PHOTOVOLTAIC SOLAR POWER:

25% of the world's electricity low-carbon in 2050!

EXECUTIVE SUMMARY

On the eve of COP21, there is no longer time to question the reality of climatic disorders; solutions must be implemented. Moreover, even today, more than 1.3 billion human beings have no access to electricity. How can we provide the energy services essential to those who are deprived of them, without any carbon emissions? Long considered too expensive and posing technical problems due to its intermittency, photovoltaic solar energy has in recent years undergone developments which give reason to doubt this diagnostic. What's more, due to future progress it is estimated that it could provide at least 25% of the world's electricity in 2050[1] instead of the 5% envisaged in most long-term planning scenarios.

1. Out of a total electricity consumption range of 35 to 40 PWh in 2050 (extrapolated from the scenarios of WEO 2014).

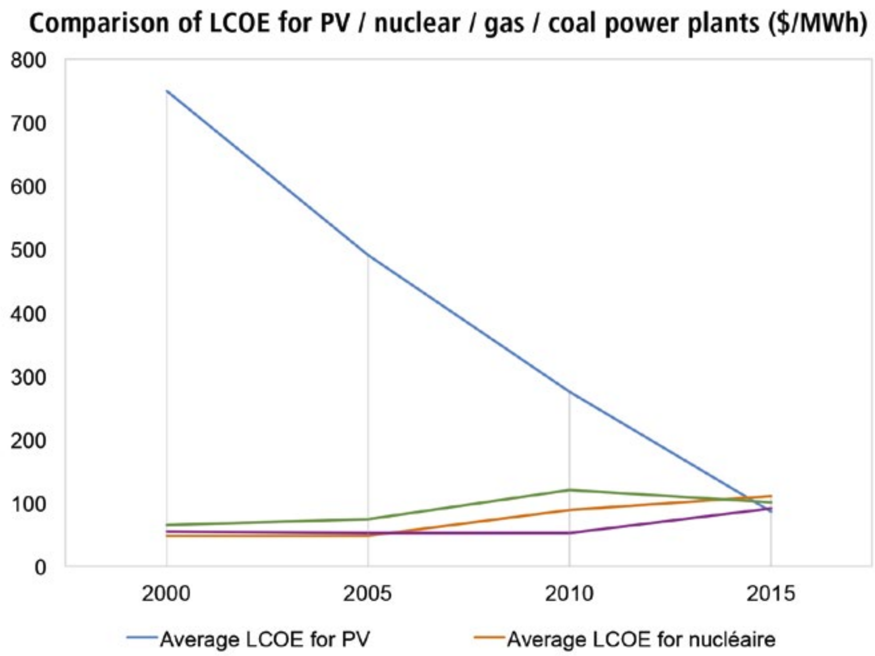
Photovoltaic solar power, an increasingly competitive energy.

Although the first discoveries regarding photovoltaic solar energy date from the 21st century, this source of energy has long remained confined to the niche market of the space industry. The electricity produced by photovoltaic power was far more expensive than that coming from other technologies (gas, coal, nuclear).

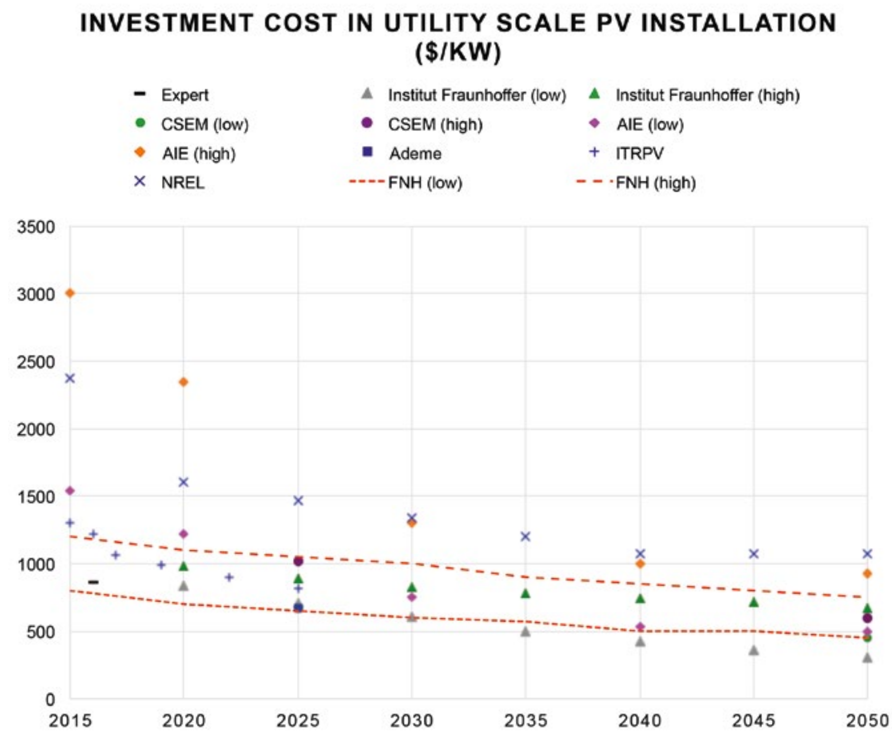
At the start of the 21st millennium, the levelized cost of a photovoltaic installation was about $750 per MWh compared with less than $70 per MWh for other types of production. Subsidies (especially in Europe) and industrial and technological progress then made it possible to expand the market for photovoltaic power and initiated a continuous fall in costs, which are now approximately the same as those of conventional production facilities.

The current and future technical developments described in detail in this study make it possible to expect a 20% to 40% reduction in the initial capital cost of a photovoltaic installation by 2030. On the 2050 horizon, based on market trends, the cost will be halved. Moreover, many manufacturers expect the lifetime of photovoltaic power plants to be lengthened, from 25 years (the service life currently adopted for calculation of the levelized cost) to possibly 30 or even 40 years.

These two developments will inevitably reshape the electricity and energy landscape profoundly compared with the current view. The levelized cost of a ground-based photovoltaic installation could be between US$50 and US$35 per MWh in 2050, and the cost of a residential installation between US$70 and US$50 per MWh.



‣ **FIGURE 1 :** COMPARISON OF THE LEVELIZED COST OF PV/NUCLEAR/GAS/COAL, FRAUNHOFFER INSTITUTE, DATA BASED ON BUYBACK TARIFFS FOR GROUND-BASED PV INSTALLATIONS IN FRANCE, LAZARD, TCDB (EXCLUDING COST OF CO2), IEA ETP 2015. ILLUSTRATION: FONDATION NICOLAS HULOT.

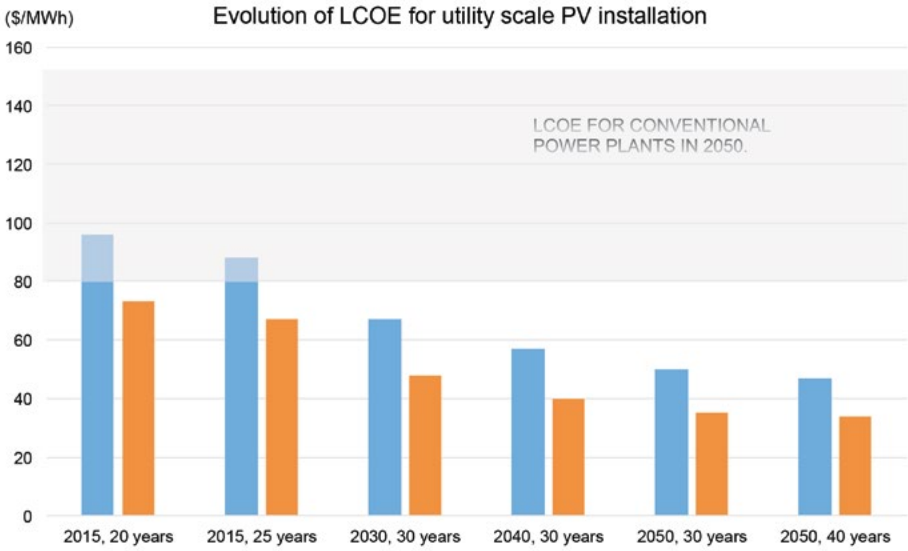


‣ **FIGURE 2 :** PROSPECTS FOR CHANGE IN THE INSTALLATION COST OF GROUND-BASED PHOTOVOLTAIC POWER PLANTS, ILLUSTRATION: FONDATION NICOLAS HULOT.

CAPITAL COST AND LEVELIZED COST

Two economic statistics make it possible to evaluate the competitiveness of an energy production installation. The initial capital cost, on the one hand, is decisive for the decision to launch a project. It is calculated in US$ per MW installed. The levelized cost (or discounted cost of energy), on the other hand, includes not only depreciation of the initial capital cost but also operating costs (maintenance, cost of primary energy) relative to the total kWh produced over the life of the installation. The levelized cost (expressed in US$/MWh) takes into account a discount rate which has the special feature of greatly reducing future costs, and thus proves unfavorable to solar energy due to the magnitude of the initial investment.

Conversely, the costs of conventional production facilities will on the whole increase. These mature technologies will see no breakthrough in competitiveness gains, while certain components of the cost of these facilities will increase (safety requirements for the nuclear industry, allowance for a carbon cost for gas- and coal-fired power stations, particulate emission reduction standards for coal and growing pressure from civil society against the extraction of fossil fuels).



‣ **FIGURE 3 :** CHANGE IN LEVELIZED COST RANGES FOR LARGE GROUND-BASED INSTALLATIONS, SOURCES: FONDATION NICOLAS HULOT (INSTALLATION COST SCENARIOS, FIGURE 2: IN BLUE, HIGH COST SCENARIO , IN ORANGE, LOW COST SCENARIO), ADEME, EXPERTS, IEA, TRANSPARENT COST DATABASE, E&Y, BNEF, MIT, ILLUSTRATION: FONDATION NICOLAS HULOT

PHOTOVOLTAIC POWER: A DIFFERENT KIND OF ENERGY!

The photovoltaic technology is based on physical principles completely different from those of other electricity production facilities. The latter are based on the classic laws of physics, using mechanisms occurring on a macroscopic scale: operating an alternator to produce electricity. The difference between the technologies is the force used to cause the rotor to turn (wind, water, steam produced by the combustion of coal, gas or nuclear fission reactions, etc.). Photovoltaic power, on the other hand, is based on quantum physics which governs the behavior of matter on or below the nanometric scale. Now, this physics is in no way similar to that which we «experiment with» every day. That makes photovoltaic power a different kind of energy. Far more modular than the others (a 1 W or 1 GW installation can be manufactured), it can still benefit from technological breakthroughs. The other production facilities, based on mature technologies, can only experience continuous improvements. This special feature of photovoltaic power means that this industry is far more similar in its development dynamics to electronics industries – which experience exponential cost reductions - than to energy industries.

Photovoltaic solar power: a clearly sustainable energy from the economic and environmental viewpoints.

The competitiveness of photovoltaic power being ensured, it is important to check that the necessary investments to make this energy a significant part of the electricity mix are feasible. Note, first, that an energy sector technology has never experienced such development, which makes it more similar to the specific development process of the electronics world, in both its speed of market penetration and the pace of innovation. In 15 years, the installed capacity has been multiplied by more than 100, to 186 GW at the end of 2014, including more than 40 GW installed in 2014 alone (a record year for investment, at US$136bn). This is the order of magnitude of the coal-fired power station capacity installed in China each year (and about 15-20% of the equivalent electricity production). This process is gathering momentum, moreover. Based on simply maintaining the annual investment level of 2014, combined with expected cost reductions, we obtain a cumulative total of 4,000 to 6,000 GW installed by 2050 (including installations to be renovated).

This scenario is really conservative because it means assuming a halt in growth in investment in photovoltaic power despite the substantial increase in its competitiveness. A capacity range of 6,000 to 8,000 GW would make it possible to meet 20-25% of estimated global electricity demand in 2050[1]. In light of the information brought together in the present study, this target seems easily attainable from an investment viewpoint and desirable from the economic viewpoint.

The study also reviews the existing literature concerning the availability of the raw materials required for such a photovoltaic power plant program and the issue of the energy return on investment. According to figures from the MIT, the first point is apparently not a major obstacle for technologies based on silicon (the second most abundant element on the planet). As regards the energy return on investment, already satisfactory, it is set to increase, thus reducing the carbon content of photovoltaic electricity (currently between 30 and 70 g of CO_2 per kWh). This clearly places this energy source in the club of energies with a sufficiently low carbon content[2] to enable us to stay on track for global warming of less than 2°C.

1. 6,000 to 8,000 GWc represents a production of approximately 8 to 10 PWh (assuming average insolation equivalent to 1350 kWh per kWc) out of a total electricity consumption range of 35 to 40 PWh in 2050 (WEO 2014 scenarios).

2. On the 2050 horizon, we should aim at an electricity production facility mix for which the carbon content is less than 100 g of CO2 per kWh and as close to 50 as possible.

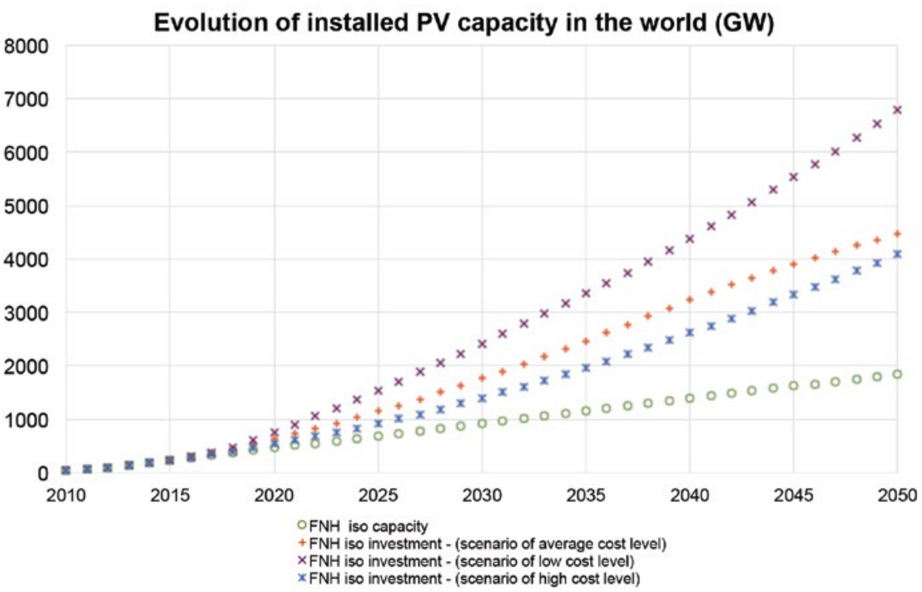


FIGURE 4 : PHOTOVOLTAIC POWER DEVELOPMENT SCENARIOS: (I) CONSTANT ADDITIONAL ANNUAL CAPACITY (EQUAL TO THAT OF 2014); (II) CONSTANT ANNUAL INVESTMENT (EQUAL TO THE 2014 LEVEL). CALCULATIONS: FONDATION NICOLAS HULOT.

Intermittency, a major obstacle to the growth of photovoltaic power?

A photovoltaic system produces only in the daytime and more in summer than in winter. This production may vary from one hour to the next as a result of changes in sunlight (e.g. passing clouds). This can cause problems of balance between supply and demand and hence at the level of electricity grid management. In order to clarify this issue, the study investigates the following three dimensions of the electricity system.

1. What is the capacity of a mature grid for coping with intermittency?

Analysis of the French grid, typical of a mature and efficient grid, shows that the current transmission systems of developed countries (equipped to manage significant fluctuations in supply and demand) can already tolerate approximately 5% to 8% of consumption supplied by photovoltaic installations without setting up a new system. At the level of distribution systems, on the other hand, a match between consumption density and production density is a rule that it is important to obey in order to ensure unconstrained deployment of photovoltaic systems.

2. Can consumption be made flexible to move in step with production fluctuations?

Consumption management (for individuals and industrial firms) makes it possible to further increase the market share of photovoltaic power in the electricity mix. By processes currently being developed, this involves either forcing the consumption of certain electrical appliances at the time of photovoltaic production peaks (in the middle of the day) or eliminating demand at off-peak production times (at night).

Most consumption management techniques are well known and, in some cases, already employed notably in France (management of hot water cylinders and development of demand response schemes). Moreover, they have significant potential for development, which should be increased by changing national regulations to enhance their economic value.

3. How to improve electricity storage?

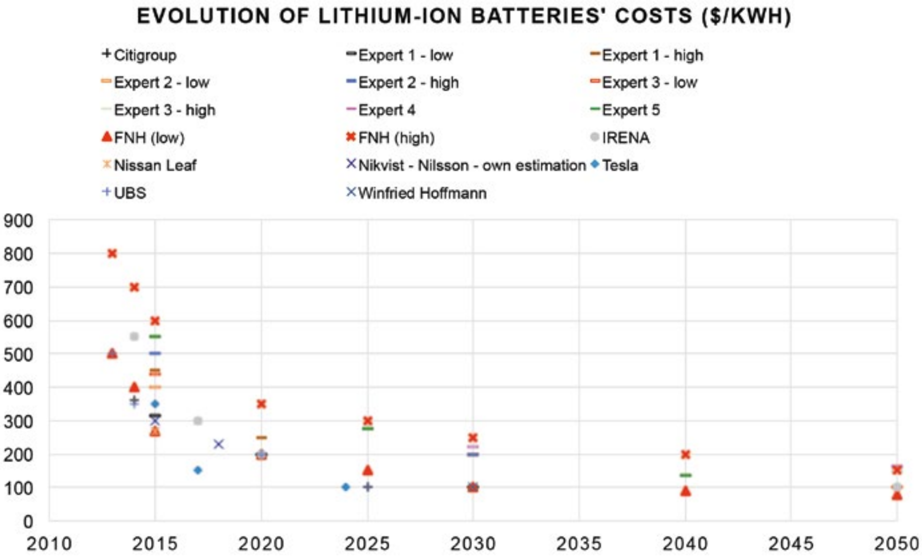
To date, the most economical means for «storing electricity» are hydraulic pumping stations, but their growth potential is limited. Recent developments regarding electrochemical storage could radically change ways of smoothing out intermittent production such as photovoltaic power. Long regarded as a costly technology, usable only for specific applications, electrochemical storage has in the last three or four years seen a rapid improvement in its competitiveness, like photovoltaic systems. For example, in 2015 firms such as Tesla and LG Chem posted capital costs of US$300-350 per kWh stored (versus about US$1000 per kWh stored five years ago). There are still significant prospects for development.

Several reports show that for a capital cost of less than US$200 per kWh stored, battery storage provides a more competitive solution than a back-up with fossil-fueled thermal equipment.

Finally, electrochemical storage has the huge merit of providing a response to the initial needs of the inhabitants in countries which have no structured electricity grids. Like for mobile phones which made it possible to avoid developing very costly infrastructure, this is a truly historic opportunity.

MANAGING CONSUMPTION MEANS CHANGING OUR WAY OF CONSIDERING ENERGY!

In the world of the electricity system as it has been developed since Edison's first electric power station in 1882, consumption is variable and production adjusts. With photovoltaic power it is production which is variable. Can electricity consumption adapt to production? Yes, to some extent: some of the services provided by electricity can cope with a time lag in the supply of electricity. Examples are the need to wash linen or heat domestic water and the housing unit (if it is well insulated). There is clearly an intrinsic flexibility in the use of the various devices and real benefits from managing consumption.



‣ **FIGURE 5 :** PROSPECTS FOR CHANGES IN THE COST OF LITHIUM-ION BATTERIES. ILLUSTRATION: FONDATION NICOLAS HULOT

WHY IS THERE A DIVERGENCE BETWEEN THE PERCEIVED COST OF THE BATTERIES AND THEIR ACTUAL COST?

Whereas the capital cost observed in the market is around US$300-350 per kWh for the lithium technology, the 2015 reports of the IRENA or the IEA on storage technologies and batteries regard the capital cost as around US$600-800 per kWh. This divergence can be explained by the fact that the batteries' electronic fundamentals confer on them a speed of innovation faster than the time for analysis by the conventional energy world. So long as batteries were expensive, their market and their impact remained anecdotal. The continuous rapid improvement in the cost of this equipment has resulted in practically an on-off dynamic: they can go very quickly from having a lack of visibility to having a major impact on the electricity system.

The transition to photovoltaic power, a turning point that must not be missed by the authorities and by industry!

The simultaneous technical and economic development of the photovoltaic power, consumption management and electrochemical storage technologies is changing the prospects for the electricity systems of tomorrow. A first effect can already be seen, with the rapid deployment of small individual devices, and elsewhere in the construction of high-capacity power plants ordered by wealthy sunny countries. This trend points to radical changes which will concern the developed countries' electricity systems. The big operators and managers of these systems, like the public authorities, must become aware of this potential for development, and facilitate it rather than ignore it or, even worse, combat it. Like it or not, some households, economic stakeholders and local authorities are thus acquiring a capacity for and an interest in becoming their own electricity producers. By allowing each actor to manage part of their electricity needs (or even energy needs thanks to the development of the electric car), the prospects for the development of photovoltaic power are radically changing the relationship between the electricity consumer and producer, a relationship that at present reflects the dominant role of the electricity system.

Those who do not make the transition soon enough will be poorly positioned in the energy organization of tomorrow. Numerous stakeholders, including large banks such as Goldman Sachs, Citigroup and UBS, have become aware of both the potential of these changes and the risk for those firms not taking them into account.

More seriously, a scenario in which photovoltaic systems were deployed by ignoring or merely bypassing the current centralized electricity system would definitely not be optimal for society. Regarding this, the legislation which will supplement the Energy Transition Act in France will have a responsibility, in particular, for encouraging such a deployment within the framework of an adaptation of the national and European electricity systems. The changes that this study glimpses for the near future therefore require a strengthening of public policies concerning the deployment of photovoltaic systems, electricity storage, consumption management, and tariff links with the grid.

A fantastic hope for those who do not yet have access to electricity, provided that it be viewed from a decentralized perspective as close as possible to the needs.

More broadly, these developments represent a fantastic opportunity for developing countries, and in particular the 20% of the global population who still do not have access to electricity, by enabling them to have control of their supplies. Regarding this, it should be remembered that what is important is not electricity in itself, but the services that it can provide: lighting, access to telecommunications (mobile phones in particular, which are a decisive factor in the African economy, access to knowledge via internet), crop irrigation, conservation of foodstuffs and healthcare (via hospital facilities capable of operating in satisfactory conditions of hygiene, having refrigeration areas and sewage treatment facilities), etc.

Such services would be provided far more rapidly and efficiently by innovative solutions based on small photovoltaic installations coupled to storage with easily transportable backup thermal systems. Whereas several decades are needed to build an electricity grid, a few weeks are sufficient to set up a small system based on photovoltaic power and energy storage.

This local approach, according to a leopard-spot pattern, i.e. with uniform distribution throughout the territory, would then gradually lead to interconnection, but not necessarily as extensively as in the case of a centralized system. Above all, it could be deployed for a lower cost, involving the local populations and gradually developing an industrial fabric notably for management and maintenance of the installations. Finally, this more modular electrification would allow populations to make use of electricity and improve their standard of living without necessarily radically changing their life style. They would be able to adapt the use of renewable energies to their perspective, which is not foreseeable in the case of centralized deployment plans which are inevitably approximate in their allowance for specific local features.

Current situation and analysis collection

The Foundation realises studies which contribute to draw up a synthesis of the state of the knowledge on a subject, by approaching as far as possible the economical, social and ecological aspects.

Previous publications:

‣ Agrocarburants
Cartographie des enjeux

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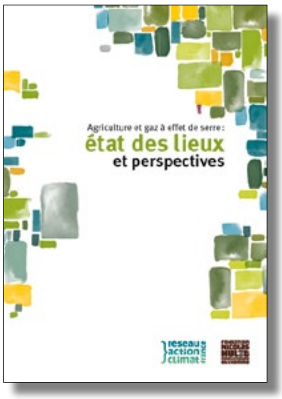

‣ Agriculture et gaz à effet de serre

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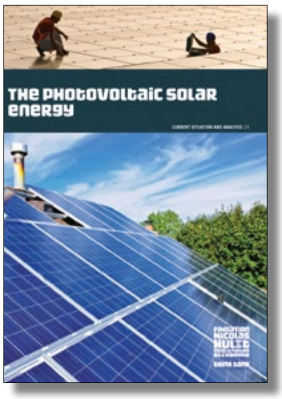

‣ The photovoltaic solar energy

(2011)

‣ Biodiversité et économie :
les clefs pour comprendre

en partenariat avec Humanité et Biodiversité (2012)

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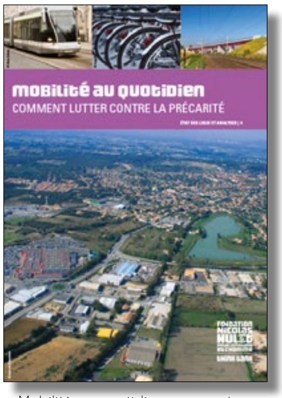
en partenariat avec le Réseau Action Climat (2014)



‣ Mobilité au quotidien : comment lutter contre la précarité

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‣ Démocratie participative :
guide des outils pour agir

2ème édition (2015)

November 2015

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We thank all the experts consulted for their contribution and the time they devoted
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THE NICOLAS HULOT FOUNDATION FOR NATURE AND MANKIND: A SOLUTION DEMONSTRATOR

Fondation Nicolas Hulot pour la Nature et l'Homme, founded in 1990, approved as being of public interest, apolitical and non-confessional, works for an ethical and supportive world which respects Nature and the well-being of Mankind. It has set itself the goal of accelerating changes in individual and collective behavior by developing and highlighting solutions in favor of the ecological transition of our societies. For the Foundation, ecology should no longer be one issue among others, but should be the focus of public and private action.

In order to perform its role, the Foundation combines thinking with action and awareness raising.

It works out new ideas and brings proposals to political and economic decision makers, with its Scientific Advisory Board and its network of high-level multi-disciplinary experts.

It identifies and assists the stakeholders in change by supporting and highlighting, in France and internationally, promising initiatives for the future so as to deploy them on a larger scale. This field reality inspires and nurtures intellectual production.

And so that everyone may be a driver of the ecological transition, it prepares socially responsible motivation tools and campaigns.

The Foundation is also a representative environmental NGO. As such, it sits in several advisory organizations such as the Conseil économique, social et environnemental (Economic, Social and Environmental Council) and the Comité national de la transition écologique (National Committee for Ecological Transition).

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This study was produced thanks to the support of

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ines INSTITUT NATIONAL DE L'ENERGIE SOLAIRE
ENERPLAN Syndicat des professionnels de l'énergie solaire
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