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Greenhouse gas emissions of electric vehicles associated with wind and photovoltaic electricity

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Abstract

Until recently, the automotive industry was solely relying on one energy resource: oil. However, because of several environmental, political and economical issues, new alternatives are now emerging, such as electric vehicles (EVs). The greenhouse gas (GHG) emissions of an EV are linked with the manufacturing of the car and the electricity production during the use phase. In this article, we study the GHG emissions linked with EVs using photovoltaic (PV) and wind electricity associated with a Renault EV.

GHG emissions are compared with EVs using average electricity from various European countries and from conventional thermal vehicles. The results show that using wind electricity always allows decreasing GHG emissions while PV impact is dependent on the country studied. Nonetheless, when using PV electricity, GHG emissions are always lower than conventional thermal vehicles.

Keywords: electric vehicle, photovoltaic energy, wind energy, life cycle assessment, greenhouse gases

1. Context, aim and scope

Until the end of the twentieth century, the automotive industry was solely relying on one energy source: oil. However, this dependence to oil has led to several issues, such as anthropogenic global warming, air pollution (especially in highly populated areas), depletion of oil, dependence of oil-consuming countries (for instance the European Union, EU) to oil-producing countries, etc. In order to

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meet these challenges, different technologies are being developed: first-generation biofuels (mainly ethanol and biodiesel), second-generation biofuels (biomass to liquid, hydrogenated vegetable oil, etc.), algal fuels, hydrogen associated with fuel cells and electric vehicles (from mild hybrid to fully electric vehicles).

In this article, we focus on electric vehicles (EVs). The environmental impact of a vehicle can be separated in four steps: car production, fuel production, car use and car disassembly and recovery. Here, we only retain the fuel production and the car use. The impact of using an EV mainly comes from the electricity production, which is dependent on the primary resource employed: natural gas, coal, nuclear, water, wind, sun, geothermal, etc. Each country has its own energy strategy, using different sources (referred as the electricity "mix"). This means that, depending on where they are driven, EVs can have very different environmental impacts. Moreover, this implies that, for customers who want to reduce their environmental impact, it is possible to couple EVs with renewable energies, such as photovoltaics (PV) or wind. The aim of this study is to assess the greenhouse gas (GHG) emissions of charging an EV with PV and wind electricity compared with an EV using average electricity mix and conventional vehicles (using internal combustion engines, ICE).

2. Materials and methods

2.1. Life cycle assessment and well to wheels analysis

Life cycle assessment (LCA) has been retained as the best tool to assess the GHG emissions associated with our system. LCA is a normalized tool (ISO 14040/14044) that sums up all the resources consumed and all the emissions of a product or a service. Here, as we only study the use phase of the cars, the LCA can be referred as a "well to wheels" (WTW) analysis, meaning that the environmental impacts are studied from the extraction of energy resources (from the "well") to the car (to the "wheels"). The WTW approach can be separated in two steps: the well-to-tank (WTT) stage, which covers the production of the required energy (liquid fuel or electricity) and the tank-to-wheels (TTW) stage, covering the consumption of energy and pollutant emissions by a car on a given distance. For EVs, the environmental impacts are limited to the WTT step, since the consumption of electricity by EVs does not emit any pollutant. Because we narrow our study to GHG emissions (CO_2 but also methane and nitrous oxide, using factors from [1]), the WTW analysis can be summed up by the following equation:

$$[(\text{energy prod. GHG } (\text{MJ}^{-1}) \times \text{energy cons. } (\text{MJ.distance}^{-1}))_{\text{WTT}} + (\text{exhaust GHG } (\text{distance}^{-1}))_{\text{TTW}}]_{\text{WTW}}$$

2.2. Photovoltaic energy

2.2.1. Description of the system

PV electricity can represent various technologies, which can be separated in three groups: silicon-based PV, thin films and other technologies. Today, silicon-based technologies represent the majority of the installed PV panels, with monocristalline (mono-Si) and multicrystalline (multi-Si) respectively representing 40% and 46% of the market in Europe in 2010 (according to the European Photovoltaic Industry Association). Thin films, especially cadmium telluride (CdTe) technologies, are now emerging, representing about 13% of the market. Thus, in this study, we focus only on these three technologies. PV is a non-centralized energy, which can be produced by both small producers and large plants (about 100 MW, [2]). The power of a PV panel is defined using the Watt-peak concept, which represents the nominal power of the PV panel exposed under a 1,700 kWh/m^2/yr irradiation. This value enables the comparison of various panels but do not represent the true power delivered. Indeed, the irradiation in Europe is strongly dependent on latitude, with values ranging for instance from 955 kWh/m^2/yr in the UK to 1,660 kWh/m^2/yr in Spain, France representing the average value in Europe (1,204 kWh/m^2/yr). Thus, the efficiency of the panel greatly varies, according to the country retained. The yield (η) of the panel, which corresponds to the electric power delivered per sun energy received, depends on the nominal power (P, Watt-peak), the irradiation (Irr, W/m^2) and the effective surface of the panel (A, m^2), according to the following equation: $\eta = P / (Irr \times A)$. The yield of silicon-based PV panels is comprised between 14% and 19% [3] for south 45° oriented panels under a 1700 kWh/m²/yr irradiation, multi-Si being slightly less efficient than mono-Si. The yield tends to decrease during the lifetime of the panel and thus we retained the average yield during a 30-year lifetime. In our study, the yield retained under average irradiation (1204 kWh/m²/yr) and optimal inclination (45° south) are: monoSi (13,1%), multi-Si (12,8%) and CdTe (9,6%).

PV panels, notwithstanding the technology considered, are composed of framed modules, which are made of cells in series. The first step of PV panel production is quartz extraction from sand. The silica contained in the quartz crystals is then turned into metallurgic-grade silicon using an electric-arc furnace. The average silicon purity obtained is equal to 98.5% [4]. This purity being insufficient for PV panels, it is purified using the Siemens process in order to obtain solar-grade silicon, with impurities being less than ppm – ppb [4]. These steps are common for both mono-Si and poly-Si panels. For mono-Si panels, round wafers are obtained from mono-Si crystals using the Czochralski process and then cut into cells. For multi-Si panels, rectangular wafers are obtained from multi-Si ingots using the Bridgeman or the block-casting processes. Multi-Si allows less losses of silicon during the process of cutting. For both technologies, the silicon is then arranged in two layers, one negative (n-layer with boron) and the other positive (p-layer with phosphorus), these two layers being put between two conducting grids. The cells are then covered with ethylene-vinyl acetate (EVA) and glass to protect them. Finally, cells are put together to form a module which is incorporated within a frame to form a panel. The manufacturing process of CdTe panels is completely different from the previously described panels because they contain no silicon. Yet, they also use two layers (a p- and an n- layer), covered by a conducting grid and protected by an EVA layer and glass. The p-layer is composed of cadmium telluride while the n-layer is composed of cadmium sulfide. Notwithstanding the technology studied, the panels deliver a low-voltage direct current, which must be turned into 220-230V alternating current to be suitable for EVs. This requires a DC/AC converter and an inverter. Cables and other small electric devices are also required to connect the PV panel to the grid or the vehicle (in this study, we consider a panel directly connected to the vehicle). All this supplementary materials are called “balance of the system” (BoS).

Though we study the impacts of the PV panels installed in EU, this does not mean that all panels are produced there. Indeed, PV panels mainly come from three geographical zones : EU, United States (US) and China. The place of production plays a role in the environmental impact of PV panel production and thus it cannot be neglected [5]. In our study, PV panels installed in the EU in 2010 come from the following regions: China (60%), EU (25%) and US (15%) (adapted from [6]).

Recycling of PV panels is not yet a developed industrial pathway, especially for thin film technologies. For both CdTe and silicon panels, recycling process are not so well known and thus we only consider aluminum (from the frame), glass and copper recycling. The other materials are either incinerated or, for the majority of them, landfilled.

2.3. Wind energy

Wind is an abundant energy, which is collected and turned into electricity using wind turbines (WTs). Wind energy is especially abundant in plains and near / above the sea. Therefore, we can consider that wind energy yields are not dependent on the country where WTs are planted, contrary to PV electricity, but depends on the wind strength in the area. The main differences are between onshore and offshore WTs while countries are only differentiated according to the number and capacity of WTs that can be planted. The nominal power of WTs varies, depending on the wind that can be harvested and thus WTs in EU tend to have nominal powers between 0.8MW to 2.3MW. According to a randomly picked sample from [7], the average 2011 WT has a 2MW nominal power and is retained in our study. Offshore WTs tend to have higher nominal powers but represent a marginal part of WTs installed in EU. Therefore, they are neglected in our study. The nominal power does not represent the actual power delivered by the WT. This power depends on the wind, which, as explained above, can greatly vary between different locations. The load factor corresponds to the actual power that the WT can deliver. This load power varies from 20% to 70%, with 25% being the average retained between southern Europe (28%, Mediterranean coast) and Northern Europe (20%, Germany).

A standard horizontal axis WT can be separated between a fixed part and moving parts. The fixed part is basically composed of a painted steel tower with concrete fundations (around 500 m^3). Steel sheets of the desired size are rolled up to form the tower which is then painted. The moving parts are mainly the blades (usually three) and the pod. The blades are composed of polyester reinforced with glass or carbon fiber. They weigh about 6,5t, with about 2,6t of glass fiber for a 39m standard blade [8]. They are attached together to a steel structure, which is connected to an electric machine in the pod. The alternating current generated by the WT is then turned into the desired voltage to be connected to the electric grid. Contrary to PV panels, the car using WT electricity is connected to the grid and not directly to the WT. In addition, no importations are considered and WT are entirely produced in EU. After 20 years of use, most of the wind turbine components can be recycled: oil, aluminum, copper and especially steel. Plastics are incinerated while other components are disposed of in landfills.

2.4. Life cycle modeling

Life cycle modeling is done using Gabi4 software [9] and data from literature [10,11,12,13,14,15,16,17,18,19] and from commercial brochures from different suppliers. For missing data, the following databases are used, by priority order: European life cycle database (ELCD, [20]), GaBi4 [9] and ecoinvent [21]. CdTe panel production were mainly modeled according to the ecoinvent database, since the literature and the suppliers are less numerous.

Figure 1 describes the production of a European PV panel. However, as shown in section 2.2, PV panels mainly come from China and a significant part also comes from US. Thus, the steps from silicon production to panel production were modified to take into account this geographical variation. The main modifications concern the electricity mix and the source of energy for furnaces and heaters (using mainly natural gas in EU and coal in China). Once built, PV panels are imported into EU. Transport distances are equal to 6,000 km and 15,600 km, respectively from US and China and panels are transported using ships. Once at EU borders, they are transported by rail from the harbor to the storage facility on 1,100 km and then transported by small trucks on 200 km. Transport inside EU, use phase and recycling steps are considered equivalent, notwithstanding the origin of the panels. WTs are separated into two systems: moving parts and fixed parts, using the same databases than PV. The main steps of fixed parts production are: concrete production, epoxy-resin production and steel processing to build the tower. Moving parts production main steps are: various steels and alloys processing and production, aluminum, tin, wire drawing, PVC, polypropylene, polyethylene, lead, glass fiber and copper. Moving and fixed parts are transported by rail and lorry on distances between 600 and 2,000 km and are assembled onsite.

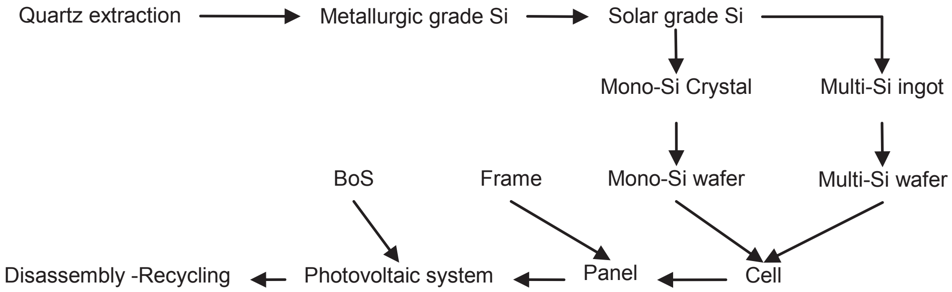

Fig. 1. Life cycle modeling of mono-Si and multi-Si panels

2.5. Other energies and selected vehicles

For our comparison, we retain an EV using the average electricity mix for various EU countries. These countries include: Denmark, France, Germany, Italy, Spain, Sweden and UK. They were both retained for their geographical location (which influence the irradiation they receive and thus the environmental impact of PV) and their electric mix. The GHG emissions of electricity mixes are taken from GaBi4 software [9] and from Renault's WTW figures (in brackets) [22]. The EV retained, for average mixes and renewable energies, is an electric Fluence (first EV sold by Renault). This car can transport five persons and has a 160 km range. Its consumption is equal to 0.47 MJ/km (official consumption on NEDC homologation cycle). Using this consumption and the GHG figures for each electricity mix, the GHG emissions of the reference EV are the following (irradiation for each country is also defined):

- Germany: 82 (71) g $CO_{2\text{-eq.}}$/km; irradiation = 972 kWh/m²/yr;
- Denmark: 99 (80) g $CO_{2\text{-eq.}}$/km; irradiation = 985 kWh/m²/yr;
- Sweden: 4 (4) g $CO_{2\text{-eq.}}$/km; irradiation = 980 kWh/m²/yr;
- Spain: 83 (57) g $CO_{2\text{-eq.}}$/km; irradiation = 1,660 kWh/m²/yr;
- France: 19 (12) g $CO_{2\text{-eq.}}$/km; irradiation = 1,204 kWh/m²/yr;
- UK: 86 (72) g $CO_{2\text{-eq.}}$/km; irradiation = 955 kWh/m²/yr;
- Italy: 92 (69) g $CO_{2\text{-eq.}}$/km; irradiation = 1,251 kWh/m²/yr.

For the comparison with conventional ICE vehicles, the methodology developed by [23] is retained. It consists of two vehicles, respectively using gasoline and diesel fuel. These vehicles are representative of the ICE average vehicle sold in the EU in 2011. The fuel production impacts are selected from the same source. These cars have the following GHG emissions (NEDC cycle):

- gasoline car: 160 g $CO_{2\text{-eq.}}$ (WTT = 22 g $CO_{2\ eq}$ + TTW = 140 g $CO_{2\ eq}$);
- diesel car: 163 g $CO_{2\text{-eq.}}$ (WTT = 28 g $CO_{2\ eq}$ + TTW = 135 g $CO_{2\ eq}$).

2.6. Functional unit definition

The vehicles must be compared on the same basis: this is the role of the functional unit (FU). In our study, we consider "driving one km on NEDC cycle" as the FU. However, since vehicles, wind turbines and PV panels do not have the same lifetime, it is necessary to define those lifetimes to have a consistent FU. The cars last 10 years and are driven on 150,000 km (meaning 15,000 km per year). This is a commonly accepted FU in the automotive industry [24]. PV panels have a 30-year lifetime, and the inverter lasts 10 years. Finally, WTs have a lifetime of 20 years. Thus, these systems are not directly comparable. To resolve this, we adopt two conventions: First, since the lifetime of the car is ten years, all calculations must be done according to this value. This means that, for PV panels, the impacts of their production and dismantling must be divided by three, because their lifetime is three times longer than the cars'. For WT, the impacts must be divided by two (lifetime = 20 years).

The second issue is the size of the WTs and PV panels. The surface of PV panels is fixed in order to provide the necessary electricity for the car, according to the yearly irradiance. Thus, in our system, the surface corresponds to the surface needed to provide the electricity necessary to drive 15,000 km/yr, which corresponds to 7,050 MJ/yr. The surface needed will depend on the yield of the PV panel and the irradiation received, meaning that for the same PV panel, the higher the irradiance, the smaller the surface. For the WT, since it produces more electricity than needed by the car, the environmental impacts are simply divided by the electricity consumed by the car to drive one km.

Finally, one must keep in mind that PV electricity is a non constant energy. The PV panel is designed in order to provide the required energy on a yearly basis. This means that, some days, the energy produced will be insufficient while sometimes it will be enough to power more than the EV. Moreover, we must also consider the fact that the EV is driven for 15,000 km on a yearly basis. This means that some days, it will not be used and thus it will not use electricity from the PV panel. Thus, we consider the following hypothesis: on a yearly basis, the electricity consumed is equal to the electricity produced. When the panel cannot provide sufficient energy, the EV is charged using average grid electricity, while when the panel is producing more energy, it is used to replace energy from the average grid. This is a simplistic approach, which is roughly equivalent to carbon compensation.

3. Results

3.1. Photovoltaic panels and wind turbines

Figure 2 shows the GHG emissions caused by PV panels (mono-Si and multi-Si) associated with the EV traveling one km (mean irradiation = 1,204 kWh/m^2/yr). GHG emissions associated with mono-Si are higher than for multi-Si, though mono-Si panels have a higher yield than multi-Si (*Cf.* section 2.2.1). This is linked to the higher energy requirements of the Czochralski process, compared with multi-Si ingot production. For one km driven with the Fluence EV, the GHG emissions are: mono-Si (12 g $CO_{2\,eq}$/km), multi-Si (9 g $CO_{2\,eq}$/km) and CdTe (5 g $CO_{2\,eq}$/km, not shown on figure 2). Though CdTe panels have the lowest yield, their GHG emissions are also the lowest, because CdTe production is much less GHG-emitting than silicon, which represents more than half of the impact for both Si technologies.

Table 1 shows the relative shares, for each PV technology, of importations. The first column represents the share of importations for the three technologies, which are considered identical. The three following columns display the share of GHG emissions for each country and technology. This shows that producing

PV panels in China emits much more GHG than in EU. This is not caused by the greater transport distances but by the energy production in China, which heavily relies on coal. This is especially true for Si-based PV panels, which are more energy consuming than CdTe.

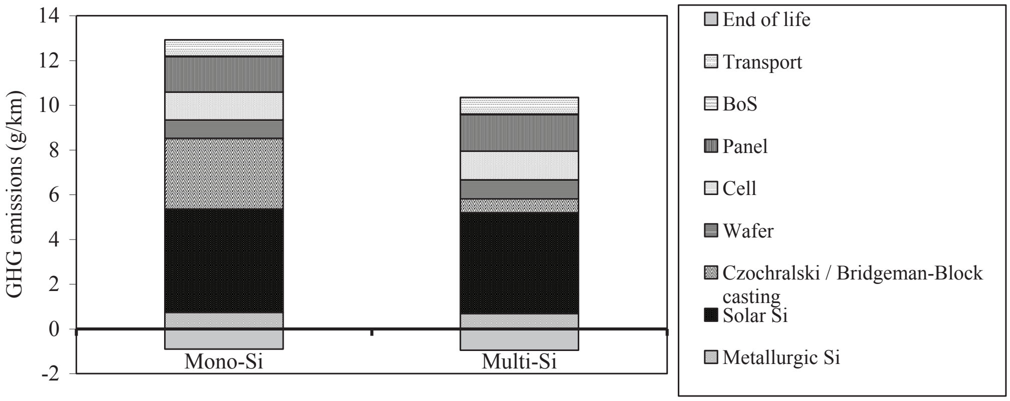

Fig. 2. GHG emissions associated for 1km driven with an EV associated with mono- and multi-Si PV

Table 1. Shares of installed PV panels and GHG emissions depending on importation countries

Country	Surface installed	Mono-Si GHGs	Multi-Si GHGs	CdTe GHGs
Europe	25%	18%	8%	>18%
China	60%	78%	87%	68%
US	15%	4%	5%	>13%
Total	100%	100%	100%	100%

Results for PV per kWh are higher than results from the literature (except for one study on CdTe ([2]). This is due to the fact that in the literature, results are usually expressed for a 1700 kWh/m^2/yr irradiation ([2], [11], [25], [26]), contrary to our study. Moreover, except in [10], PV panels are usually considered to be manufactured in EU. This lowers the GHG emissions compared with our study. For instance, if mono-Si PV panel production occurred only in UE, our results would decrease by 28%, from 92 g $CO_{2\text{-eq.}}$/kWh to 66 g $CO_{2\text{-eq.}}$/kWh. Moreover, considering an irradiance equal to 1,700 kWh:m^2/yr, GHG emissions would fall to 47 g $CO_{2\text{-eq.}}$/kWh, comparable with values from Ito et al. (50 g $CO_{2\text{-eq.}}$/kWh) [2] and Fthenakis et al. (55 g $CO_{2\text{-eq.}}$/kWh) [11].

WT results are simpler since only one technology is investigated and all WTs considered are produced in EU. Driving one km using electricity coming from WT emits 1.5 g $CO_{2\text{-eq.}}$/km, with fixed parts representing 0.8 g $CO_{2\text{-eq.}}$ and moving parts 0.7 g $CO_{2\text{-eq.}}$. Thus, the GHG emissions of WTs are far inferior than PV. Results (12 g $CO_{2\text{-eq.}}$/kWh) are consistent with latest literature data. Guezuraga et al. (2011) [27] found, for a 2MW turbine, 9 g $CO_{2\text{-eq.}}$/kWh, using a load factor equal to 34%. This means that, using a load factor equal to 25%, GHG emissions would be equal to 12 g $CO_{2\text{-eq.}}$/kWh, as in our study. Jungbluth et al. 2005 [28], found, for a 0.8 MW WT, emissions significantly lower and equal to 9 g $CO_{2\text{-eq.}}$/kWh (11 g $CO_{2\text{-eq.}}$ using a load factor equal to 20%). Using the ELCD database, GHG are even lower, equal to 7 g $CO_{2\text{-eq.}}$/kWh. However, Arvesen and Hertwich (2011) have found significantly higher values, with 16.4 g $CO_{2\text{-eq.}}$/kWh for a 2.5 MW WT with a 23.6% load factor [29]. This means that our results correspond to an average value between all data from literature.

3.2. Comparison of EV depending on EU countries

Depending on the country investigated, the GHG emissions associated with the average electricity mix can greatly vary, as described in section 2.5. Between these countries, the PV panel emissions also vary, the surface needed being dependent on the sun irradiation. The following map shows the GHG emissions associated with the 7 selected countries for PV (40% mono-Si, 46% multi-Si and 13% CdTe) and average electricity. Wind electricity and internal-combustion-engine vehicles (gasoline and diesel fuel) are the same for all countries, emitting respectively 1.5 g $CO_{2\text{ eq.}}$/km, 160 g $CO_{2\text{ eq.}}$/km and 163 g $CO_{2\text{ eq.}}$/km. The following conclusions can be drawn:

- for every country retained, the EV emits less GHG than diesel and gasoline vehicles when using average electricity mix;
- WT always emits less GHG than PV or average mix, whatever the country retained;
- sun irradiation has a strong influence, GHG emission for PV vary between 7 to 12g $CO_{2\text{ eq.}}$/km;
- conclusions between average electricity and PV depend on the country studied. For most countries (UK, Spain, Denmark, Germany, Italy and Spain), PV has lower GHG emissions than average electricity. For France, PV emissions are close to average mix, though lower. Finally, for Sweden, which uses high amounts of renewable energy and has a low sun irradiation, PV emits more GHG than the average mix.

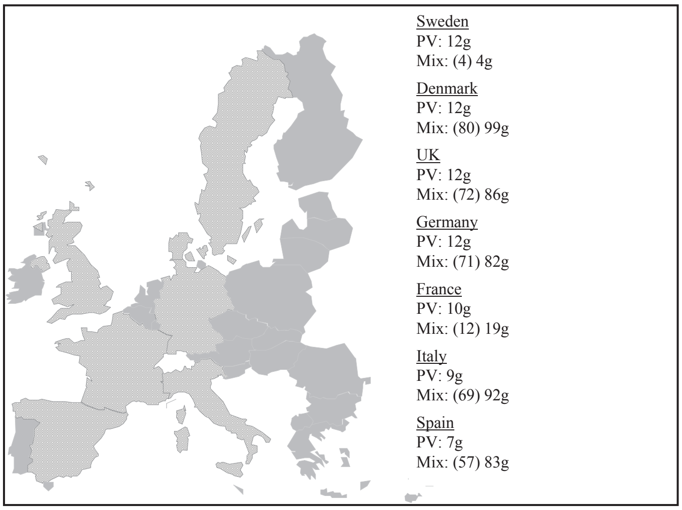

Fig. 3. GHG emissions associated for 1km driven with an EV using average electricity mix and PV

4. Discussion and conclusion

4.1. PV results

Results show that GHG emissions from panels produced in China are higher than in US or EU. This is due to the fact that emissions associated with energy production in China are higher (China extensively uses coal). To take into account the Chinese context, we only changed the emissions associated with energy production but keep the same process efficiencies and emissions. This is a limitation because the databases used do not contain data about Chinese processes. Thus, we might over- or underestimate the GHG emissions associated with Chinese panels. Considering the fact that Chinese panels represent about 60% of panels currently being installed in EU, the error might be significant. Nevertheless, this is an issue which overpasses our study and is encountered in many other LCAs.

PV panel lifetime was set to 30 years, since it is the lifetime which is the most commonly found in the literature. Changing the lifetime to 20 years, would lead to different results. Since the BoS has almost negligible GHG emissions, we can consider that switching from a 30-year to a 20-year lifetime would be the same as multiplying the results by 3/2. This would not change the conclusions, as PV GHG emissions would remain lower than average electricity for UK, Germany, Spain, Denmark and Italy. The difference between French average electricity and PV would be smaller. Recycling is taken into account mainly by recycling the aluminum frame, copper and glass. Yet, as shown on figure 2, most GHG emissions are associated with silicon production, purification and cutting into wafers. This means that, as long as the silicon cells cannot be recycled, the recycling will not have a large impact on PV emissions.

4.2. Comparison between EV and ICE vehicles

The ICE vehicles retained are average European vehicles such as defined in [23]. However, in 2011, many vehicles emit less than 135-139 g CO_2 / km. If we consider an average champion that would emit about 90 g CO_2 / km during its use phase, this would correspond to 104 and 118 g CO_2 / km respectively for gasoline and diesel in a WTW point of view. Even so, the GHG emissions of EVs would be lower when using the average electricity mix. The difference would be small for some countries (such as Denmark or Italy) or still very significant for some others (France and Sweden). For PV and WT, the difference remains very high and EVs emit much less GHG than ICE vehicles, wherever they are driven. The consumption of vehicles are calculated and measured on the NEDC homologation cycle. This cycle is defined in the EU to calculate the official CO_2 emissions and fuel consumptions, for instance to enable the client to compare different vehicles from different brands. It does not represent all emissions of all cars in all situations, since, for the same vehicle, the fuel consumption greatly varies depending on the driver behavior: eco-driving, congestion, heating and cooling systems turned on or off, etc. Thus, the conclusions in this article are only valid on NEDC cycle and cannot be compared to studies that would use other cycles. In this article, we only studied the use phase of EVs and ICE vehicles. That is to say, we did not conduct the whole car LCA. Therefore, the conclusions can only be drawn for the use phase (the well-to-wheels analysis) and are not sufficient to conclude between ICE vehicles and EVs. The GHG emissions of an EV are not the same as for an ICE vehicle, because they respectively use an electric engine with a battery and an internal combustion engine. The aim of this article is not to compare EVs and ICE vehicles, however, as a sensibility analysis, the impact of taking into the battery should be investigated. Considering that the battery of the vehicle represents around 20 g $CO_{2\text{-eq.}}$/km (Renault internal data), this would not change the conclusions for PV and WT. Even with 20g $CO_{2\text{-eq.}}$/km added, an EV using WT electricity would emit 21-22g $CO_{2\text{-eq.}}$/km. For PV electricity, this would lead to emissions between 27 – 32 g $CO_{2\text{-eq.}}$/km, still far less than ICE vehicles. Finally, for average electricity mixes, the conclusions would depend on which vehicles EV are compared to. Compared with the average ICE vehicles, the conclusions do not change, even for countries with high GHG-emitting electricity, such as Germany or UK. However, for these countries, the GHG emissions between EVs and champion ICE-vehicles would be approximately equivalent. For countries with low GHG emissions, the EV remains less impacting, even compared with ICE champions. The low impact of the Li-ion battery, compared with ICE vehicles, is confirmed by data from the literature. Indeed, Data from literature ([30], [31], [32]) range from 7 to 12 g $CO_{2\text{-eq.}}$/km, being even lower than Renault's calculations.

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