shortage.

- Power plants based on renewable sources are highly intermittent as far as production is concerned.

- Release of renewable energy to the power grid must be controlled in some way to maintain the status of the grid balanced.

- Software remote control of power plants is mainstream today along with forms of energy storage.

NEXT UP

At its core, renewable energy is about capturing energy in the nature (i.e., kinetic energy of the wind) and transforming that into electricity that can be transferred and sold. Operating a renewable power plant, though, is not a walk in the park.