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# Renewable energies: public policy challenges

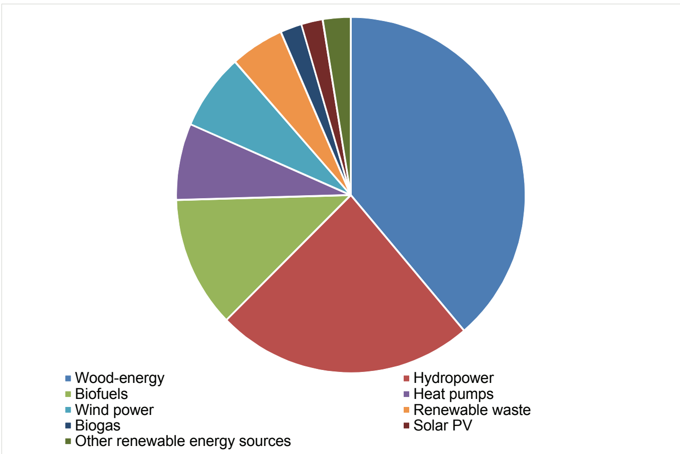
- Renewable energy sources (RES) are low-carbon energies available right within our borders, and as such can be of great value in addressing the challenges of climate change and energy security. In 2014, renewable energies accounted for 14.6% of France's gross final energy consumption[1]. The French Energy Transition Act for Green Growth sets renewables targets of 23% and 32% as a share of gross final energy consumption by 2020 and 2030, respectively.

- However, renewable energies are still more costly than conventional energies. A significant share of this additional cost is borne by energy consumers, particularly in the form of energy taxation and biofuels blending obligations. Public aid is also provided to support heat production from renewable energy sources (RES-H). The two most significant aids available today are the Energy Transition Tax Credit (CITE) and the Heat Fund.

- Comparing the various types of renewable energies shows sharp disparities in terms of the cost of avoiding one tonne of $CO_2$, which ranges from €59 to more than €500 for electricity production it follows that the cost of the energy transition is likely to vary significantly depending on which renewable energy sources are pushed to the fore.

- The combustion of biomass for heat production appears to offer an economically efficient way to reduce $CO_2$ emissions. Of the various renewable technologies available for the production of electricity (with the exception of hydropower, which was excluded from the scope of this study), onshore wind power is the least costly.

**Share of each type of renewable energy in the primary energy production from renewable sources in 2014 (22.4 Mtoe)**




*Source: SOeS, Bilan énergétique de la France pour 2014 [Energy Balance for France, 2014].*

(1) Source: Energy Balance for France, 2014, SOeS, July 2015. Gross final energy consumption is the sum of final energy consumption (as defined by the IEA and Eurostat), network losses plus electricity and/or heat consumed by the energy sector for the production of electricity and/or heat.

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## 1. France has ambitious targets for the deployment of renewable energies

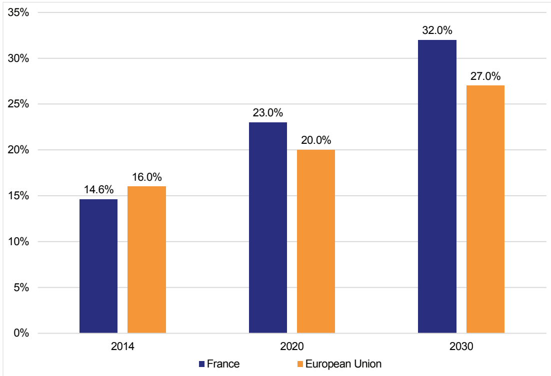
Renewable energy sources (RES) deliver two major benefits to society. One is that they do not emit greenhouse gases and thereby contribute to climate change mitigation. The other is that they allow us to limit imports of fossil fuels (which cost France a total of €56bn in 2014), with the knock-on effect of reducing the macroeconomic risk related to a potential oil shock. The advantages of renewables justify public policy interventions to promote their use.

France has a binding target of sourcing 23% of its final energy consumption from renewables by 2020. This obligation is defined by Directive 2009/28/EC on the promotion of the use of energy from renewable sources within the European Union, which sets a target RES share of 20% at the European level. For the transport sector, all Member States are subject to a mandatory target of 10% of energy from renewable sources. However, each Member State has the flexibility to choose which type of renewable energy it will develop to meet its binding commitments as defined by the European Union. France has cascaded its own 23% target per type of energy and per sector in its National Action Plan (PNA) for the promotion of renewable energies.

For the post-2020 period, the Energy-Climate policy framework recently adopted by the European Union set a binding European target of 27% for renewable energies consumption by 2030. No binding national targets have been set by the European Commission, which nevertheless reserves the possibility of taking further action to ensure the delivery of the European target. France's Energy Transition Act for Green Growth calls for the country to increase the RES share of energy consumption to 32% by 2030, broken down into more specific goals of 40% in electricity production, 38% in final heat consumption, 15% in final fuels consumption and 10% in gas consumption. The multiannual energy plan (PPE) stipulated by the bill will cascade these targets to each sector, defining the capacities and capacity ranges to be attained by 2018 and 2023 respectively, and thus replacing the current National Action Plan for the promotion of renewable energies.

In 2014, renewable energies accounted for 14.6% of France's gross final energy consumption[1]: 18.4% in electricity production, 18.1% in heat and 7.7% in transport. The overall RES share in gross final energy consumption falls slightly short of the trajectory defined in the National Action Plan (which called for a 15% share of RES by 2014). This is primarily due to slower-than-expected growth in renewable heating/cooling.

**Chart 1: Target RES share as a percentage of final energy consumption in France and the European Union**




NB: The figure for 2014 reflects actual deployment of RES; the 2020 and 2030 figures are the defined targets.

*Source: SOeS for France in 2014; Eurostat for the EU in 2014; DG Trésor calculations for the other years.*

### Box 1: **The various forms of renewable energy**

An energy is termed "renewable" when it is derived from sources that are perpetually replaced by Nature. Unlike the so-called "fossil" fuels (crude oil, natural gas, coal) derived from dead, buried organic matter altered and transformed into hydrocarbons over millions of years, renewable energies are not a source of greenhouse gas emissions.

The main renewable energy sources used for electricity production today are hydropower and wind power, which exploit the kinetic energy of watercourses and wind respectively, and photovoltaic solar energy, which exploits solar radiation.

The term "biomass" refers to all plant-based and animal-based organic matter. It can be burned to produce electricity or heat (either locally or in a central plant with distribution via a heating network), or both of these simultaneously (cogeneration). Wood is the main type of biomass used for these purposes. Alternatively, biomass can be first transformed into biogas by fermentation, which may take place either spontaneously (such as in landfills that contain organic waste) or in digesters (the case of sewage treatment sludge or agricultural waste). The biogas can then be used to produce heat, or heat and power, or it can be injected into the gas distribution grid. Finally, biomass can be transformed into biofuel (biodiesel mainly from vegetable oils, and bioethanol from sugar or starch, in the current state of the art).

Geothermal energy exploits the Earth's heat. Shallow geothermal energy, the technology most widely used today, is used to heat buildings through the use of heat pumps.

A distinction is drawn between intermittent renewable energies (e.g., wind power or solar photovoltaic energy) and other renewables. The operating period of the intermittent energies is determined essentially by external factors, in this case meteorological conditions. This differs from other so-called "schedulable" sources, which can be switched on or off at will and thus adjusted according to demand, with varying degrees of flexibility. In other words, intermittent renewables may pose problems due to their lack of reliability. In fact, only some RES (such as certain types of hydroelectric plants) have the flexibility to be used to meet electricity demand peaks, for example.

(1) According to SOeS, Energy balance for France, 2014, July 2015.

## 2. The form and magnitude of public support for renewables varies with the type of RES and the sector

A number of mechanisms have been put in place to promote the various types of renewable energy. These are described below.

### 2.1 The main support for electricity production from renewable sources today (RES-E) is a guaranteed feed-in tariff. The cost of this system currently comes to € 4bn but is destined to rise sharply in the years ahead. It is financed by electricity consumers

Until the end of 2015, the development of renewable electricity production was supported by an obligation incumbent upon the French power utility EDF to buy back the renewable electricity generated at a guaranteed feed-in tariff calculated to ensure the profitability of RES-E installations. Since the start of 2016, a new support mechanism has replaced the guaranteed feed-in tariffs for some new electricity production installations. The new mechanism grants a premium in addition to the market price at which generators sell their RES-E (see Box 2). However, as this support mechanism applies only to the new installations, most of the RES-E production infrastructure remains subject to the feed-in tariffs. The costs associated with either the feed-in tariffs or the market price premium are financed by electricity consumers - households and businesses - via the Domestic Consumption Tax on Electricity for End-Users (TICFE)[2]. From 2017, a share of the carbon tax will also be allocated to finance renewable energies.

For the consumer, the average cost of renewable electricity feed-in tariffs (excluding non-subsidised hydropower) came to € 141/MWh in 2014, ranging from € 89/MWh for onshore wind power to € 422/MWh for solar photovoltaics[3]. This represents an average additional cost of € 107/MWh compared to the average market price of electricity for that year.

Featuring the highest average additional cost, solar photovoltaics account for 70% of the cost of supporting RES-E while supplying only 15% of all subsidised RES-E production. This significant additional cost includes in particular the higher cost of all the RES-E production installations, including those which enjoyed very high feed-in tariffs when the sector was in its infancy. Thanks to technological progress, the additional costs of the most recent installations are more modest (on the order of € 170/MWh for installations that applied for a grid connection in 2014[4], and € 50/MWh for ground-based solar plant projects that applied within the framework of the call for tenders in June 2015).

According to the French Energy Regulatory Commission[5], the cost of the Contribution to the Additional Costs of Electricity (CSPE) relating to renewable energies totalled € 3.7bn or € 9.9/MWh[6] in 2014 and are estimated at € 4.0bn for 2015[7] (or € 11.1/MWh[8]). These costs will continue to rise as new RES-E production capacity comes on stream in the years ahead. The magnitude of the increase will depend on the technologies chosen for deployment, and this will be decided under the multi-annual energy plan (PPE).

RES-E production installations can also be eligible for other forms of support coupled with a feed-in tariff or premium. For example, installations that produce electricity partly from waste-derived biogas are eligible for investment subsidies via the Waste Fund of the French Environment and Energy Management Agency (ADEME) (ADEME granted investment subsidies on the order of € 40M in 2014 for anaerobic digestion of agricultural waste) as well as regional subsidies. Household solar photovoltaic installations were also supported with the Sustainable Development Tax Credit (CIDD) until 2012. The budgetary cost of this support totalled € 500M in 2011 and € 200M in 2012.

(2) Until the end of 2015, these expenditures were financed by the CSPE (Contribution au Service Public de l'Électricité - Contribution to the public electricity service). The contribution paid by each electricity consumer was proportional to his electricity consumption up to an annual ceiling amount. Effective 1 January 2016, the CSPE was transformed into an excise tax on electricity, the TICFE, with an expanded scope (while maintaining low rates to safeguard the competitiveness of the highest energy-consuming undertakings).

(3) Deliberation of the French Energy Regulatory Commission of 15 October 2015 concerning the proposal on the additional costs of electricity and the unit contribution for 2016, Annex 2, "Additional costs of electricity reported for 2014".

(4) Calculations by DG Trésor based on feed-in tariffs in effect in 2014 according to the MEDDE and the Report of the French Energy Regulatory Commission on grid connection requests received in 2014 (Deliberation of 22 January 2015 on the communication to the Government of the S15 and V15 coefficients defined in the order of 4 March 2011 as amended setting the requirements for eligibility for feed-in tariffs for electricity produced by installations utilising solar radiation, Annex, "Report of completed connection requests for installations utilising solar radiation".)

(5) Deliberation of the French Energy Regulatory Commission of 15 October 2015 concerning the proposal on the additional costs of electricity and the unit contribution for 2016.

(6) Assuming a basis of 375,0 TWh in 2014, Deliberation of the French Energy Regulatory Commission of 15 October 2014 concerning the proposal on the additional costs of electricity and the unit contribution for 2015.

(7) Idem.

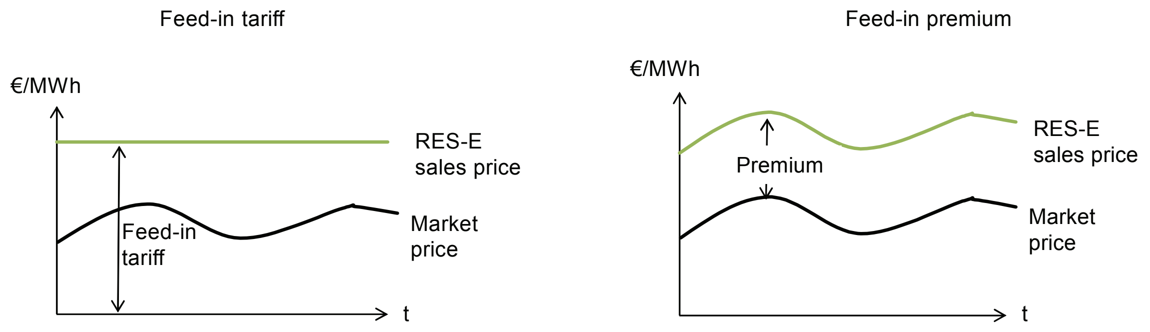
(8) Deliberation of the French Energy Regulatory Commission of 15 October 2015 concerning the proposal on the additional costs of electricity and the unit contribution for 2016.

## Box 2: **Premium in addition to market price**

Until 1 January 2016, France's support mechanism to promote renewable electricity production was based on feed-in tariffs guaranteed for periods of 10 to 20 years. The Guidelines on State aid for environmental protection and energy adopted by the European Commission in June 2014 stipulate that from 1 January 2016, renewable electricity generators must sell their electricity directly in the market and that aid is granted "only as a premium in addition to the market price whereby the generators sell their electricity directly in the market" (except for the smallest installations, which may continue to receive the feed-in tariff[a]). This measure applies to all aid schemes which have not yet been notified to the Commission (in France's case, only the aid scheme to support onshore wind power has already been notified). Article 104 of the French Energy Transition Act for Green Growth adopted in July 2015 institutes a feed in-premium (called *complément de rémunération*).

The aim of this reform is to make RES-E producers more responsive to the market and incentivise them by giving them a stake in the hourly and seasonal variations in the market price of electricity. Specifically, the reform should discourage producers from generating electricity under negative prices; the disincentive should limit the magnitude and the frequency of this occurrence. A further potential benefit of the premium could be to incentivise the siting of production in areas where it is more closely correlated with the market price, all other factors being equal. Moreover, the reform provides for the premium to be calculated ex post, i.e. it will be adjusted such that, over a given period (such as one year), the total remuneration of a producer with an average production profile will be equivalent to the remuneration that would have resulted from a fixed feed-in tariff. The advantage of this calculation method is to continue to shield producers from electricity price fluctuations from one period to another.

**Chart 2: Sales price of RES-E with each aid mechanism**




*Source: DG Trésor.*

a. Installations with an installed capacity of less than 500 kW, except for onshore wind energy, whose installed capacity is limited to 3 MW.

### 2.2 More than € 500M per year is allocated to heating from renewable sources (RES-H) via investment aid in the form of tax credits and the Heat Fund

Heating from renewable sources (RES-H) is subsidised mainly via a tax credit and the Heat Fund managed by ADEME.

- **Energy Transition Tax Credit (CITE, formerly CIDD)**

The Energy Transition Tax Credit (CITE), which replaced the Sustainable Development Tax Credit (CIDD) in 2014, is meant as an incentive for households to make energy improvements to their homes. Accordingly, it subsidises the acquisition costs of certain types of equipment aimed either at reducing consumption or at producing energy from a renewable source. The tax credit, the rate of which was differentiated according to the type of equipment until 2012, is currently applied at a blanket rate of 30%. It is important to note that solar photovoltaic energy, which was initially within the scope of the Sustainable Development Tax Credit (CIDD), was excluded in 2013 as part of a streamlining of the RES aid policy, with the feed-in tariff becoming the main aid instrument for RES-E. Today, only RES-H is eligible for the tax credit. On average, the annual cost of subsidising RES for households first via the Sustainable Development Tax Credit, then via the Energy Transition Tax Credit (beginning in September 2014) totalled € 900M for the period 2006-2013 and exceeded € 1bn per year between 2008 and 2011. The cost is estimated at about € 300M annually since 2013.

**Table 1: Annual budgetary cost of the Sustainable Development Tax Credit (CIDD) for RES installations**

| M€ | 2010 | 2011 | 2012 | 2013* |
|---|---|---|---|---|
| **RES** | **1454** | **1017** | **659** | **337** |
| *Photovoltaics (rooftop)* | *325* | *502* | *202* | - |
| *Solar heating* | *91* | *91* | *82* | *26* |
| *Wood biomass* | *234* | *160* | *142* | *170* |
| *Heat pumps* | *556* | *264* | *233* | *118* |
| *Other RES* | *248* | | | *23* |

*Source: Synthèse de l'évaluation du crédit d'impôt pour le développement durable, Rapport pour le comité d'évaluation des dépenses fiscales et des niches sociales, Avril 2011.*
*[Summary evaluation of the Sustainable Development Tax Credit allocations, Report to the Committee for the evaluation of fiscal expenditure and social niches, April 2011]*

The budgetary cost of the Sustainable Development Tax Credit in year n corresponds to project commitments made in year n-1.
*DG Trésor estimates based on a sample of 500,000 income tax returns for the 2012 tax year.

- **Heat Fund**

Introduced in December 2008, the Heat Fund supports the promotion of biomass energy, geothermal energy (direct or via heat pumps), solar heating, energy recovery, as well as the development of heating networks that use these energies. The fund grants investment aids, with the major share being allocated to projects selected through calls for tender at the national level in France.

The fund had an endowment of € 1.2bn for the period from 2009 to 2013, averaging € 240 M/year with € 220 M for

2014. Aid under this fund is applicable to the multi-occupancy residential, tertiary, agricultural and industrial sectors.

For the period 2009-2013, the aid granted by the Heat Fund to support RES-H projects came to an average of nearly € 60/toe with a range of almost € 30/toe for large-scale wood-heating projects[9] to more than € 810/toe for solar heating[10] (see Table 3).

**Table 2: Aid granted by the Heat Fund in the period 2009-2014 (in €M)**

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|
| Heat Fund | 169 | 300 | 250 | 250 | 220 | 220 |

*Source: Rapport législatif, Projet de loi de finances 2013 et 2014 - Développement durable, énergie, climat.*

**Table 3: Aid granted under the Heat Fund by energy source**

| Period 2009-2013 | €M | €/toe** |
|---|---|---|
| Wood other than BCIAT* | 253 | 44 |
| Wood BCIAT | 260 | 29 |
| Deep geothermal energy | 75 | 71 |
| Biogas | 3,8 | 16 |
| Solar heating | 64 | 812 |
| Distribution via RES heating networks | 406 | 171 |
| **Total** | **1 062** | **58** |

*Source: DGEC.*

*BCIAT : Biomass Heat Industry Agriculture Tertiary .
**toe: tonne oil equivalent. 1 toe = 11.63 MWh.

### 2.3 Biofuels deployment is currently supported mainly by a target blending ratio with penalties for non-compliance

In its National Action Plan for the promotion of renewable energies, France set a target renewables share of 10.5% for the transport sector by 2020. The Energy Transition Act for Green Growth sets a target renewables content of 15% for motor fuels by 2030.

Biofuels account for most of the RES deployed in the Transport sector today. Renewable electricity and gas constitute avenues for longer-term development

The French aid scheme to support biofuels growth is underpinned mainly by a General Tax on Polluting Activities (TGAP), which is imposed upon distributors who do not attain the minimum biofuels blending obligation, currently set at 7% in petrol and 7.7% in diesel fuel. Distributors who fail to comply with blending obligations are liable to a tax calculated as the product of the difference between the target and actual blending ratios multiplied by the sales of the respective motor fuels (excluding VAT). The revenues generated by the TGAP are practically nil for diesel fuel, reflecting the fact that distributors are successfully meeting the blending obligation for biodiesel (see Table 4). However, the same cannot be said of petrol distribution, which generated TGAP revenues of nearly € 100M in 2014, due to an overall bioethanol blending ratio of 6.1%, versus the defined target of 7%.

The higher costs of biofuels production, plus the TGAP amounts due (in the case of petrol distributors who fail to comply with blending obligations) are passed on to motor fuel consumers, who thus ultimately bear the cost of this support mechanism.

Moreover, under the Additional Budget Act for 2015, a reduction of 2€ct/l in the Domestic Tax on the Consumption of Energy Products (TICPE) was introduced with effect from 1 January 2016 in favour of SP95-E10 petrol (unleaded petrol containing between 5 and 10% bioethanol by volume) over SP95-E5 (which contains less than 5% vol. of bioethanol) and SP98. In parallel, a partial exemption from the TICPE for biofuels produced in approved production units was eliminated at the end of December 2015.

**Table 4: TGAP revenues generated by non-compliance with biofuels blending obligations**

| TGAP per year in in €M | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| TGAP Ethanol | 108.5 | 149.0 | 157.0 | 149.0 | 95.6 |
| TGAP Biodiesel | 0.5 | 0.4 | 0.1 | 0.1 | 0.1 |

*Source: Cour des comptes d'après données des services des douanes jusqu'à 2010, services des douanes pour 2011, 2012, 2013 et 2014 .[French Government Audit Office based on Customs Administration data until 2010, and Customs Administration for 2011, 2012, 2013 and 2014].*

### 2.4 Biogas production and injection into the natural gas grid is supported by a guaranteed feed-in tariff, the cost of which - currently on the order of € 8M - is borne by natural gas consumers

In a similar manner to RES-E production, the production of biogas for injection directly into the natural gas grid is supported by a guaranteed feed-in tariff[11]. The latter is financed by gas consumers through a contribution for the additional costs of biomethane. These additional costs have risen sharply in recent years, totalling € 1M in 2013 and projected by the French Energy Regulatory Commission to reach € 3.3 and € 7.6M in 2014 and 2015, respectively. For 2015, the contribution per unit of energy stood at € 0.015/MWh[12].

(9) Installations with annual heat production in excess of 1 000 toe: these installations are eligible for the Heat Fund through requests for Biomass Heat Industry Agriculture and Tertiary (BCIAT) projects.
(10) Calculations performed for a RES-H installation with a service life of 20 years, taking a discount rate of 4%.
(11) Order of 23 November 2011 setting the requirements for eligibility for feed-in tariffs for biomethane injected into the natural gas grid.
(12) Order of 10 December 2014 setting the provisional amount of additional costs of electricity relating to feed-in tariffs for biomethane and the unit contribution for 2015.

## 3. Deploying RES is a way to curb greenhouse gas emissions, but the cost of abatement varies significantly depending on the type of RES deployed

Renewable energies are low-carbon energies that use abundant national resources (for solar and wind power, the limitation in France is the lack of suitable sites still available in the country. For biomass, the main challenge is to exploit existing resources, only about half of which are currently being used[13]). As such, renewables have a dual role to play both in combating climate change and in securing energy supply. On the downside, these energies are still relatively costly today, which raises the issue of how the potentially high cost of deploying them affects public finances, businesses and household purchasing power.

### 3.1 The cost of each tonne of CO2 avoided is a useful indicator for comparing the socio-economic value of deploying the various types of renewable energy

To minimise the cost of attaining greenhouse gas emissions reduction targets, the priority must be given to the actions with the lowest cost to society for each tonne of $CO_2$ avoided. In 2009, a commission chaired by Alain Quinet established a trajectory for the "shadow price" of $CO_2$, defined as the marginal cost of avoided $CO_2$ assuming an efficient attainment of our emissions reduction targets[14]. The estimated costs of one tonne of $CO_2$ avoided (see Table 5) can thus be compared

i) for RES-E and RES-H (assuming a start-up in 2015 and a 20-year service life) with the average discounted shadow price of $CO_2$ for the period 2015-2034, or € $78_{2015}/tCO_{2eq}$ avoided;

ii) for biofuels (for which the additional cost considered is the currently observed additional cost) with the current shadow price, or € $47_{2015}/tCO2_{eq}$ avoided.

**Box 3: Key methodological assumptions for calculating the cost per tonne of avoided $CO_2$**

The results presented in terms of cost per tonne of avoided CO2 are based on some important assumptions:

i) **The technology replaced by the RES.** The lower the carbon content of the replaced energy, the higher the additional cost of supporting the technology in proportion to the amount of emissions avoided, and vice versa. For electricity, it is tricky to identify which energy source is being replaced, and the latter may even vary over the life of the RES-E installation. The results shown are based on substituting renewable energy sources for electricity produced from a state-of-the-art gas power plant. Actualy, in addition to gas, RES-E could replace nuclear power, which is another low-carbon energy, as well as other fossil fuels, such as coal or fuel oil, which are more carbon-intensive than natural gas.

ii) **Fossil fuel price assumptions:** The more costly the fossil fuel, the lower the additional cost of RES, and vice versa. The results shown are based on the energy price trajectories given in the New Policies scenario of the ***World Energy Outlook 2015*** published by the International Energy Agency (IEA) in October 2015. This scenario considers a natural gas price of € $43_{2030}$/MWh in 2030. The price assumption for 2015 stands at € 21.5/MWh, which is the average spot price observed in France in 2015[a]. As for the biofuels price assumption, it is compared with the price of traditional motor fuels observed in December 2015.

iii) **The discount rate assumption.** According to the recommendations of the Quinet Report, from the social perspective the discount rate must be the sum of a risk-free rate of 2.5% plus a risk premium which, averaged over all the investments of the economy, is equal to 2%, and the more counter-cyclical the investment rate of return, the higher the risk premium. Because renewables shield society from the risk of rising costs of fossil fuels, we choose to retain an overall discount rate of 4%. It is also worth mentioning that the conclusions of this study are robust enough to hold up to a change in this rate.

For most of the technologies, the results are also based on the present costs of production, which are difficult to identify. For technologies involving a feed-in tariff, we assumed that the tariff granted reflected the production cost of the RES value chain (except for biogas, for which the production cost assumption turns out to be higher than the feed-in tariff when the investment aids are taken into account[b]). The issue of the validity of this assumption is beyond the scope of this study, and is periodically analysed by the French Energy Regulatory Commission[c]. Regarding the RES-H supported by the Heat Fund, in accordance with the fund's principle, the support granted is deemed to exactly cover the additional cost of production. ADEME cost data were used for wood-fired boilers and heat pumps, and IEA cost data were used for the traditional technologies.

a. At the North Gas Exchange Point (GEP) according to Powernext data.
b. Investment aids cannot be cumulated for the other technologies.
c. Most recently in April 2014 ("*Coûts et rentabilité des énergies renouvelables en France métropolitaine*" [Costs and profitability of renewable energies in France].

(13) Biomass from forests, poplar stands and bocage (mixture of woodland and pastureland) available for energy production by 2020, November 2009.

(14) "La Valeur tutélaire du carbone" ["Shadow price of carbon"], Report of the Quinet Commission, Centre for Strategic Analysis, 2009.

**Table 5: Social costs of avoiding emissions through the deployment of RES**

| | | Cost per tonne of $CO_{2eq}$ avoided (€/$tCO_{2eq}$) |
|---|---|---|
| RES-E (assumption based on substitution for a combined-cycle gas power plant) | | |
| Solar photovoltaics | | |
| | Building Integrated Solar Photovoltaics (BIPV) | 535 |
| | Simplified BIPV | 235 |
| | Large-roof photovoltaics (> 250 kWp) | 190 |
| | **Ground-based PV** [a] | **71** |
| **Onshore wind power** | | **59** |
| Offshore wind power | | 438 |
| Biomass[b] | | **67**-202 |
| Biogas[c] | from agricultural waste (mainly livestock effluents) | 112 |
| | from agricultural waste excluding effluents (e.g. crop residues) | 373 |
| | from non-hazardous municipal solid waste landfills | 94 |
| RES-H | | |
| Heat fund | **Wood excludingBCIAT** | **11** |
| | **Wood BCIAT** | **8** |
| | **Geothermal** | **18** |
| | **Biogas** | **8** |
| | Solarheating | 208 |
| | **Heating networks** | **44** |
| Heat pumps (replacing a state-of-the-art gas boiler)[d] | | 493 |
| Individual wood-fired boiler (replacing a state-of-the-art gas-fired boiler)[d] | | 147 |
| Biogas injection[e] (replacing natural gas) | | |
| | from agricultural wastes (mainly livestock effluents) | 208 |
| | from municipal waste | 211 |
| First-generation biofuels[f] (replacing fossil motor fuels) | | |
| | Ethanol | 138 |
| | Biodiesel | 201 |

a. The analysis performed here pertains to the solar farms in the latest call for tenders of the French Energy Regulatory Commission (CRE).
b. The upper limit corresponds to the cost without heat recovery and the lower limit corresponds to overall energy efficiency of 50% (ratio between final energy and primary energy) with cogenerated heat substituting for the heat produced by a gas-fired boiler.
c. With the assumption of an end to feed-in tariffs and sale of electricity in the market after 15 years, and investment subsidies covering 30% via the Waste Fund. In accordance with the ADEME data ("Bilan national des projets Biogaz" [National assessment of biogas projects], July 2013), these estimates are based on *(i)* an overall energy efficiency of 64% and an assumption of substituting 30% cogenerated heat from anaerobic digestion of agricultural wastes for "fossil" heat and *(ii)* an energy efficiency of 62% and substitution of 10% cogenerated heat from non-hazardous waste landfills for "fossil" heat.
d. Substituting renewable heat for heat produced by an individual gas-fired boiler with an efficiency of 80 % and a natural gas carbon content of 181 $gCO_2$/kWh (gross calorific value).
e. With the assumption of an end to feed-in tariffs and sale of biogas in the market after 15 years, and investment subsidies covering 30% via the Waste Fund.
f. The GHG emissions considered here do not include any emissions related to Indirect Land Use Changes (ILUC). Taking those additional emissions into account, the cost of emissions avoided would be € 348/$tCO_{2eq}$ pfor ethanol, while biodiesel would not lead to any gain in terms of $CO_2$ emissions.

*Source: DG Trésor calculations. Technologies with a cost per tonne of CO2 avoided below the shadow price are shown in boldface. .*

Any additional emissions relating to back-up generating capacity installed to make up for the intermittence of RES-E production are ignored.
*BCIAT : Biomass Heat Industry Agriculture Tertiary.

## 3.2 Other than hydropower[15], onshore wind power is the least costly RES-E technology

Of all the renewable energy sources for electricity production, onshore wind power features the lowest cost per tonne of $CO_2$ avoided (€ 59/$tCO_2$ avoided). That cost is significantly lower than the average discounted shadow price of carbon for the period 2015-2034. This would also be the case of cogeneration from biomass, considering the favourable assumption of replacing all heat generated using fossil fuels by cogenerated heat. However, using biomass solely for heat production appears to offer even higher efficiency (see below).

For ground-based solar PV farms, the cost per tonne of $CO_2$ avoided is also lower than the shadow price (€ 71/$tCO_2$ avoided) taking the average cost of the June 2015 call for tenders into account. In contrast, the cost per tonne of $CO_2$ avoided is still much higher than the shadow price for either rooftop photovoltaics or offshore wind power.

Nevertheless, it is important to underscore the fact that the assumption of substituting for a gas-fired power plant is very conventional and probably optimistic, given the current overcapacity of the electricity markets in France and more generally in Europe, which the strong growth in RES is actually helping to sustain. The market price of electricity, which averaged € 39 to 40/MWh in 2015 and stood

(15) Given the significant disparities in its costs and its limited resources, hydropower has been excluded from the scope of this analysis.

at about € 29/MWh in early 2016, thus appears far lower than the discounted average generating cost of a gas-fired power plant (operating for 3 000 hours) considered here (€ 59/MWh). There is great uncertainty as to how long it will take to resorb this excess capacity, and the timeline will depend on supply and demand trends. If the oversupply is not rapidly absorbed, then the costs per tonne of avoided $CO_2$ could be much higher than estimated here for all of the RES-E technologies, although their respective cost rankings would not change.

### 3.3 It appears to be socially and economically preferable to use biomass and biogas for heat rather than electricity production

With the exception of solar heating, all the renewable energies supported by the Heat Fund prove to be relatively efficient solutions for reducing $CO_2$ emissions. In a context of limited biomass resources, it therefore seems preferable to allocate those resources first and foremost to heat-only production (provided there is sufficient demand), rather than to cogeneration, which offers lower energy efficiency and consequently a higher cost per tonne of avoided $CO_2$.

Likewise, biogas use is optimised by collective heat production, provided sufficient market outlets are available, rather than by cogeneration. As for injecting biogas into the grid, the cost of purifying the biogas must be taken into account. Thus, both cogeneration and injection into the gas grid lead to costs per tonne of avoided $CO_2$ that exceed the shadow price, whether the biogas is produced from non-hazardous landfill waste or mainly from livestock effluents. Indeed, although the combustion of the methane released by these effluents leads to additional gains in terms of GHG emissions due to the replacement of methane emissions by $CO_2$ with its lower global warming potential, this benefit is not sufficient to offset the cost of anaerobic digestion of agricultural waste, which is still very high.

The cost per tonne of avoided $CO_2$ by substituting a heat pump for a gas-fired boiler is still high as well (€ 493/t$CO_2$ avoided).

### 3.4 In the transport sector, the cost per tonne of $CO_2$ avoided by incorporating first-generation biofuels is far higher than the shadow price, even without taking any indirect land use changes (ILUC) into account

For bioethanol and biodiesel, the costs per tonne of avoided $CO_2$ are three and four times higher than the shadow price, respectively[16]. This calculation does not take ILUC -, the emissions that result from establishing an energy crop in place of a food crop, which is in turn displaced to natural areas with higher carbon stocks (forests, in particular) into account. By applying ADEME estimates for the impact of ILUC[17], the cost per tonne of avoided $CO_2$ for bioethanol would increase by a factor of 2.5 while for biodiesel, taking ILUC emissions into account would completely wipe out all $CO_2$ emissions gains.

**Laure GRAZI and Arthur SOULETIE**

(16) The estimates of extra costs of biofuels compared to traditional motor fuels are taken from the Report of the French Government Audit Office (January 2012): "*La Politique d'aide aux biocarburants*" ["Policy on aid for biofuels"] after updating the prices of traditional motor fuels to reflect the situation of December 2015.

(17) "*Revue critique des études évaluant l'effet des changements d'affectation des sols sur les bilans environnementaux des biocarburants*" ["Critical review of studies evaluating the effect of land use changes on the environmental balance of biofuels"] published in March 2012, based on a meta-analysis of 561 assessments. The mean value of emissions relating to direct and indirect land use changes would add 61 $gCO_{2eq}/MJ$ to the environmental balance of first-generation biodiesel and 31 $gCO_{2eq}/MJ$ to the environmental balance of first-generation ethanol.

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