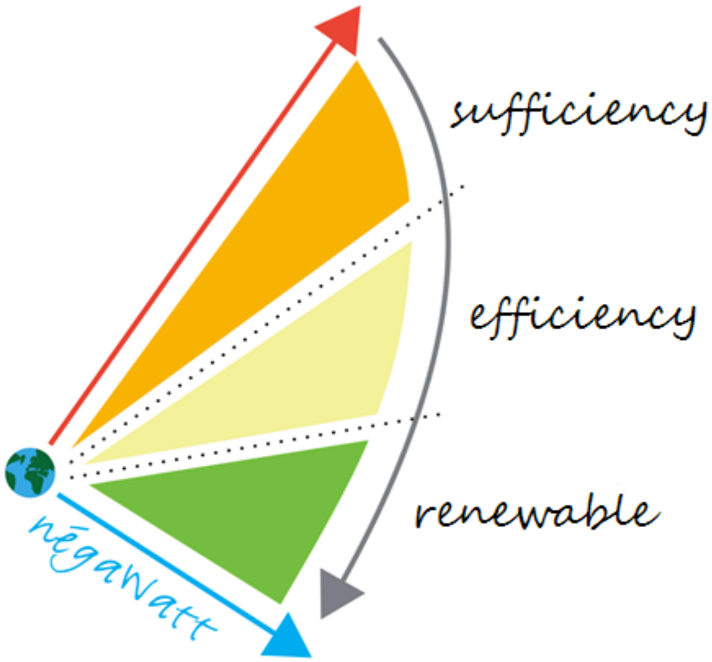
Executive Summary

October 2011
(last update : July 2013)

The négaWatt 2050 Scenario



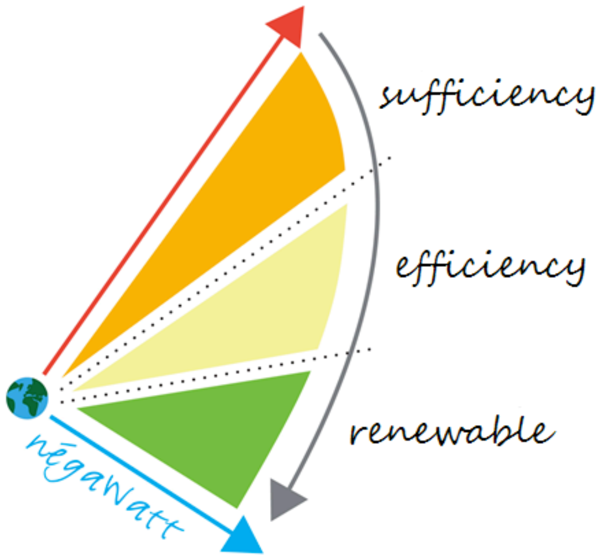
The négaWatt 2050 scenario in brief

- An energy scenario for France based on proactive energy sufficiency and efficiency efforts, leading to a 65% cut in primary energy consumption by 2050 compared to 2010. This is what 'negaWatt' is about: making 2/3 of the way towards a truly sustainable society by avoiding the use of unnecessary Watts!
- While still maintaining a high level of energy services for heating, moving, and specific electricity needs.
- Giving priority to renewable energy sources to meet the remaining energy demand. In 2050, they make up 90% of our energy resources.
- With a better coordinated management of gas, electricity, and heating grids to ensure the demand is met at any time and the power grid is constantly balanced.
- Anticipating the end of conventional fossil fuels, and restricting their use to industrial raw materials, the petrochemical industry, and a few other specific uses (such as aviation).
- Halving carbon emissions by 2030, and cutting them by a factor 15 by 2050, compared to 2010.
- Leading to a decarbonised energy system compatible with a full nuclear phase out by 2033.
- A cumulative amount of CO_2 emissions between 2011 and 2050 that is in line with a fair contribution to the objective of limiting global warming below 2 degrees by 2100, considering the country's share of the global population.
- As regards land use and agriculture, a balanced energy scenario including a relocalisation of productions and a substantial use of biomass for material and energy production, in line with the Afterres2050 scenario developed by the research unit of the NGO Solagro.
- A country moving towards more energy independency and democracy, creating hundreds of thousands of sustainable jobs, and providing a key role in our energy future to local territories and their stakeholders.

The keys to a sustainable energy future

Since its creation in September 2001, négaWatt has grounded all its activities on a simple philosophy: regarding the energy issue in the right way, by first considering our energy needs before discussing energy supply. We need heating, lighting, mobility in the first place, and not uranium, oil, or wood.

Then we may look at the most sustainable ways of meeting those energy service needs, by following a three-step approach:



- **Sufficiency,** consisting in an assessment of our needs and finding individual and collective ways at prioritising the most valuable, restricting the most extravagant, and cutting the most detrimental energy usages.
- **Efficiency,** meaning efforts to reduce the unitary amount of energy to satisfy a certain need, mostly through technological choice all along the chain.
- **Renewable sources**, to ensure that the least polluting and most sustainable energies are favoured.

As an illustration, carefully sizing a lighting installation and using highly efficient luminaires and lamps can already cut the electricity need by a factor five or more. It will then be much easier to supply it through renewable energy. This simple example can be extrapolated to all our forms of energy use, from the most insignificant to the most substantial.

The urgent need for an energy transition

This approach is the only one that can solve our ever pressing energy challenges. There is urgency both in term of impacts and resources.

The fossil fuel consumption growth - coal, oil and 'natural' gas - is not sustainable. On the one hand, it increases greenhouse gas emissions that lead us ever faster towards a climate change with immeasurable consequences. On the other hand, it speeds up the depletion of finite resources, bringing us ever closer to major geostrategic and economic tensions.

The Fukushima disaster, 25 years after Chernobyl, reminds us that nuclear energy cannot be considered an acceptable alternative; and it remains a marginal source at global level, representing less than 3% of the world's final energy supply.

By contrast, renewable energies already supply more than 13% of the worldwide energy consumption and are by far the most abundant resource at our disposal, in any case the only one in the long term: total solar energy reaching Earth, in direct form or through biomass, wind, and the water cycle, represents more than 10,000 times the energy consumed by humanity.

Energy sources such as oil, gas, coal, and uranium, are being rapidly depleted: at current rates, the world may have a few decades of oil stock, and two or three centuries of coal left. On the contrary, **renewable energies** such as solar, wind, hydro, wood, biomass, biogas, and geothermal will constantly renew and persist as long as humanity needs them.

An energy system based on sufficiency, efficiency, and renewable energy sources is the only viable way for the future. The transition towards this sustainable option is not only desirable, it is also possible. Provided we go for it quickly, and start acting right now.

Energy systems have long lead times: the infrastructures and their socio-economical surroundings that we build today will impact energy production and consumption well beyond the first half of this century. The 2050 horizon is already around the corner!

'Postponing major decisions is the most certain way of being too late'

And yet our behaviour seems to be more and more focused on the short term. Centred on our immediate consumption needs, obsessed with GDP growth, blinded by the financial pressure from markets, we act as if we could forever count on progress' magic wands to escape from the worst case scenario at the last minute.

It is all the more urgent to get started as the risks we face accumulate: every drop of oil consumed brings us closer to depletion, every gram of CO_2 released into the atmosphere contributes to the greenhouse effect for decades after being emitted, every additional year a nuclear reactor operates makes it more dangerous. Postponing major decisions is the most certain way of being too late.

A sustainable and realistic scenario

Integrating long-term constraints into our short-term decisions is the good way to start. We need not only to share a desirable vision for the mid-century, but also agree on the path to get there: a long-term scenario only makes sense if there is a common acceptable future in view.

In response to the weaknesses of the official French State energy scenarios as regards sufficiency, efficiency and renewables, the négaWatt Association has decided to publish its own scenario in 2003, updated in 2006. Subject to debates and now acknowledged, it inspired some of the measures of the 2009 '*Grenelle de l'environnement*' bill that altered France energy policy, though in a very insufficient way. Despite a few improvements, the provisions were far from meeting the desired objectives. Worse, the lack of a clear vision prevented from really accelerating the energy transition beyond the 2020 horizon.

Based on its experience and due to the growing urgency, the négaWatt Association decided to further update and refine its scenario in 2011. The new version is the result of a one-year joint effort from a group of a dozen energy experts and practitioners contributing strictly in kind.

This even more ambitious **"100% négaWatt" scenario** relies on a set of essential principles:

- In addition to technical and cost-efficiency criteria to rank energy solutions, it uses social and environmental criteria. It means in particular that options such as new nuclear reactors, carbon capture and storage, or shale gas extraction have been discarded.

- The scenario does not require any major technological breakthrough. We might have good news before 2050, such as 3rd generation liquid or gaseous biofuels, but they cannot be foreseen at the moment. The scenario is only based on realistic and mature solutions, whose technical and economic feasibility has been proven even if they have sometimes been poorly developed at an industrial level yet. This allows a robust path while remaining open to future potentials.

• The scenario is not restricted to mitigating climate change. Decarbonising energy is not the only issue; we must strive to reduce all risks and impacts our energy system is responsible for. Constraints on water, raw materials, and land use, have to be taken into account as well. On this last point, the scenario is coupled with the Afterres2050 scenario (developed by Solagro, a French expert NGO), another forecasting work focused on the use of biomass for food, energy, and materials, and using a similar approach than négaWatt.

The 2012-2050 négaWatt scenario relies on an ambitious but realistic path in line with a core principle of sustainable development: *'Passing down benefits and incomes to future generations instead of burdens and debts'.*

A bottom-up modelling

The energy transition obviously requires an economic and societal transformation, in which changes as supported in the négaWatt scenario are determined by the physical and natural constraints we are facing.

Since standard economic signals do not reflect long-term constraints on energy resources and their impacts, they do not encourage economic agents to take adequate decisions.

'The economy must adapt to physical reality, the other way round is simply impossible'

Furthermore, official models used in France for energy forecasting have relied on purely economic assumptions, in which only the lowest short-term cost matters for consumers: this short-sightedness prevents from building alternative paths that take into consideration the greater good first and lowest cost for society as a whole in the longer term.
The modelling used for the 2011 version of the négaWatt scenario does not directly link energy-related choices and GDP: should this connection be considered a worthwhile indicator - which remains to be proved -, a specific calculation module could easily be added (along with the calculation of other potentially relevant indicators).

But what it does is, starting from evolutions in energy uses and sources, to assess the overall activity and job content of an energy transition. Field experience and foreign examples show us that the latter can trigger beneficial social and economic dynamics, especially compared to a no-action scenario.

Our 2011 scenario uses a substantially reinforced methodology to model in detail each energy usage and resource within an overall dynamic outlook for the evolution of the energy system.

The model is based on a bottom-up analysis in five steps, starting from **energy services** in three main categories:

• **Heat**, including household and tertiary space heating, hot water, cooking, and heat used in industrial processes

• **Mobility**, i.e. all means of displacing persons, raw materials and manufactured goods

• **Specific uses of electricity**, including lighting, appliances, IT equipment, electronics, as well as electric motors used in industry and buildings, such as in elevators.

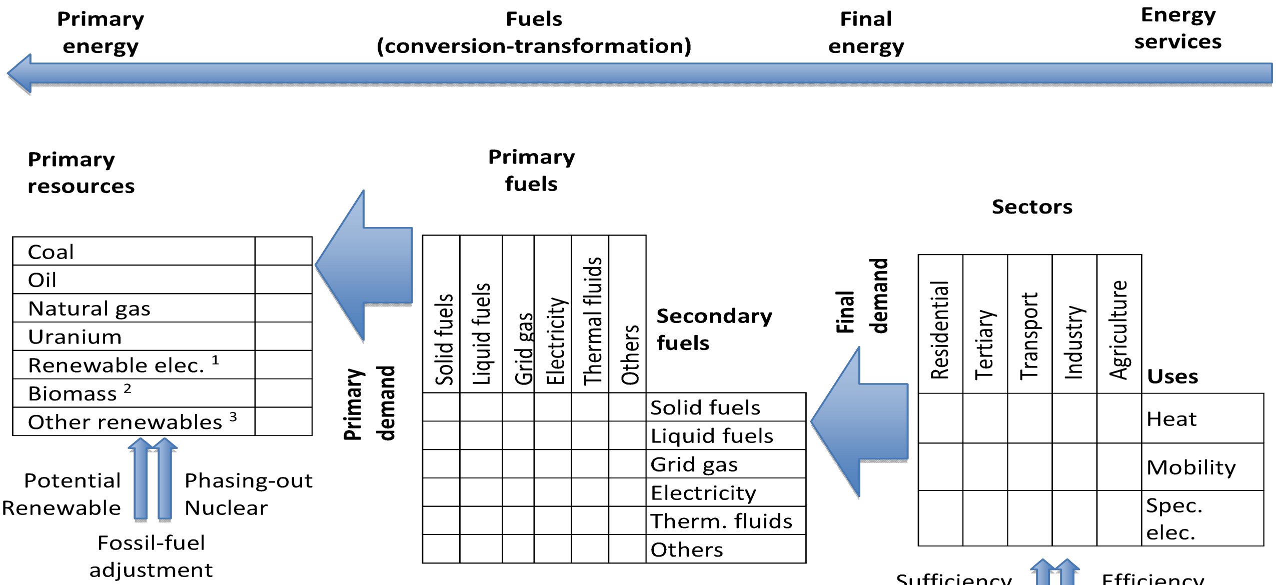
These services are analysed by sector (residential, tertiary, transport, industry, agriculture) in calculation modules that integrate several thousands of parameters related to sufficiency and efficiency, in order to provide residual energy load assumptions for these needs year by year.

The choice of the most appropriate energy source to meet each need (solid, liquid, or gaseous fuel, heat, electricity…) is then made to be able to assess the quantity of **final energy**, that is the energy delivered to consumers. The following step is to assess the quantity of **primary resources** (oil, gas, uranium, renewables…), delivered in France or imported, that is necessary.

The potential of renewable energy sources to meet the demand is assessed taking into account their respective development stages, and the progressive nuclear phase-out. Fossil fuels serve as complement to balance demand and supply.

For electricity, the balance needs to be ensured not only on a yearly average basis but instantly at any moment. This is adequately foreseen in our scenario, on an hourly basis and up to 2050 through the joint consideration of typical consumption and production curves integrating the dynamic calculation of the contribution of adjustable supply sources (e.g. thermal power stations, large hydro…), and other flexible solutions such as load shifting and electricity storage.

NégaWatt 2011-2050 scenario modelling



[1] Renewable primary electricity: hydro, wind, photovoltaics, sea energies…
[2] Solid biomass, liquid biomass and biogas
[3] Other renewables: thermal solar, geothermal, urban waste…

Updated reference point

Any forecasting scenario needs a reference year. It is usually the most recent year for which statistics are available: it was 2005 for the 2006 scenario, it is 2010 for the 2011 version. Since the horizon remains 2050, this is not an insignificant difference: it means five less years to succeed, while the urgency has increased in the meantime.

From a geographic point of view, the model is limited to mainland France and includes changes only within its boundaries. The French négaWatt scenario relies on a self-sufficiency vision for energy, yet the aim is not to isolate France from the rest of the world: the country continues to exchange with other countries, but reduces its energy dependency (including for electricity).

As far as demographics are concerned, the scenario retains the median hypothesis of the most recent forecasts published by the French National Institute of Statistics and Economics (INSEE), that includes a significantly higher projected population for 2050: 72.3 million inhabitants instead of 65 million previously, in other words 7 million more people whose needs have to be met.

'Updated demographic forecasts: 7 million more people to feed, house and move by 2050'

Within this demographic trend, the scenario considers several specific evolutions that deviate from usual INSEE forecasts. The scenario takes into account the necessary changes in our relationship to land: we need to recover the sense of distance and space that we lost in the past decades. Urban sprawl, increasing distances to work, longer consumption circuits, and land artificialisation have become unsustainable, and not only for energy reasons. Our model considers a slowing down of these trends thanks to policies and measures recommended in coherence with other sectors.

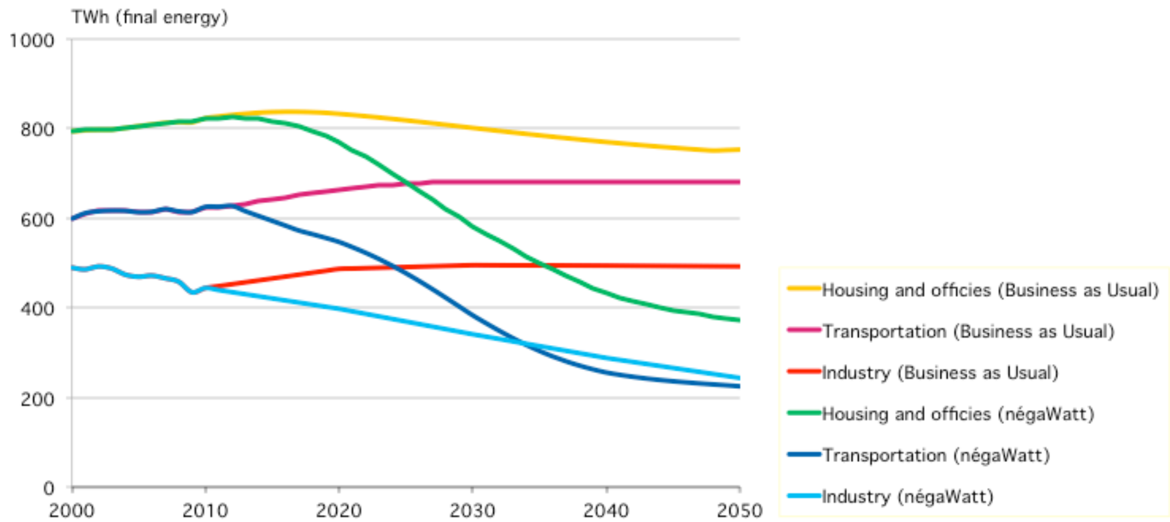
In addition, events witnessed in France since 2005, such as the implementation of the '*Grenelle de l'environnement*' bills and the economic crisis in 2008, have led us to adjust the business-as-usual (BAU) reference. Built in a similar way as the négaWatt scenario, it estimates what would happen if current trends were carried on without engaging the changes négaWatt recommends.

The 2011-2050 BAU scenario foresees a stabilisation of energy consumption in the long term, that results from a relative balance between basic energy saving efforts on the one hand, and population and energy service demand growth on the other. On the supply side, the BAU scenario assumes a continuation of the nuclear power program, and a modest and poorly-supported development of renewable energy sources.

Between half and two thirds of energy use avoidable in all sectors

The négaWatt scenario assesses in every sector the energy saving potentials expected from sustained sufficiency and efficiency efforts. Among a total final energy consumption of 1908 TWh in 2010, the highest potentials are identified in residential and tertiary buildings, with nearly 400 TWh of savings by 2050 compared to the BAU scenario - that is a 49% reduction, and transports with more than 450 TWh of savings, that is a 67% reduction. Then comes industry, with a 250 TWh potential, i.e. a 51% decrease. While changes in farming and land use practices are essential for balancing needs and resources in the scenario, agriculture as such as a sector remains marginal in terms of specific energy consumption (fuels for tractors, greenhouse heating, etc.); we have included it in the industry sector.

■ **Final energy consumption evolution by sector in the négaWatt and BAU scenarios** (in TWh)



Buildings: a major challenge for energy

Buildings today account for more than 40% of our final energy consumption, mainly for heat-related uses: space heating, air conditioning, hot water, and cooking. Energy consumption levels are very much linked to building design and equipment, and therefore take time to evolve. The renewal of the building stock is extremely slow, with barely 1% of new building constructions each year. Even if very strict building codes are applied to new houses, it would be insufficient.

The négaWatt scenario includes different sufficiency approaches. It assumes notably a stabilisation of the average number of persons per household at 2.2 (instead of an endless continuation of the current reduction trend reported by INSEE). The difference means as much as 3 million less homes needed by 2050. It also considers a stabilisation of the average surface of new households, as well as the development of small grouped housing. In tertiary buildings, it supposes a substantially slower expansion of surfaces than current trends, from 930 million square meters today to 1.2 billion in 2050, compared to 1.5 billion in the BAU scenario.

Efficiency efforts focus on dramatically improving the energy performance of buildings, through wall and roof insulation and heating system optimisation. Massive energy saving potentials are at stake here, and should be harvested both in new and mostly existing buildings.

'A major building refurbishment program for the entire stock is a key point for the

This indispensable energy renovation program is a key to the scenario success. It starts with the old building stock constructed before 1975, and extends to more recent residential and tertiary buildings. After an initial warm-up period, the pace grows at about 750,000 households and 3.5% of tertiary surfaces renovated every year until 2050.

Renovation works should systematically seek a high level of performance to reach an average consumption of 40 kWh of primary energy per square meter for space heating needs, that is four times less than today. A similar ambition is to be applied to new buildings at the passive house level (on average 15 kWh per sqm per year in the residential sector, and 35 in tertiary buildings).

In parallel, the most efficient heating and cooling systems - primarily based on renewables – are progressively installed. Currently widespread natural gas, oil, and direct electric heating systems eventually disappear completely to be replaced by wood heating (covering 30% of heating needs), renewable gas (33%), electric heat pumps (17%), district heating (12%), and solar thermal (9%). Imported fossil gas is gradually substituted by biogas or gas produced from renewable sources.

Residential and tertiary buildings are also responsible for a large part of **specific electricity** consumption (47% of the total), which accounts for only 10% of our total final energy consumption but concerns uses that are indispensable for our comfort. The négaWatt scenario identifies about thirty of them to which the usual methodology is applied: following a socio-demographic analysis, sufficiency and efficiency options are investigated, and current best practice and highest performance levels are systematically targeted.

Some space is left for future new uses that are unheard of yet, but can be anticipated due to technological and social evolutions. In total, the average specific electricity consumption by household decreases from 2,850 kWh per year in 2010 to around 1,400 kWh per year by 2050, while ensuring a better satisfaction of identified needs. In the tertiary sector, the scenario leads to a 45% decrease of the specific electricity consumption in 2050 compared to 2010.

Transport: the need for a long-term view

The transport sector needs a robust vision to deviate from the current situation. Transport alone accounts for 33% of our final energy consumption: a little less than two thirds for transporting people, and the rest for transporting goods, 94% of which is fossil oil-based. We need to preserve a freedom of movement while ceasing to be so much car-dependent, at least as they are today.

‘In the long term, keeping a freedom of movement while getting free from the constrained car monopoly’

The négaWatt scenario assumes differentiated evolutions according to the best fit for each travel purpose, distance to be covered, and transport infrastructure density along the route (from rural to downtown urban areas).

First, it believes feasible an overall cut in mobility needs through improved urban planning policies and new social practices. The number of kilometres driven for the same service could be reduced through alternatives to the current urban sprawl trends, revitalisation of rural areas, development of on-line shopping, and use of collaborative teleworking offices. The scenario foresees an average gain of 25% on the total number of kilometres travelled per person per year.

The more densified the living space and short the travel distance, the less justified the use of an individual car. In the scenario, cars ultimately account for 49% of all kilometres covered per person per year compared to 61% today.

Mobility is primarily shifted to softer transport modes, such as walking and cycling for short distances, and public transports for longer ones – which of course supposes a coherent urban design and development of regional train and bus networks. Within city centres, very flexible systems such as small shared electric vehicles and taxis complement the supply, and contribute to eventually phasing out current cars completely.

In addition, gains are realised in energy consumption through better transport planning to increase the number of persons per vehicle, and through stricter regulation such as lower speed limits, increased motor efficiency, and lighter vehicles according to their use: as a consequence, the unitary consumption per kilometre drops by 57% between 2012 and 2050.

However, the main progress comes from fuel switching: from fossil oil to two alternatives. The first one is electric vehicles, whose development entails challenges for electricity grids and raw material supply, but could be particularly appropriate for short trips in urban areas: they contribute up to 21% of the total distances covered by cars in 2050.

The second is gas-powered cars, buses, and trucks. This fuel type has both intrinsic advantages and a potential for gradually supporting renewable energy sources. Natural gas can be progressively replaced by renewable gas when biogas and synthetic gas increase their share in the grid. Use of gas in vehicles is already fairly common in Italy, and can be implemented on existing oil and diesel car models. Most existing petrol stations could be connected to gas networks (except in very remote places where some oil-powered vehicles could be maintained). In the scenario, gas-fuelled vehicles ultimately make for more than 65% of car travels. In addition, these vehicles are equipped with possibly rechargeable hybrid motors, which significantly improves their energy efficiency.

The same approach applies to freight. Similarly, 83% of interurban transportation of goods in 2050 becomes gas-fuelled, while 13% in urban centres is achieved through small electric vans. The scenario also considers higher loading rates per vehicle, as well as a modal shift towards rail that counts for 40% of tons-kilometres by 2050, and river transport that reaches 5% of the total.
Above all, as for passengers the scenario is based on a change in freight volume trends correlated to a significant change in industrial patterns. Instead of increasing linearly with population, the total ton-kilometres decreases by 2.5% between 2010 and 2050.

Industrial transformation

An energy transition goes hand in hand with a deep evolution of the industrial sector. Its current final energy consumption (23% of the total French consumption) is relatively stable due to efforts by industries to improve their energy intensity (i.e. quantity of energy necessary per output produced), but also as a result of offshoring (that “hides” intermediary energy consumptions as factories are moved abroad).

The négaWatt approach introduces a new perspective by investigating genuine needs, and linking the demand for raw and manufactured products to sufficiency and efficiency at each production step. As an example, the scenario foresees a significant reduction in packaging and printed papers by re-implementing bottle deposit schemes, or eradicating advertising fliers. More generally, the reinforcement of repairability and recyclability principles, and most of all the end of planned obsolescence that is currently the rule, allow for a corresponding reduction in production needs. In addition, specific energy needs in industry are considered according to the particular evolutions of each sector: some will diminish, such as in the agricultural sector through a 45% reduction in fertilizers, or a 30% cut in materials for car manufacturing, whereas other will grow, such as in the building material sector because of thermal renovation efforts. Overall, the scenario forecasts a reduction of 10% to 70% of material needs depending on the sector. And this remains possible despite a 15% population growth and the relocation in France of most manufacturing industries. The latter appears as a necessary condition to optimise energy consumption and greenhouse gas emissions, as well as avoid that the impacts of our consumption of manufactured products are exported to foreign countries.

Efficiency is applied to all industrial processes. The scenario includes for example an average efficiency gain of 35% for electric motors, and differing gains for those industries using combustible fuels, from 32% in the iron and steel industry to 50% in cement factories. It also envisions the development of CHP and heat recovery systems on industrial sites.

The key to going even further is through material recycling: the scenario assumes an increase in recycling rates up to a realistic maximum taking into account processes, and collection constraints. For instance by

‘In industry, the key to deeper energy savings is trough material recycling’

2050, 30% of plastics and 90% of steel are made from recycled material, compared to 4.5% and 52% today respectively.

As in the building and transport sectors, these changes are based on a bottom-up approach from needs up to technical processes, and allow for a greater use of renewable energy sources. Beyond their contribution *via* an increased use of electricity, they partially replace fossil fuels: charcoal and recycled plastics in iron and steel and cement industries, renewable gas and wood elsewhere, as well as solar heating that can cover more than 30% of low temperature needs, and 15% of medium temperature needs by 2050.

Agriculture at the heart of the transition

Like industry, agriculture links consumption and production. With hardly more than a 2% share of total final energy consumption, its direct impact is low, however it has an important role in emission of non-CO_2 greenhouse gases (methane and nitrous oxide), as well as in energy production through biomass. It is also important to ensure that crops for biomass energy do not compete with food and material production, the other essential goals of agriculture.

The analysis here builds on the Afterres2050 scenario, that applies the same sufficiency and efficiency approaches to all stages of the agricultural chain: demand management, loss reduction, recycling of organic waste, etc. The Afterres scenario is notably centred on an evolution of food habits, targeting a better nutritional balance and a reduction of current overconsumption of carbohydrates (sugars), lipids (fats), and animal proteins. The projected 2050 diet includes half as much meat as today’s, less dairy, but a higher portion of fruits, vegetables, and cereals.

‘Like our energy consumption, our meat consumption is not sustainable.’

This adjustment has a beneficial impact on energy and land availability: livestock farming requires much more land surface and energy than producing vegetables, and we have reached a level of meat consumption that is simply not sustainable at the level of the planet.

The Afterres scenario assumes a halving of animal stocks, and a fivefold reduction of intensive animal farming. Agricultural processes shift towards organic farming on the one hand, and ‘integrated’ production on the other hand that applies more eco-friendly farming techniques (crop mixing, longer rotations, ban of deep tilling, agroforestry, seed planting optimisation, and use of natural fertilisers). These two methods cover each a half of total cropland, and allow for a division by a factor four or five of chemical fertiliser and pest control needs, while maintaining good yield levels and improving soil quality.

Like for industry, these changes contribute to a greater food sovereignty. France can continue to export, notably to European countries where cropland per capita is lower, and still import several tropical products (tea, coffee, cocoa…). However it stops importing grains from America to feed its own livestock.

Toward sufficient, efficient, and renewable energy uses

Illustrated by this opportunity of eating better and healthier, sufficiency does not mean at all less pleasure! The négaWatt scenario for France does not lead to deprivation. People would live a little more in small multi-flat buildings, however without a significant reduction of dwelling surfaces. They would save much on heating bills while experiencing an increased thermal comfort, both in Winter and Summer. Domestic electric appliances would be more energy efficient and used more rationally, leading to halving specific electricity use.

Consumption and production patterns would evolve, as would tertiary, industrial, and agricultural activities. At the end of the day, French people would not necessarily consume less, but better. These changes would also lead to a better geographical distribution of activities over the country, enabling a reduction of distances to cover. Benefiting from more tailored and diversified transport infrastructures, travels would be done in more comfortable conditions.

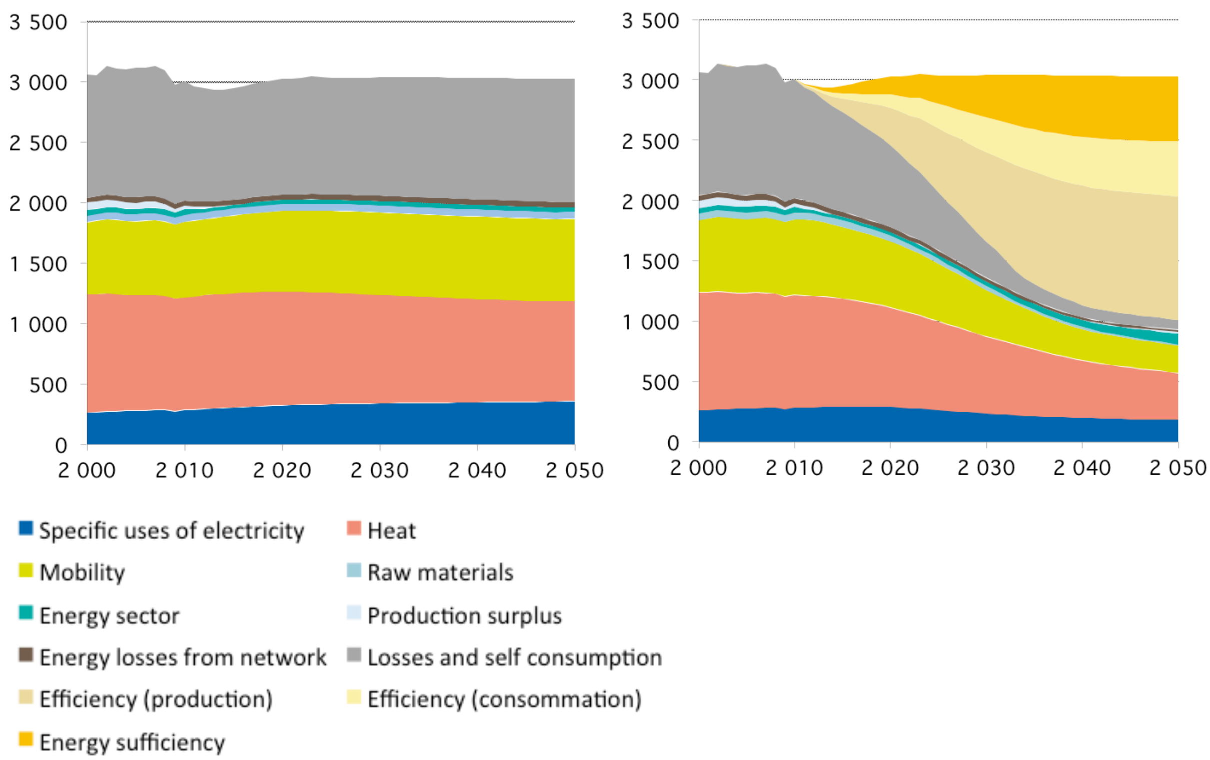
As a result of these ambitious yet realistic evolutions over one or two generations - if we just think how different our lives are from our grandparents'! - the energy saving potentials would be massive, as shown in our calculations: 54% for heat, 64% for mobility, and 'only' 36% for specific electricity due to its increased share in energy uses.

In total, final energy savings amount to more than 60% per person. Sufficiency and efficiency count each for about a half in this result, with differences according to the sector: more sufficiency in transport, and more efficiency in buildings.

'Ambitious yet realistic changes over one or two generations'

Considering that by 2050, about 2.2 times less energy would be required to satisfy the needs of the French population compared to the business-as-usual scenario, it is possible to fundamentally reconsider the discussion about energy supply. The assumptions in the négaWatt scenario, supported by the necessary changes in infrastructures and equipment, allow for an almost complete switch towards renewable energies: in 2050, they can cover close to 90% of heat and mobility, and nearly 100% of specific electricity needs.

Comparison of final energy consumption by uses in the BAU and négaWatt scenarios (in TWh)



The rise of Renewables

To meet the energy demand that remains after sufficiency and efficiency, the scenario prioritises a supply based on renewable energy sources, and then evaluates how fast fossil and nuclear sources can be substituted accordingly. The approach remains realistic. It builds notably on a conservative estimate of potentials, on industrial experience from past programs in France, as well as and above all on lessons learned from success stories abroad.

The négaWatt scenario also capitalises on the main strength of renewable energy sources: their diversity and complementarity. Optimising the mix of sources helps addressing the specific development challenges and impacts of each of them.

‘A performant biomass-based system is a core pillar of the energy transition’

Renewable sources producing electricity currently attract much of the attention, although electricity only represents 23% of our final energy consumption. Therefore, as regards quantity, the main challenge lies elsewhere: a successful energy transition requires foremost a modern biomass exploitation system.
The négaWatt scenario is in line with assumptions of the Afterres2050 scenario, in which land surfaces freed by changes to the agricultural system may be used for biomass energy supply, and production of bio-sourced materials that contribute to energy savings in other sectors by substituting non-renewable materials.

The first biomass resource is wood. Assuming a quasi-stable forest surface in the next decades, its wood output could still be doubled through a better management, the development of agroforestry, and a more systematic use of wood waste. Wood energy could reach 263 TWh by 2050.

The scenario then relies on exploiting agricultural resources at several levels. One of them is the massive development of methanisation of livestock excrement and a part of crop solid residues. Prairie grasses can also be an excellent source for methanisation. The decline of livestock farming would free about 1.5 million hectares than can be dedicated to it, bringing biogas production up to 157 TWh in 2050 compared to only 4 TWh today.

This biogas production can be used to fuel vehicles, and remains more favourable in terms of yields and impacts than liquid biofuels - even when considering possible future progress of the latter. Consequently, the production of liquid biomass by 2050 in the négaWatt scenario does not rise beyond current levels.

In total, a tripling of the use of biomass by 2050 allows to produce 433 TWh of energy, that is almost 45% of primary energy needs by then.

On top of huge agricultural resources, France enjoys one of the largest potentials in Europe for each renewable electricity source: hydro, wind and photovoltaics. Only the first one has already been significantly developed with 77 TWh per year, which is assumed to remain stable in the scenario.

'France renewable energy potential is among the largest in Europe'

The first priority is to unlock the on-shore wind potential, a sector in which France has been late. This can be achieved through a tripling of the installed power capacity by 2020, and then again a multiplication by 2.5 before 2050, with a total of 17,300 turbines in operation compared to 4,000 in 2011. The development of off-shore wind comes later, first through turbines fixed in submarine grounds at shallow waters, then through turbines mounted on anchored platforms in the windiest areas. With a mere 4,300 high capacity turbines, off-shore could produce almost half of the 209 TWh expected from wind in 2050.

Starting with a strong initial boom in the first years, solar photovoltaics then reach cruising speed and increase more gradually to reach an annual production of 90 TWh in the long term. The large majority of the installed capacity is mounted on buildings, while the rest consists in solar farms on land that does not have competing uses, such as polluted soils, artificialised areas, vicinity of transport infrastructures, etc. Under a two third / one third respective share, less than 5% of the total French roof area would need to be equipped, while ground systems would require in total a 30 km x 30 km surface, only 30% of which would actually be covered by panels.

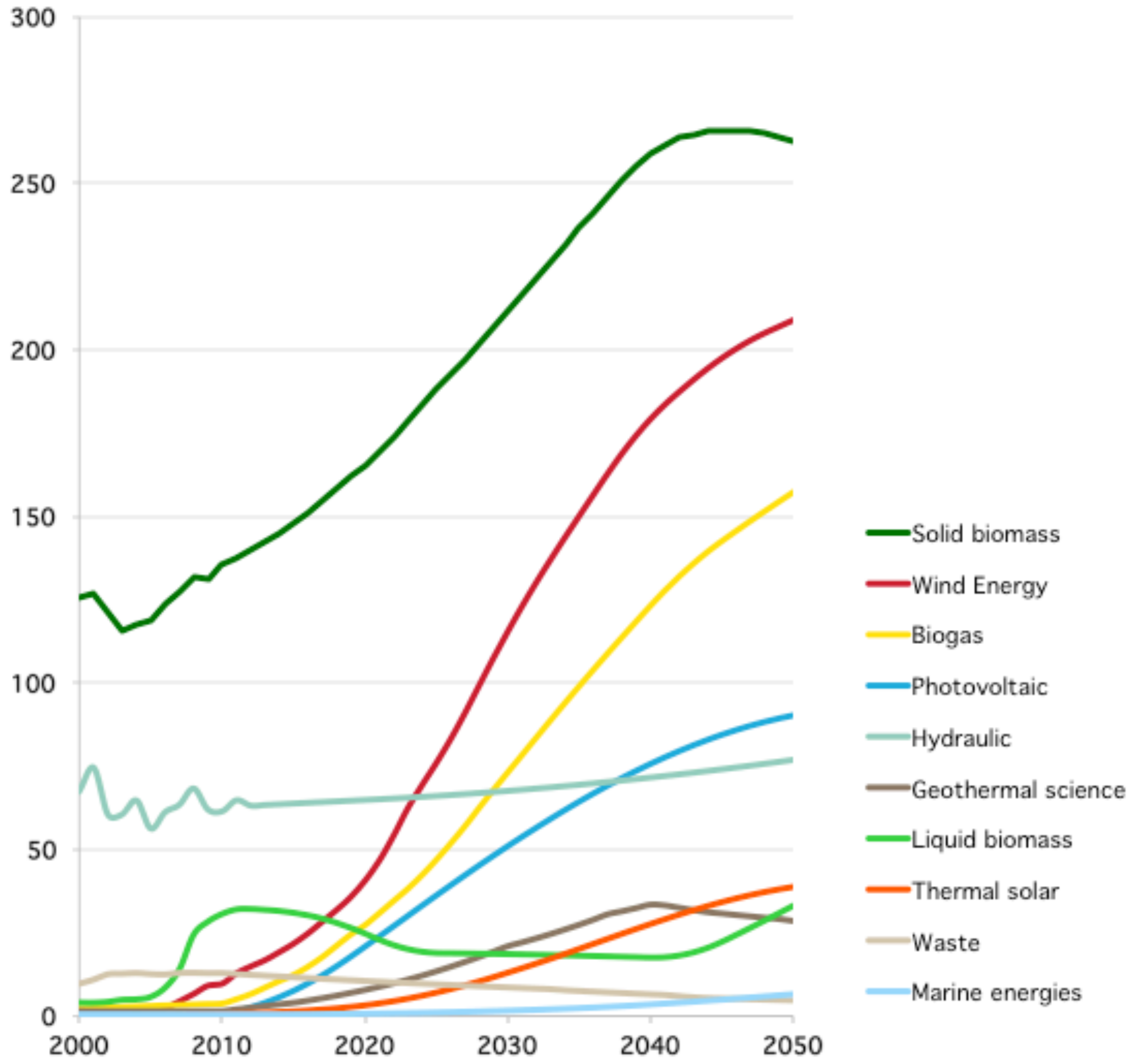
Renewable electricity sources, including a modest contribution from marine technologies, reach in total 383 TWh in 2050, covering almost 40% of primary energy needs.

Other renewable sources can be exploited. Geothermal energy, mostly for heat supply, increases from a single TWh today to 29 in 2050. On the other hand, energy recovery from domestic waste incineration decreases from 13 to 5 TWh, due to its poor efficiency, local pollution issues, and the development of material recycling rates.

Solar thermal, almost inexistent in France at present, should also be strongly developed: with more than 120 million square meters of panels on residential, tertiary, and industrial buildings, it could supply 39 TWh of primary heat.

Altogether, this realistic development of renewable energy sources leads to supplying 990 out of the 1,100 TWh of primary energy needs in 2050. Under the négaWatt scenario, France succeeds in implementing an energy transition resulting in a 90% renewable energy mix.

■ **Development of renewable energy sources in the négaWatt scenario**



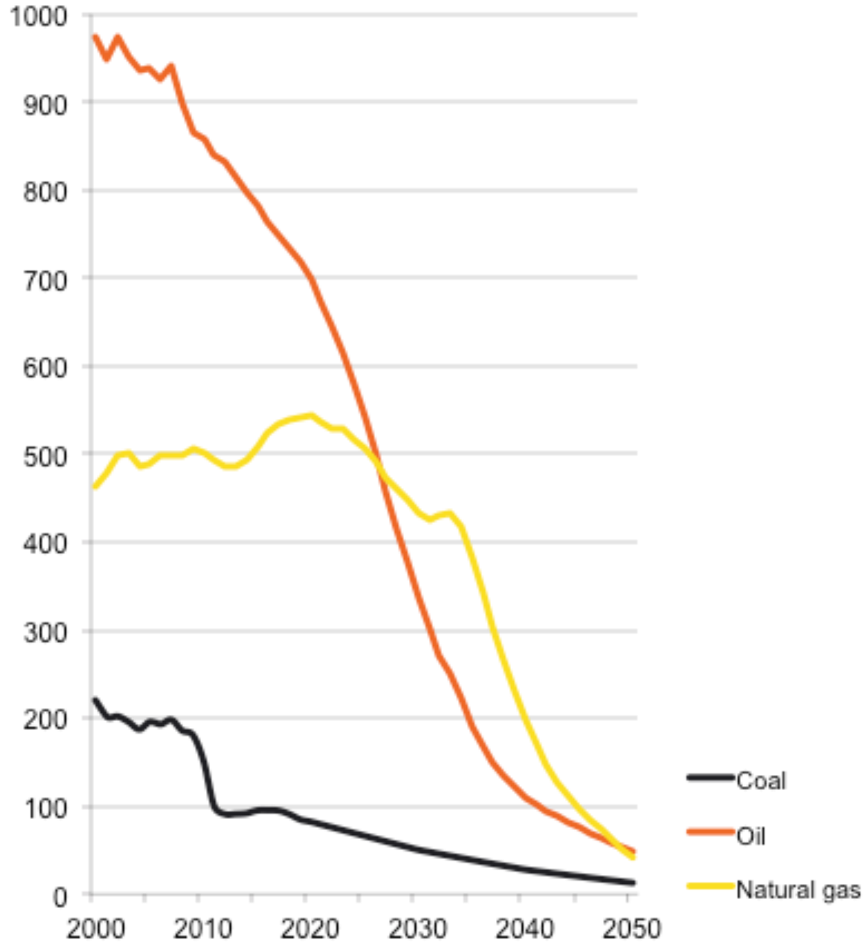
A marginal use of fossil fuels

Under the négaWatt scenario, only 10% of the 2050 energy demand needs to be supplied by non-renewable sources, while today oil, fossil gas (improperly named 'natural gas'), and coal meet more than 70% of the demand. Thus, France has the potential to nearly end its strong fossil dependency in four decades.

With 13 TWh from coal, 42 TW from fossil gas, and 48 TWh from oil, the 2050 fossil fuel consumption is almost 15 times lower than in 2010. The use of these residual fuels varies:

- Oil principally remains in transport, where it fuels around half of the remaining vehicles using liquid fuels.
- Coal is mainly used for producing heat for specific industrial processes, and as raw material for the steel industry.
- Last, fossil gas contributes to a few TWh of flexible electricity generation, and to CHP systems (notably on some industrial sites).

■ **Evolution of oil, fossil gas and coal consumption under the négaWatt scenario** (in TWh)



Important to note, the fossil gas decrease only truly starts after 2035, because gas power plants are temporarily used as a back-up solution to maintain the electricity supply balance while nuclear reactors are progressively shut down. This additional gas consumption is offset in other sectors through building renovation and the development of renewable gas, whether biogas or synthetic methane. After the final shutdown of all nuclear reactors, the fossil gas consumption can decrease steeply between 2035 and 2050.

A complete phase-out of fossil fuels to reach 100% renewable energy may also be considered, although it would potentially require costly and complex additional efforts: its relevance and added-value should be assessed with all criteria in mind. While not excluded, it is not part of the 2050 négaWatt scenario at present.

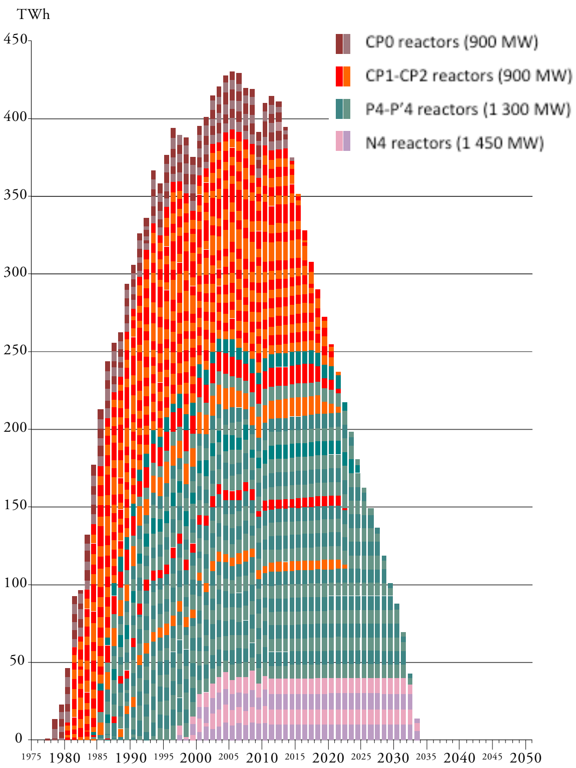
A gradual and reasonable nuclear phase-out

The gradual replacement of nuclear power by renewable energy allows to eventually consider a full phase-out of this technology, that currently represents more than 75% of the French electricity supply. The négaWatt scenario adopts a very pragmatic approach in this instance: progressively shutting down reactors without replacing them as sufficiency/efficiency/renewable alternatives make it possible. The pace takes into account nuclear safety challenges as well as as the evolution of energy demand.

The approach considers electricity needs over the years, the part that can be supplied by renewables, and the remaining share that still requires conventional capacities to achieve the necessary electricity grid balance on an hourly basis. A cross analysis of these needs with the ageing status of nuclear reactors - that strongly influence their level of safety - leads to refining the pace of each nuclear reactor shutdown. If required, fossil fuels (notably gas) are temporarily mobilised as a back-up solution until négaWatt alternatives deliver.

The ageing of the French nuclear fleet is a sensitive issue. Several reactors have already reached or exceeded a 30-year lifetime, considered at planning phase to be the reasonable maximum. The nuclear industry now aims at prolonging to 40 years, although there is little feedback and experience. In any case, following the p ost-Fukushima reassessment of safety risks, this 40-year target cannot be further pushed back: no safety device reinforcement will ever be able to completely upgrade the initial conception, nor compensate for the ageing of non-replaceable components.

■ **Nuclear capacity in the négaWatt scenario** (in TWh)



Age peak issues must also be taken into account: 80% of the reactors, representing more than 60% of the current electricity production, have been put in service between 1977 and 1987, and all others except one in the following decade. Just as it has been anticipated in the similar German nuclear phase-out agreement in 2000, it is necessary to consider some flexibility around the age of each reactor shutdown, in accordance with safety-related criteria.

A Modelling of the impact of each shutdown allows to find out the optimum balance between these different constraints. As a result, the phasing–out process comprises three main phases.

During a first phase, the current over-capacity and export reserves allow for a quick closing down of the least safe reactors, starting by the oldest ones. This way, up to 3,500 MW of nuclear capacity can be removed every year.

The pace then stabilises at a lower level - around 2,500 MW per year -, thus enabling renewable energies to take over progressively without market disturbances.

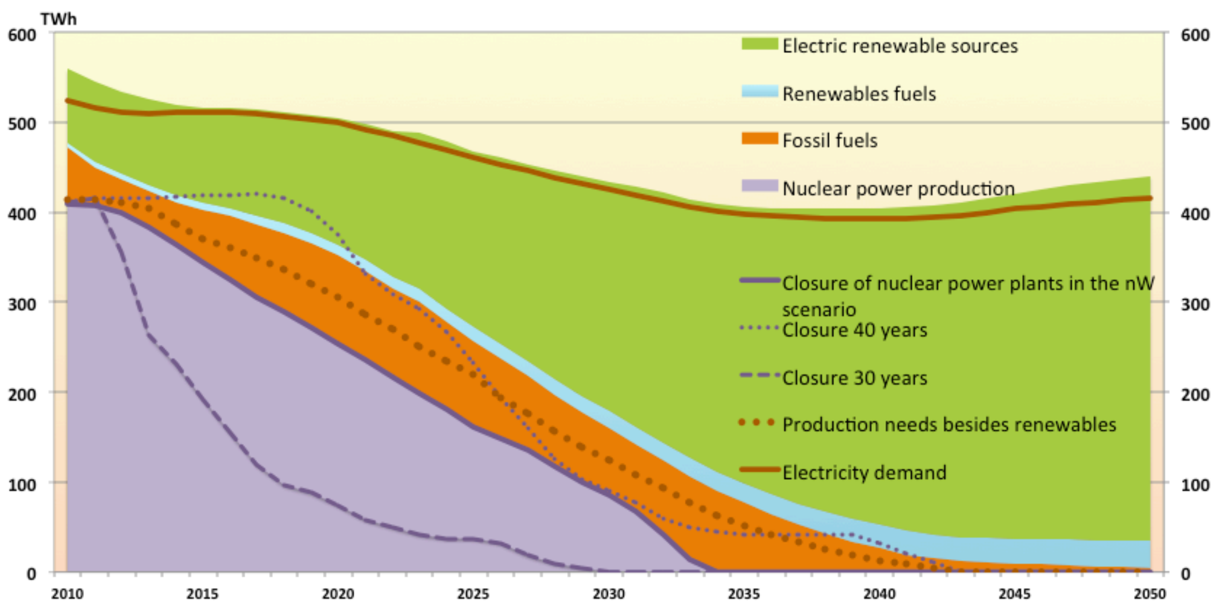
Finally, the pace of shutdown accelerates once again during the last years, with up to 4,000 MW shut down every year, to cope with the dismantling of the nuclear industry (even if for some reactors the 40-year limit hasn't been reached). Indeed, phasing out nuclear power does not concern only reactors, but also a number of factories to prepare and manufacture the nuclear fuel, take care of radioactive waste, and specific bodies related to monitoring and controlling nuclear facilities. From an industrial, economic, and safety point of view, it would make no sense to maintain or renew all these structures for only a small number of reactors still in operation.

The last nuclear reactor would shut down in 2033, corresponding to a 22 year-long phasing-out process. This moderate pace is the result of a careful optimum calculation between different constraints. On the one hand, reactors need to be closed sufficiently quickly – between their 30^{th} and 40^{th} operating year – to cope with safety challenges. On the other hand, it is important to take into account the pace of renewable energy development in order to avoid an uncontrolled peak in substitution by fossil gas.

These constraints play differently over the coming decades. During a first period, it is the pace of efforts on saving electricity and developing renewable sources that matters most. Then, the ageing of nuclear reactors takes over as the most crucial constraint. The "crossing" takes place around 2027.

It is thus indispensable to plan ahead and engage in the nuclear phase-out now to ensure a sufficient level of alternatives in the coming 15 years, before we hit the "40-year cliff" of the nuclear fleet. Our multi-criteria analysis shows that the window of opportunity is quite narrow, between 2030 and 2035. Adequate decisions have to be taken in the coming years.

■ Optimisation of constraints for defining the pace of nuclear reactor shutdown



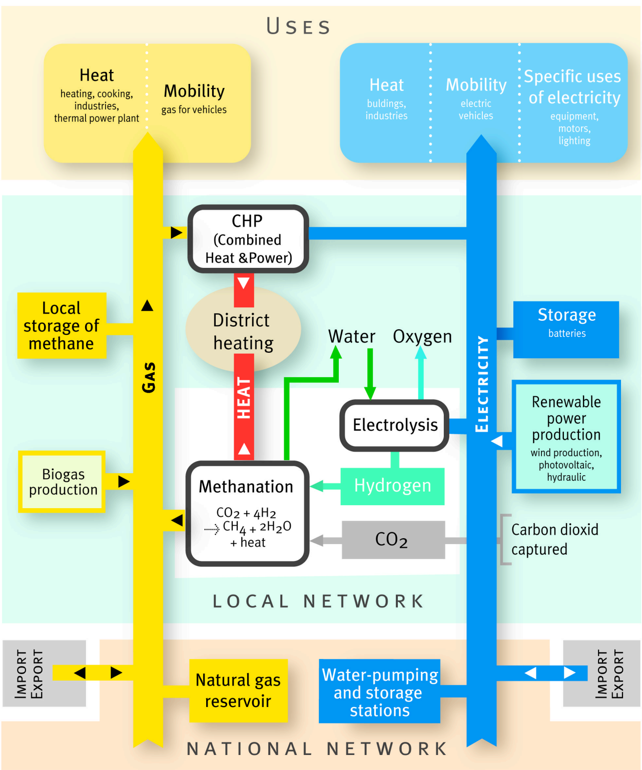
Complementarity of energy grids to achieve 100% négaWatt

The arguments against fluctuating (rather than 'intermittent') renewable energy sources are often very exaggerated. However, it is true that in a 100% négaWatt energy system the need to permanently ensure an instantaneous balance of the electricity grid is a challenge, as a significant share of sources cannot be directly controlled – except by disconnecting them.

The solution obviously lies in storage facilities at various power range level and grid nodes. Water-pumping and storage stations already do the job in the existing grid. Their overall capacity reaches a maximum, but they could be operated much more efficiently.

Different types of electro-chemical storage batteries (Lithium-ion, Vanadium, Sodium-Sulphur, etc.) are often mentioned, as well as the opportunity to use electric vehicles as "mobile batteries", or to produce hydrogen for fuel-cells through water electrolysis. However, none of these solutions seems to be able to provide the level of storage that is necessary. By 2050, the question is not just a few hours of supply adjustment to cope with a daily demand peak, but the capacity to store several hundreds of GWh produced during days or weeks of sunshine or strong winds, and to restitute them when the situation changes.

Grid complementarity: the methanation example



A promising solution – currently seriously looked at in Germany – is methanation. Discovered by the French Nobel-prize winner Paul Sabatier in 1912, it produces synthetic methane through a simple reaction between hydrogen from electrolysis and carbon dioxide from combustion. This methane can, just like biogas, substitute fossil gas in gas networks.

This way, electricity is converted into molecules that can be perfectly stored.

On top of this, the strong reduction of the winter peak electricity demand, mainly caused today by electric heating that will be progressively eradicated, will make the hourly electricity grid balance much easier to achieve.

By 2050, the négaWatt scenario assumes around 50 TWh of synthetic methane injected into the gas grid, a sufficient amount to fully offset the variability of renewable electricity production, as well as a source of by-produced heat that can fuel local district heating.

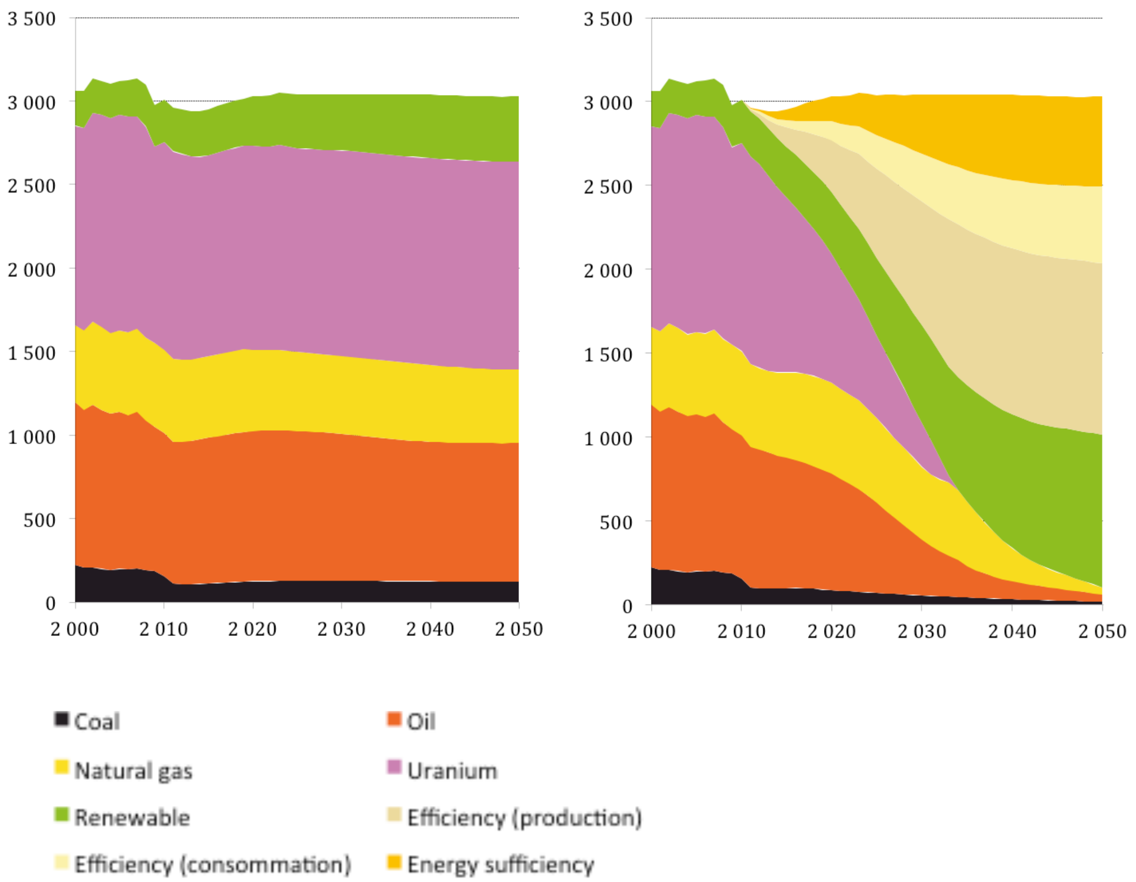
France has developed more than 150 TWh of underground gas storage capacity. Beyond the storage of excess generation by renewables, the high flexibility of gas as an energy carrier can therefore be used in complementarity with the electricity grid, rather than the absurd competition between energies that currently prevails.

Toward a 100% sustainable primary energy system

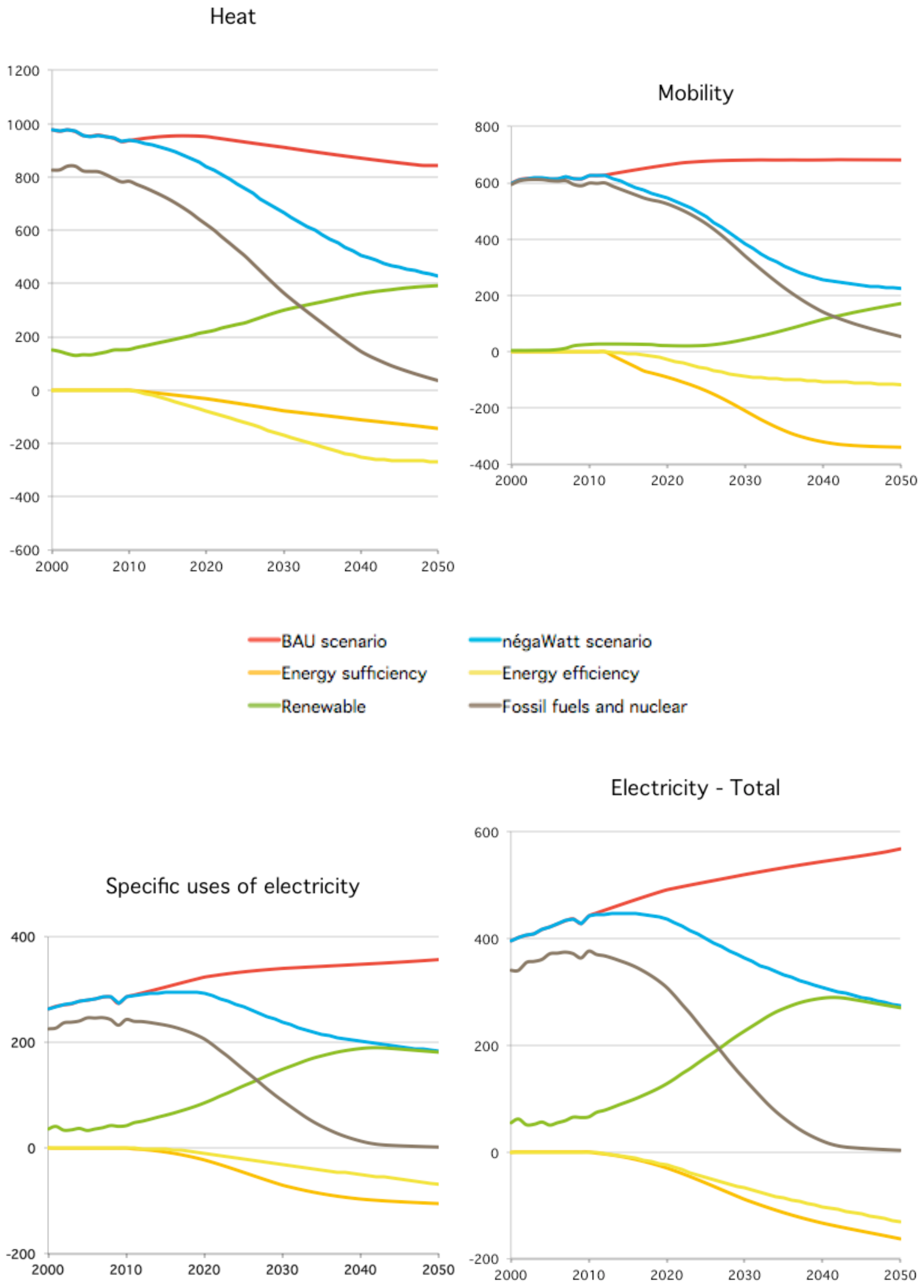
The négaWatt scenario demonstrates the feasibility of a transition towards an energy system based on flow resources. By 2050, the French society consumes 2,000 TWh less primary energy than today, i.e. about a two third reduction. This is about 30% of the energy resources it would consume in a BAU scenario. By 2050, France nearly reaches 90% of renewable sources in its primary energy supply.

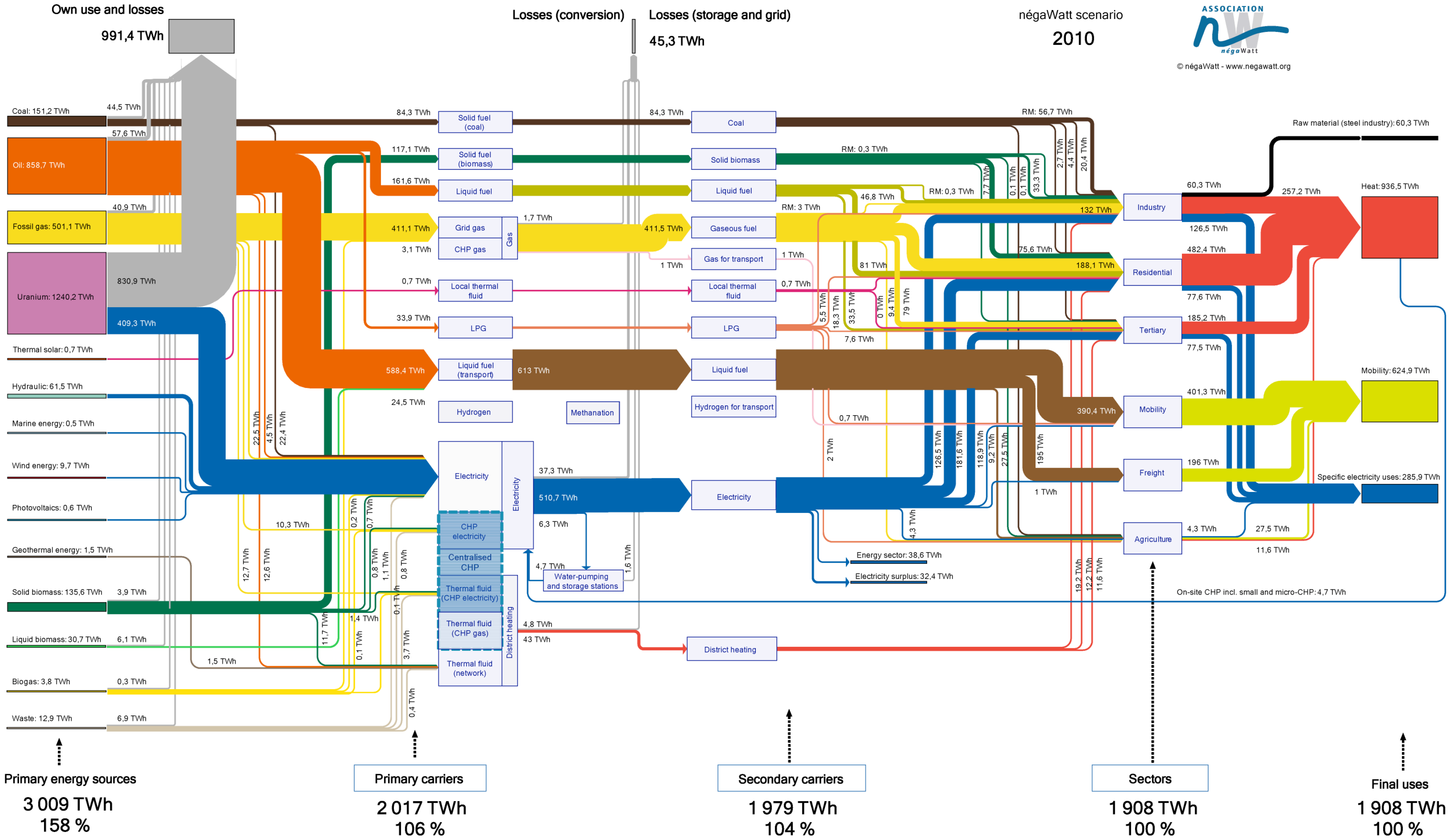
This change goes together with a significant increase in the efficiency of the energy system, with the final/primary energy ratio growing from 63% to 84%. This notably results from a revolution in the way energy carriers such as electricity and gas are managed, exploiting their diversity and the complementarity of their grids.

Comparative evolution of primary energy production by sources in the BAU (left) and négaWatt (right) scenarios (in TWh)

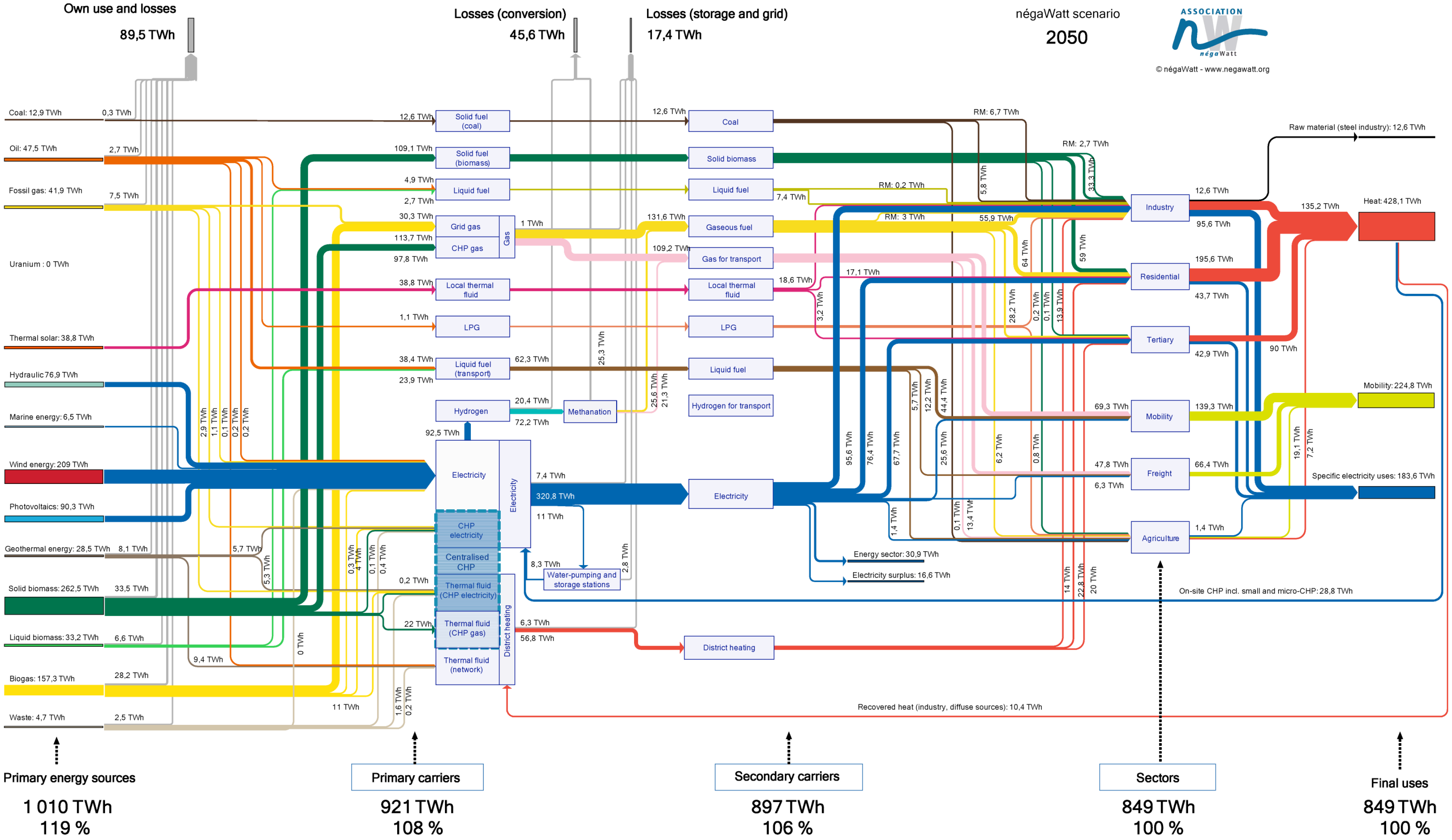


■ **Evolution of sufficiency, efficiency, renewable, and fossil/fissile fuel shares in final energy needs by main uses** (in TWh)





Note :
1) This diagram does not represent actual grids, but flows and losses due to the different energy conversion steps from primary to final sources. For instance, biogas in 2010 is not actually injected in the national gas grid but used locally. This doesn't change the overall picture.
2) Most figures are rounded to simplify the chart. It means they don't all add up perfectly.
3) RM = raw material



Note :
1) This diagram does not represent actual grids, but flows and losses due to the different energy conversion steps from primary to final sources. For instance, biogas in 2010 is not actually injected in the national gas grid but used locally. This doesn't change the overall picture.
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3) RM = raw material

A scenario that addresses 2050 societal challenges

A crucial question remains: is such a scenario consistent with the urgency of global energy and climate challenges?

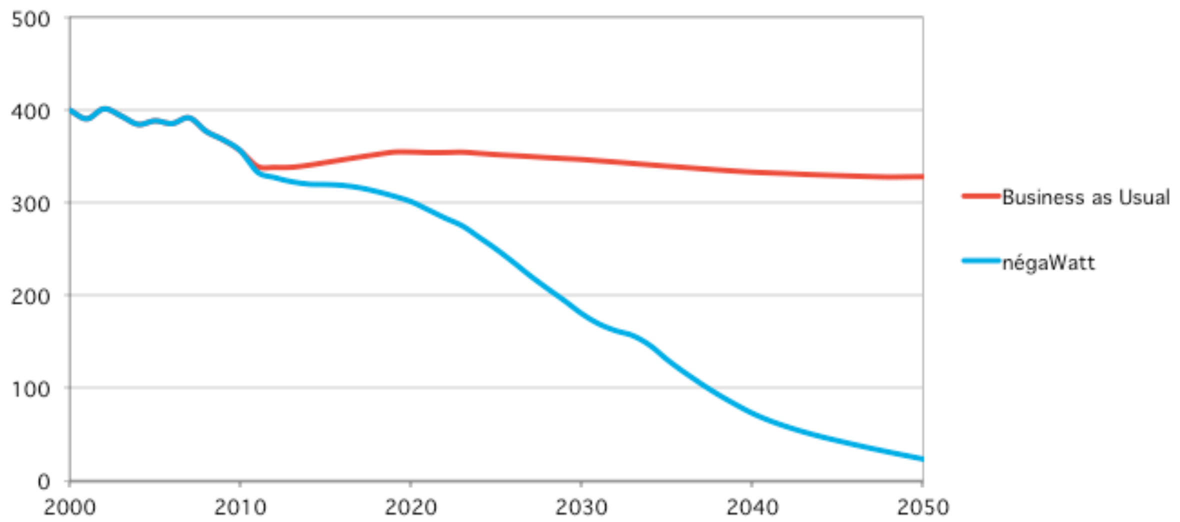
Nuclear-related risks for France and its neighbours are reduced by the quick shutdown of reactors with the highest risks, then by engaging in a well-planned and consistent full phase-out by 2033. The cumulative number of nuclear operating hours by 2050 is divided by a factor 3.2, leading to a much smaller radioactive waste burden for future generations.

The end of cheap oil (*peak-oil*) is well anticipated by limiting its use to oil-based chemistry, industrial raw materials, and some very specific uses (industry, aviation). Imported fossil natural gas is gradually substituted by biogas and synthetic methane produced from renewable electricity.

Compared to 2010, energy-related CO_2 emissions are halved by 2030, and **reduced by a factor 15** by 2050.

Cumulated CO_2 emissions between 2011 and 2050 reaches 7 billion tons: this figure is consistent with the share of global emissions that can be allocated to France given its demographic weight and a fair worldwide burden sharing, if we want to keep a chance to limit global temperature increase below 2°C by 2100.

■ **Annual energy-related CO_2 emissions in the négaWatt and BAU scenarios** (in $MtCO_2$)



Energy-related CO_2 emissions currently represent around 70% of total greenhouse gas emissions (GHG) in France. Another 20% is attributable to agricultural processes and waste management, and the rest to non-combustion based industrial processes.

Under the Afterres2050 scenario, a detailed assessment of GHG emissions caused by agriculture has been carried out and shows that a reduction by a factor 2.5 seems to be the maximum reachable limit for this sector.

When considering all GHG emissions, the négaWatt scenario reaches an overall reduction factor of 5.9 by 2050.

How much does it cost?

This is of course a crucial question, about which misleading and rebuttable figures circulate, often based on simplistic guesstimates. But this is a tricky question as well!

First, because before discussing the cost of energy transition, one needs to know what it is to be compared to. We are not in a situation where doing nothing is an option: as assessed in 2006 by Sir Nicholas Stern, previous World Bank Economist-in-Chief and Vice-President, actively mitigating climate change will cost 15 to 20 times less than inaction.

As regards nuclear, there will be costs for dismantling nuclear reactors and managing nuclear waste over thousands of years, irrespective of the decision to phase out or continue with this technology.

Second, because asked in such a way this question suggests that the energy transition would only mean costs and not benefits, which is obviously untrue:

- **sufficiency actions** are typically those that cost nothing or very little - since they mainly refer to choices or behaviour, while they prove beneficial by making us save energy and in turn money.
- **Efficiency actions** usually need an initial investment that (thanks to the savings generated) is always beneficial to society in the long term, and may also be profitable in the short or mid-term for those who undertake them. Although it is preferable to favour actions which have the quickest return on investment, others should not be cast aside.
- **Renewable energies** have small operating costs, but the initial investment is often higher than for fossil fuels and nuclear. However, the costs of the latter do not include all their environmental externalities, and is expected to rise in the future. On the contrary, the cost of renewable energies is decreasing through industrial dynamics, and they are meant to become competitive.

From a strictly economic point of view, the energy transition can be seen as an investment that will undoubtedly become profitable for society in the short or longer term.

Besides, the capital invested in the energy transition is not thrown out the window. It will lead to saving dozens of billion Euros on oil and gas imports. It will generate billions of Euros of turnover for businesses in the energy service, efficient equipment, and renewable energy sectors, as well as hundreds thousands jobs and huge opportunities for exporting on a growing global market. A job impact assessment carried out on the négaWatt scenario[1] clearly showed that the energy transition represents a substantial opportunity for France economic recovery.

In stark contrast, simply upgrading the 58 French nuclear reactors to a "post-Fukushima" safety level would swallow dozens of billion Euros. In a context of restricted budgets, investments should go in priority to the energy transition and not to obsolete polluting technologies, so that our energy demand can be lowered, our energy independency increased, and local low-polluting and job-creating energies developed.

Reversing the question into what benefits the energy transition would provide, before discussing how much the investment will be, makes the answer obvious: what are we waiting for to engage into this no-regret path?

[1] A study by CIRED-CNRS, downloadable (in French) at: http://www.negawatt.org/etude-emplois-economie-p120.html

Where to begin?

Following a decade of analysis and discussions, négaWatt has elaborated a set of consistent policies and measures that can be recommended. They aim to establish the proper institutional framework, implement economic instruments that combine short and long-term signals, and set safeguards in priority sectors while the energy and industrial production is redirected.

They also support a pedagogical approach to the necessary change: the energy transition will only succeed if everyone understands its urgency and the cost of inaction, and if it is implemented by all and for all.

These recommendations cover four main areas :

⇨ *How can society as a whole move towards the energy transition?*
The issue of governance

Energy transition as considered here is such an essential and ambitious project that it can only become reality if the multitude of small and big necessary decisions have sufficient legal force, to prevent the numerous private interests that will be affected from hampering or slowing down an already lengthy process.

For this, it is necessary to rely on three complementary instruments that will have to be engraved at highest level in legal texts of the French Republic :

- A **constitutional principle**: the right for any citizen to have access to a safe and environmentally-friendly source of energy at an acceptable price, through policies based on sufficiency, efficiency and renewables.
- An **Energy Transition Bill**: aimed at translating the aforementioned principle in concrete terms, such a law should be urgently implemented after a consultation process involving the National State, the Parliament, businesses, trade-unions, local authorities and civil society.
- The establishment of an **Independent Energy, Climate, and Environment Authority** in charge of supporting policy-makers, monitoring their decisions, and sanctioning breaches in the implementation of the Energy Transition Bill. This Authority must be independent from the legislative and executive powers, and have the financial means to conduct investigations and take firm decisions.

Three priorities should be put high on the agenda:

- **Giving decision powers back to local territories,** through a new step in the decentralisation process centred on local energy management and energy autonomy,
- **Engaging citizens in the energy transition,** through a massive awareness-raising, informational, educational, and training campaign about energy and climate,
- **Reconsidering urban planning rules,** having in mind the consistent goals of reducing non-renewable energy needs and creating better ways of “living together”.

⇨ *How to make sure the economy serves a sustainable society goal rather than the opposite?*
A fair price for energy

A solution has to be found to cope with two conflicting challenges: the necessity for energy prices to reflect all environmental, economic and societal costs, and the need to secure a right to access energy even for the poorest families. A four-step approach is recommended:

- The establishment of **a single fiscal instrument** in the form of a Primary Energy and Environmental Externalities Contribution (”CEPEx” in French), that would account for the impact of all energy supply chains in the country.
- A **widespread use of “bonus-malus” schemes** on all goods generating a recurrent energy consumption, designed so as to prevent stock growth.
- The implementation of a **progressive energy tariff principle**, in order to discourage overconsumption while making it easier for everyone to access a vital amount of energy.
- The development of an **Action Plan to eradicate fuel poverty,** aimed at favouring households' independency through preventive and educational actions financed by the revenues of the aforementioned measures.

⇨ *How to reduce energy needs in all sectors?*
The role of sectoral policies

Beyond horizontal principles and economic instruments, the success of the energy transition relies on the implementation of energy saving programs in priority sectors.

- **Building energy performance regulations**, with the same level of ambition and thoroughness for refurbishments than for new buildings, also including standards for appliances and equipment.
- The objective of **a more reasonable passenger mobility and rational freight system,** through a diversification of transport modes and strong incentives for modal shifts towards the most efficient technologies.
- The launch of a huge **action plan to save non-renewable energy resources and raw materials** in all industrial sectors, notably through the promotion of reuse, repair, and recycling with a view to relocate production in France.

⇨ *How to meet our energy needs sustainably?*
The ***energy supply issue***

- Supporting the development of **renewable energy sources**, whose contribution to the general interest should be acknowledged by law and should legally justify interventions upstream (e.g. R&D and market support mechanisms), as well as downstream (coordination and decentralisation of energy grids).
- **Phasing out nuclear energy**, taking into account safety and climate change challenges, and favouring a substitution of nuclear power by renewables.

Making the wish a reality

Seeing the energy transition as 'an additional burden' would be a mistake; balking without understanding the chance it represents, and the great opportunities it can offer would be totally missing the point.

By relaxing constraints upon us, the energy transition detoxifies us from "easy energy", contributes to mitigating the impacts of future energy and climate crisis, and drives us together towards an energy autonomy that will help us face the future with higher serenity and resilience.

The energy transition as proposed by the négaWatt scenario is in no way a jump into the unknown. Quite the opposite: it is a path of both no-regret and minimum risks.

A no-regret path, as even if other options become available tomorrow, the efforts made on sufficiency and efficiency will already be done and can be preserved.

A path of minimised risks, in comparison to the threat of seeing our social model collapsing under the triple burden of fossil peaks, climate change, and potential nuclear disasters. Minimum risks does not mean overcautiousness, or isolationism in a defensive strategy. This path is also our generation's responsibility to '*act so that the effects of our action are compatible with the permanence of genuine human life'* (Hans Jonas).

So, what are we waiting for? Let's make the first steps now, the wish needs to be made reality.

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The négaWatt Association, founded in 2001, is an energy expert and strategy think tank, concerned by addressing first the right questions and providing operational answers to switch to a sustainable energy system.

Its leadership and coordination is managed by the so-called "négaWatt Company", a group of around twenty experts and practitioners relying on a network of more than 800 individual members contributing in kind.

As a not-profit organisation under French law, its financial resources principally come from donations and member subscriptions. Several private Foundations, NGOs and business sponsorships also provide support to the work carried out by the association.

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Established in 2009 by the négaWatt Association, the négaWatt Institute is a training and research body, focused on energy and sustainable development topics.

Its role is to prepare and support the implementation of an energy transition in the French society, using négaWatt's tools as its main references.

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