PÖYRY

TIPPING POINTS MULTICLIENT STUDY – JUNE 2019

# How falling technology costs and retail tariffs will shape the electricity system

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# Table of Contents


**1. How could rapidly falling technology costs disrupt the power sector? .... 4**

**2. Impact of tariffs ........ 6**

How current retail tariff structures could distort the market ........ 7

Changing the tariff arrangements results in a more efficient outcome ........ 7

**3. Take-up of new technologies and tariff reform ........ 10**

How current retail tariffs can encourage rooftop solar ........ 10

Tariff reform with time-of-day retail prices and smart meters ........ 11

**4. How can smart meters and tariff reform change demand and prices? .... 13**

Retail tariff structures change demand ........ 13

Retail tariff structures change wholesale prices ........ 14

**5. Could a Tipping Point emerge? ........ 17**

What happens if half of all residential and commercial customers install solar? ........ 17

Could a Tipping Point emerge in any European country? ........ 18

**6. Future capture prices for renewables ........ 20**

What is the capture price and cannibalisation? ........ 20

Why is this important? ........ 21

How supply curves and price duration curves will change ........ 21

**7. Price volatility and batteries ........ 24**

The return of the batteries ........ 24

How electric vehicles could disrupt the battery business ........ 25

**8. Conclusions ........ 26**

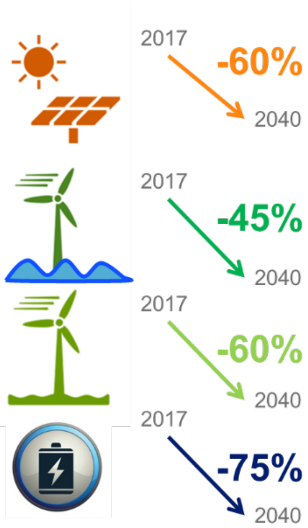
**Annex A – Modelling approach ........ 28**

A1 BID3 modelling framework ........ 28

A2 Retail expansion – what should a customer buy? ........ 29

# 1. How could rapidly falling technology costs disrupt the power sector?

**Exhibit 1.1 – Reductions in costs of new technologies**




*During 2017-18, Pöyry carried out a major multi-client study to investigate how rapidly falling costs of renewables and batteries could transform the power sector. The study focused on how retail customers – in particular residential and commercial – could shape the future of the energy system with behind-the-meter generation, and how retail tariffs may alter this transformation.*

With rapidly falling costs of solar, wind and batteries, it is accepted wisdom that the power market is changing faster than ever before. Costs of renewables such as onshore and offshore have dropped by 40-50% in the last ten years, whilst solar and Li-ion battery storage costs have fallen by 70-80%.

Some take the view that a future of large scale onshore and offshore wind, solar farms and grid-scale batteries will become dominant, whilst others think the future is all about 'decentralisation' – small scale behind-the-meter solar and batteries giving consumers the ability to generate and store their own energy.

Given the major changes that could occur, Pöyry carried out a major multi-client study in 2017-18 to look into the impacts. This study examined different scenarios in which rapidly falling technology costs could transform the retail electricity market with every household having rooftop solar, basement batteries and electric vehicles.

***Key questions we looked to answer included:***

- How could the structure of retail bills affect technology roll-out, and overall cost of decarbonisation?
- How rapid could residential and commercial take-up of behind-the-meter solar and batteries be?
- Will falling renewable and battery costs lead to merchant build (without subsidy)?
- How important will RES-on-RES competition be?
- Will future price volatility increase, or decrease?

Other technologies, such as hydrogen, are currently being widely discussed in relation to the pathway to 2050 and decarbonisation of heat. However, in this study we look at a horizon to 2040 and focus on a steady decarbonisation in the electricity sector, electrification of transport, without substantial adoption of hydrogen or rapid decarbonisation of the heat sector.

This study involves looking at both the wholesale power market – with large scale generation – and also the retail sector, such as houses and offices. In the wholesale market, we wanted to ensure that we captured the impact of both the decision to generate ('unit commitment'), as well as the decision to build new generation ('capacity expansion'). But also in the retail sector we needed to capture the hourly decisions on when to charge/discharge a battery or electric vehicle depending on retail tariff, alongside the decision as to when consumers to would decide to buy one.

No existing modelling could accomplish what we wanted, so we had to build one that could

No existing modelling platform optimises both the wholesale and retail markets simultaneously, so we had to build one that could do. This involved extending our existing BID3 modelling platform to allow simultaneous modelling of the wholesale market and retail sector. The novel techniques used are described in more detail in the annex.

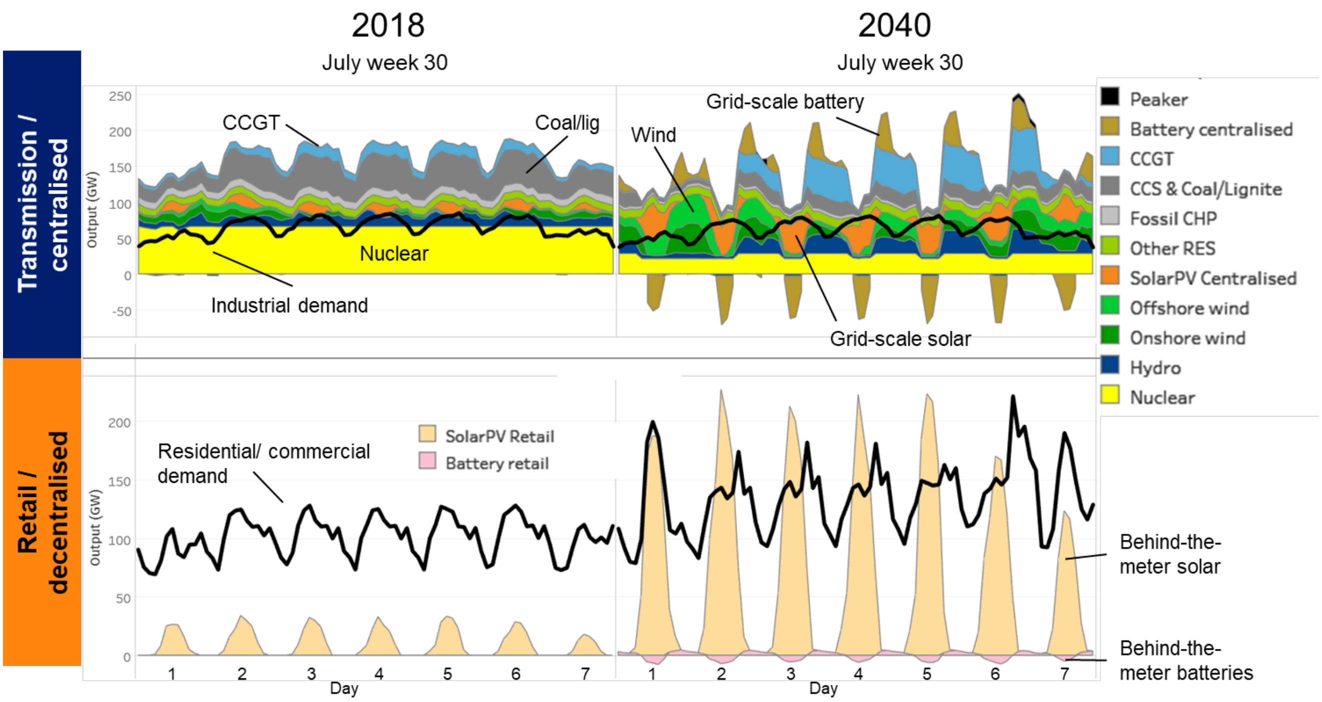
In the Tipping Points study we show how radically the energy system will be evolving over the next few years. Critically, how retail tariffs are structured in the future has a massive impact on outcomes. With current retail tariffs, large amounts of behind-the-meter solar is built. Although this doesn't lead to an unstable situation, it is potentially a highly uneconomic outcome with billions spent on less economic rooftop renewables, whereas this money could be more productively spent on renewables elsewhere. By changing billing structures with hourly time-of-day tariffs on smart meters, and moving grid charges to a fixed per-customer basis, most of these uneconomic outcomes are avoided. However, no change to current retail tariffs leads to a dramatic increase in rooftop solar, and an increase in grid-scale storage to manage the power surges and dips.

**Exhibit 1.2 – The transformation of the wholesale and retail markets in Central-West Europe**

*If current retail tariffs continue in European countries, and technology costs continue to fall, we could see a radically different world.*

*By 2040 at the retail (decentralised) level, most houses have solar on their rooftops, with diesel and petrol cars mostly replaced by electric. Demand from end-customers has risen and become more peaky due to charging of cars, whilst generation from solar panels means power flows 'up' the network during daytimes.*

*On the transmission/centralised system, there is a lot of battery build to help manage the large solar generation, with renewables dominant on the system.*




Notes: Generation and demand shown for France, GB, Germany, Belgium, Netherlands, Switzerland, Denmark.

# 2. Impact of tariffs

*Retail prices paid by households and businesses are composed of a number of different elements. The headline element of any electricity bill is the cost of generating electricity (the 'wholesale price'), but this is typically only a third of a consumer bill. Large components of the bill also have to cover the cost of the transmission and distribution network, policy support costs such as renewables subsidies and of course taxes such as VAT.*

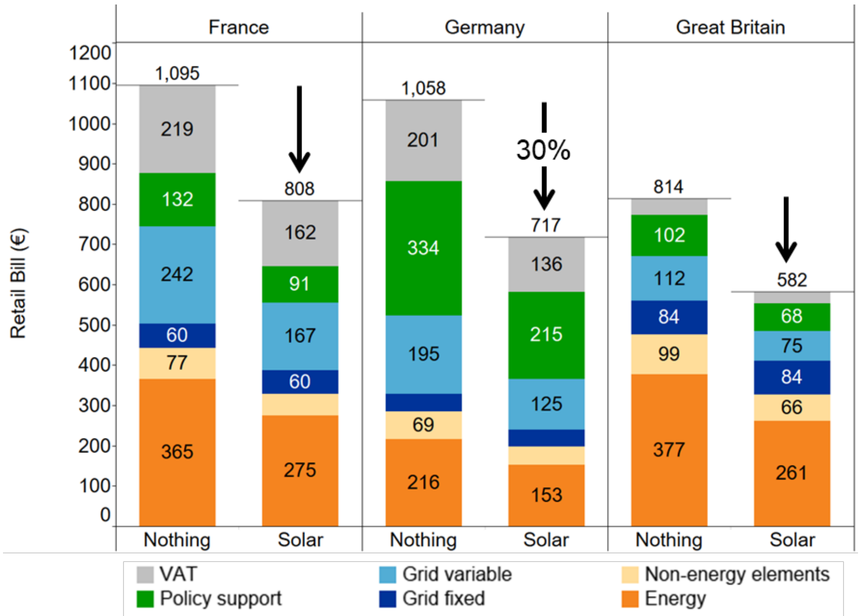
Current retail tariffs can create strong but potentially perverse incentives on consumers

Despite the majority of policy support costs and network costs being large fixed capex and opex and hence not varying per kWh of electricity consumed, on most consumer bills these costs are levied on a per kWh of energy consumed basis. Historically this has been a convenient and simple way to levy charges – as all customers have a meter – and means higher consumption customers pay more of the share of network and policy support costs.

As a result, there is a strong incentive on consumers to reduce the energy they buy from the grid, as each kWh consumed is much more expensive than the underlying wholesale energy cost. In the past, this was a sensible logic as it encouraged energy efficiency. However, with the rise of decentralised (rooftop) solar generation, consumers can opt instead to generate their own energy. By installing solar panels, they can avoid paying their 'fair' share of fixed system costs, but still rely on having a network connection.

**Exhibit 2.1 – Typical retail tariff savings from a solar panel**

*Under current tariffs structures, typical residential electricity bills in France, Germany and Great Britain save about 30% per year by building solar.*




Source: Eurostat and Pöyry.

When free-riding occurs with millions of customers, we have a serious problem

The benefits of a reliable electricity supply whenever needed from the grid, but avoiding paying for most of these grid costs by generating your own energy, is referred to as 'free riding': individual customers are relying on other customers to pay for a common good whilst avoiding these costs.  This 'free riding' not only leads to customers without solar panels subsidising the costs of those with panels, but also can result in a deeply inefficient electricity system, where large amounts of money are spent on behind-the-meter generation, which is expensive or unneeded.

Where the free riding occurs with thousands of households, the issue is small and lost in the noise of the rest of the electricity system costs.  However, if millions of households start generating their own electricity via solar panels, and avoiding grid costs, then a serious issue emerges.

## How current retail tariff structures could distort the market

Pöyry has looked at how changing something as simple as the tariff structure could radically alter the investment incentives and hence the electricity market itself.

We ran two different scenarios through our power market model, BID3.  The incentives faced by wholesale investors and retail customers are very different due to the tariff structures they face.

In NW Europe over the next 12 years, using current tariff structures leads to 280 GW of behind-the-meter solar being built.  During the summer, large amounts of solar mean that electricity prices would frequently fall to zero, with more electricity supply than demand.  As a result, 30 GW of grid-scale batteries would be built by investors looking to profit from the high spreads available.

## Changing the tariff arrangements results in a more efficient outcome

However, if regulators and governments change tariff structures so that grid costs and policy support costs are paid on a per-household basis (rather than per kWh of electricity consumed) this radically changes the capacity base and results in significant system cost savings.

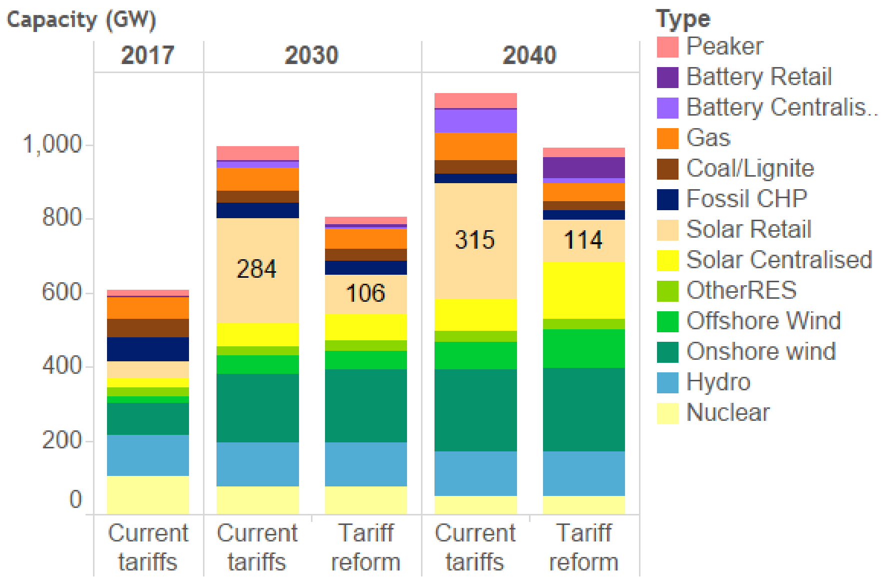
Different tariff arrangements dramatically change the amount of rooftop solar that is built

In 2030, instead of 284 GW of behind-the-meter solar, a mere 106 GW is built instead.  The change in tariffs removes the inventive for retail customers to invest in solar panels.  Instead, we would see an additional 10 GW of large scale solar and 10GW of onshore wind being built, as returns to these investments improve as a result of fewer zero price periods. In 2040 the difference become even greater, with a difference of 250 GW in the amount of solar built, despite identical carbon emissions.

These differences are shown in the chart below.

**Exhibit 2.2 – Installed capacity from now to 2040**

*Reforming retail tariffs reduces rooftop solar, and increases 'centralised' build of technologies.*

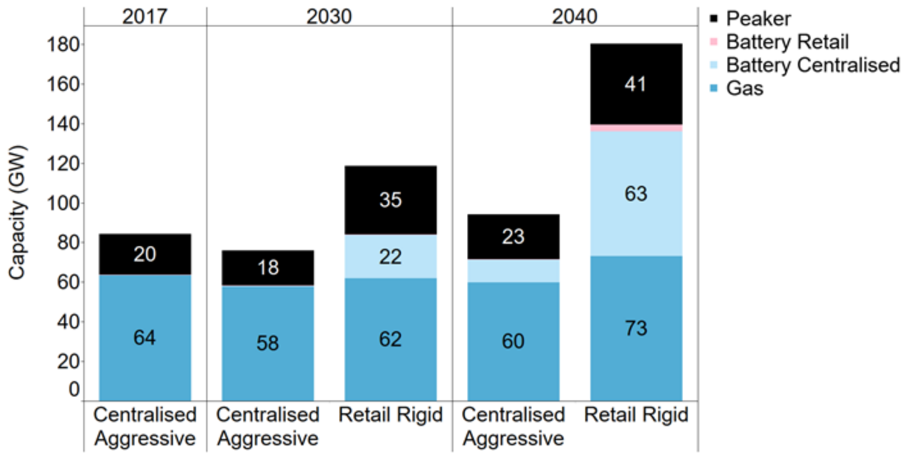



In both of these scenarios the carbon emissions reductions and demand are the same, but the investment would be much greater with a continuation of current electricity tariffs.

The impact on battery developments is equally dramatic. With 'Current Tariffs' 63GW of 2 and 4-hour batteries are built in NW Europe to manage the large amounts of rooftop solar and relatively inflexible charging of Electric Vehicles. However, the 'Tariff Reform' world of smart meters and mainly fixed (per kW) network and policy support costs leads to much less need for batteries – only 10GW of grid scale batteries are built.

**Exhibit 2.3 – Grid scale battery build**

*Large amounts of grid scale batteries are built to help manage the variability of rooftop solar.*



In total, the savings from tariff reform could amount to €100bn across NW Europe, simply by encouraging more economic investment decisions across the sector. Furthermore, given the rapid take-up of new technologies, we estimate that by 2025, half of houses in Central and NW Europe could invest in rooftop solar, with the savings on their retail bill outweighing the costs of installation. If households make a decision to buy solar panels, only to discover that changing tariff structures means they are not economic, this could lead to stranded costs and deeply disgruntled householders.

This enormous value at stake should encourage more governments to consider retail reform as soon as possible and not wait.

# 3. Take-up of new technologies and tariff reform

*The BID3 platform built for the Tipping Points study allows us to examine both how quickly new technologies may be adopted, along with the impact of key policy instruments such as the impact of adoption of smart meters or changing tariff structures. The model evaluates the cost savings to customers from different 'investments' in rooftop solar or batteries, and those cost savings change depending on whether the customer pays time-of-day tariffs from a smart meter, or whether they can avoid policy support or network costs.*

## How current retail tariffs can encourage rooftop solar

Current tariffs encourage a rapid take-up of rooftop solar

As shown below, when we run the model for a 'current tariffs' world, with flat annual retail electricity prices, we see a rapid increase in rooftop solar installations. Due to falling electric vehicle costs, we also see a rise in households (and commercial businesses) that have electric cars and delivery vehicles, as well as properties that have EVs and solar panels.

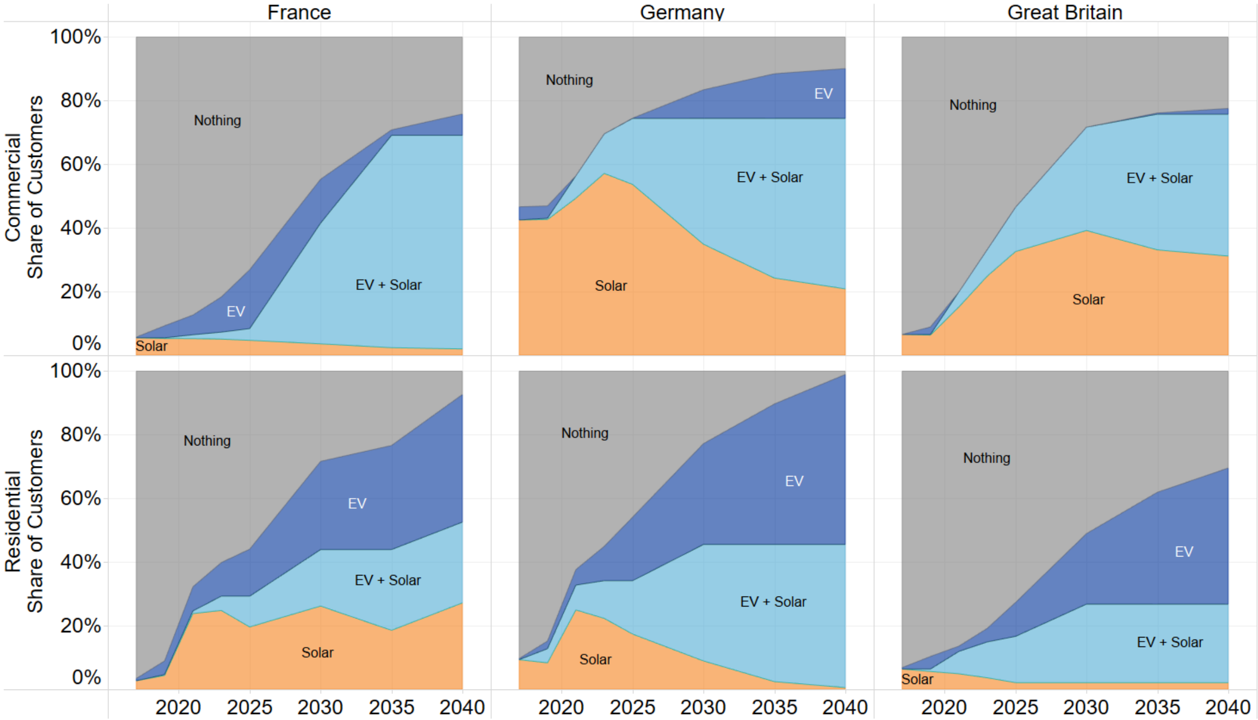
In Germany and GB, about half the households with an EV also install solar, as this leads to the greatest cost saving. As a result, houses with solar only (and no EV) are very rare. In France, given the higher electricity demand (due to electric heating rather than gas), more households without electric cars decide to buy solar panels. The solar allows them to offset a greater proportion of their electricity bills due to the higher energy demand.

It is notable that no households choose to install batteries (either with or without solar panels). With our assumptions, the 'business case' for buying a residential Li-ion battery simply is not strong enough given the costs of purchase. In particular since we assume that the electricity bill is flat across the year as in most countries currently, there are no opportunities for arbitrage revenue based on varying hourly electricity prices.

In the commercial sector (which spans a wide range from small single-premise retailers to large shopping centres) take-up varies again. In many cases rooftop solar makes an economic business case, particularly when there is a large roof space and substantial onsite demand – for example supermarkets or warehouses. Many of these businesses take advantage of charging Electric Vehicle fleets onsite, given the incentives offered due to avoiding policy and network charges.

**Exhibit 3.1 – Current tariff structure: share of customers by technology type**

*With the current retail bill structure, there could be a rapid increase in both solar-only and 'solar plus electric vehicle' households and commercial businesses.*




## Tariff reform with time-of-day retail prices and smart meters

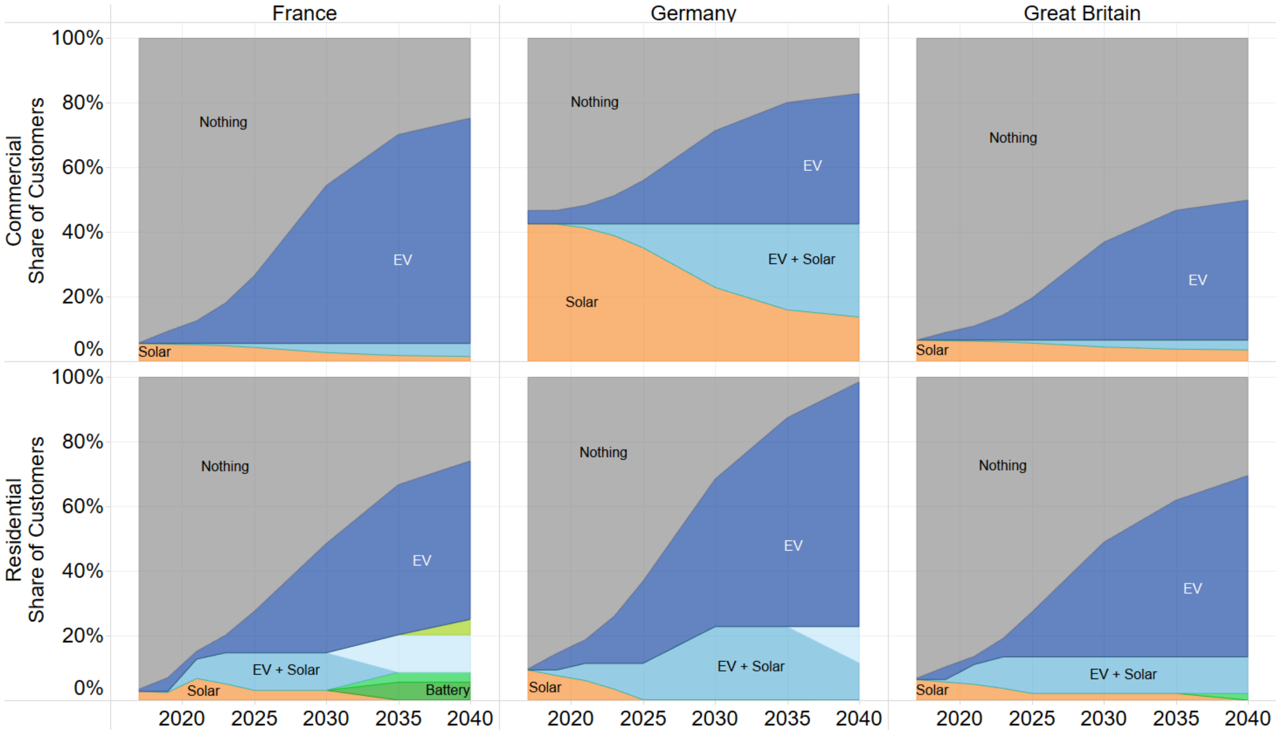
A tariff reform crashes the 'business model' of behind-the-meter solar

However, if governments rapidly implemented tariff reform, largely removing variable charges for policy and network costs, along with smart meters to expose customers to varying-time-of-day tariffs, the take-up of technologies alters. The adoption of household solar reduces substantially, as much of the value from installing solar is in the avoidance of policy support costs and network costs that can now no longer be avoided. Note that both scenarios have the same $CO_2$ emissions, but with the difference occurring at the large-scale generation level.

In France and GB, there is a small uptake of residential batteries, as a few early adopters decide to buy household batteries. This is aided by the ability of the residential batteries to arbitrage hourly prices on their smart meters.

**Exhibit 3.2 –Tariff reform structure: share of customers by technology type**

*Tariff reform changes the incentives on retail and commercial customers, and leads to lower rooftop solar (with the same decarbonisation overall).*




Overall, the evolution of solar, batteries and EVs is not solely driven by technology costs or consumer preferences, but heavily influenced by government policies on tariffs and how the large fixed costs in the electricity system are 'smeared' onto end-user bills.

# 4. How can smart meters and tariff reform change demand and prices?

*As we have already seen, changing tariff structures can have a big influence on the take-up of various technologies, in particular rooftop solar. However, it also affects how people choose to consume electricity, and in turn it affects electricity prices.*

## Retail tariff structures change demand

Tariff structures can have a substantial impact on the shape of demand and the pattern of generation

In the diagram below, we've shown the GB electricity system split into the 'wholesale' system which includes large generation and demand, and the 'retail' system, which includes all behind-the-meter generation (like rooftop solar) and residential and commercial demand.

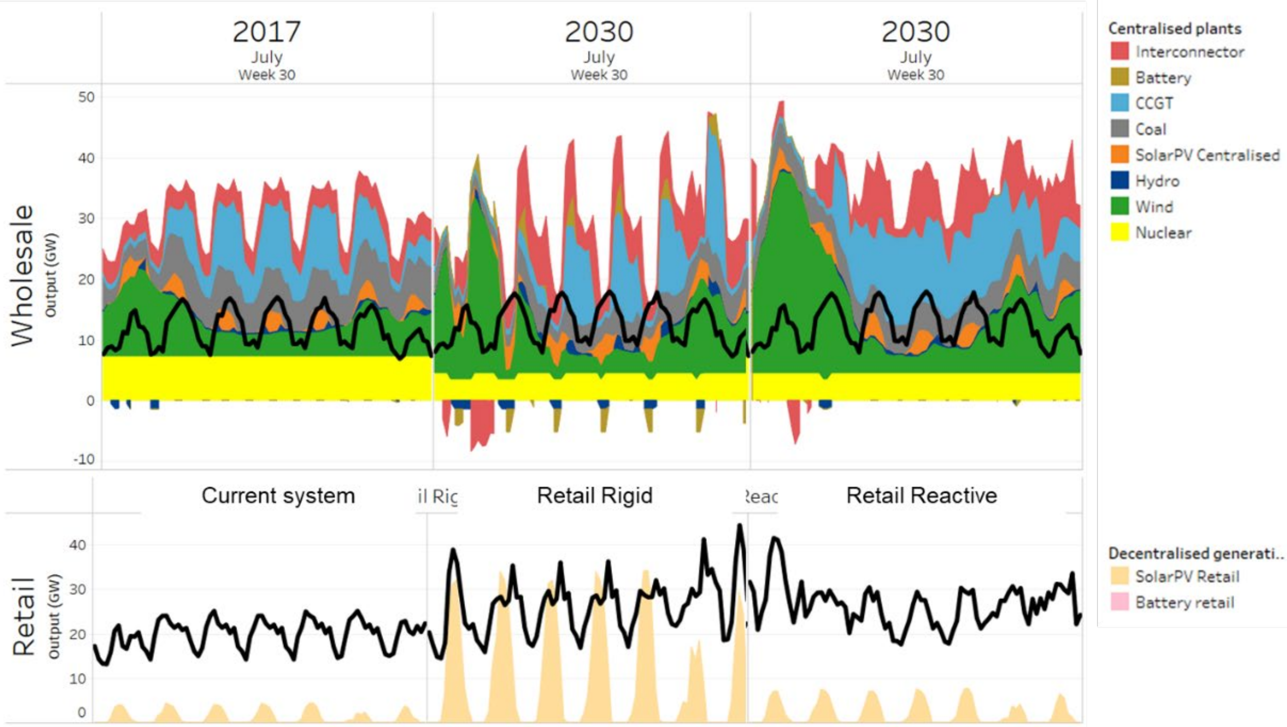
We've compared a typical week in July in 2017 with how the system could evolve to 2030, with or without tariff reform.

The 2017 demand and generation patterns show a strong day-night cycle and weekday/weekend cycle, with small amounts of behind-the-meter solar generation. By 2030 this picture has changed dramatically – albeit differently depending on the deployment of smart meters and tariff reforms.

In our 'Current tariff structures' scenario, demand becomes spikier as electric vehicles are frequently charged at peak times. In addition, rapid deployment of solar on rooftops creates a daytime spike in generation (and hence a 'dip' for the wholesale system to manage). This creates a complex dispatch of plant on the 'wholesale' system, with batteries and flexible generation and interconnectors all required to manage the large swings of power.

**Exhibit 4.1 – Hourly generation and demand for wholesale and retail markets**

*The current system could evolve very differently in the next 10 years depending on the progress of tariff reform.*




In the Tariff Reform world, electric vehicles follow signals from smart meters in response to the wholesale electricity price and changes in generation from wind and solar. In turn this leads to a much more responsive demand system. Solar generation from rooftop solar is lower, because (as previously discussed) the 'business case' is less compelling in a Tariff Reform world. Finally, the wholesale system is much more stable, as more flexible demand and less solar generation create a simpler system with less daily swings in power generation and consumption.

## Retail tariff structures change wholesale prices

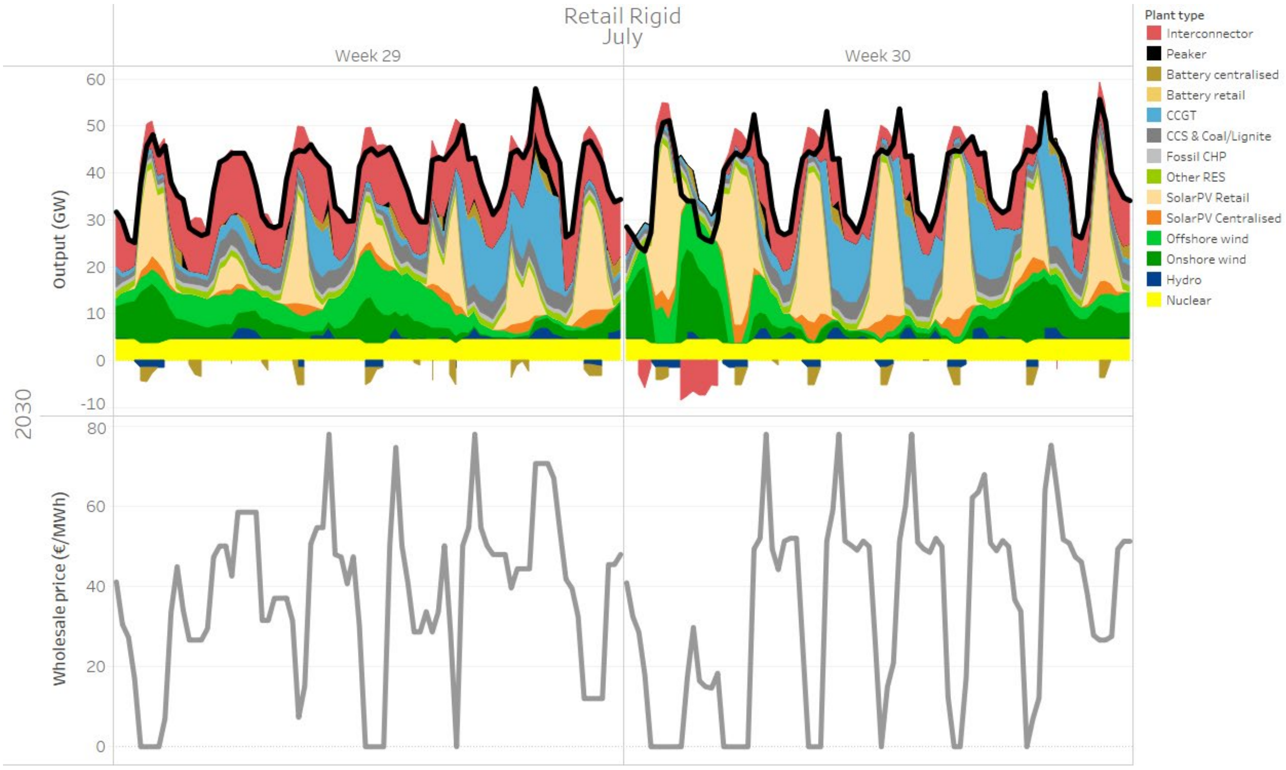
Tariff structures also influence wholesale price shape and volatility

In the following two diagrams, we group all generation on the system (both behind-the-meter and large-scale generation) and show how that interacts with prices in the two different futures.

In our 'Current Tariffs' world, the large swings in daytime solar can be clearly seen in light yellow, and the resulting electricity prices are highly volatile. There are many periods of zero prices (due to the high infeed of solar generation) although not enough to drive a substantial increase in the build of batteries (as these daytime zero prices only occur during the summer). There are price peaks every evening due to lower solar generation coinciding with the demand peak.

**Exhibit 4.2 – Current tariffs: hourly generation and prices**

*Generation, demand and prices are much more volatile with current tariff structures.*

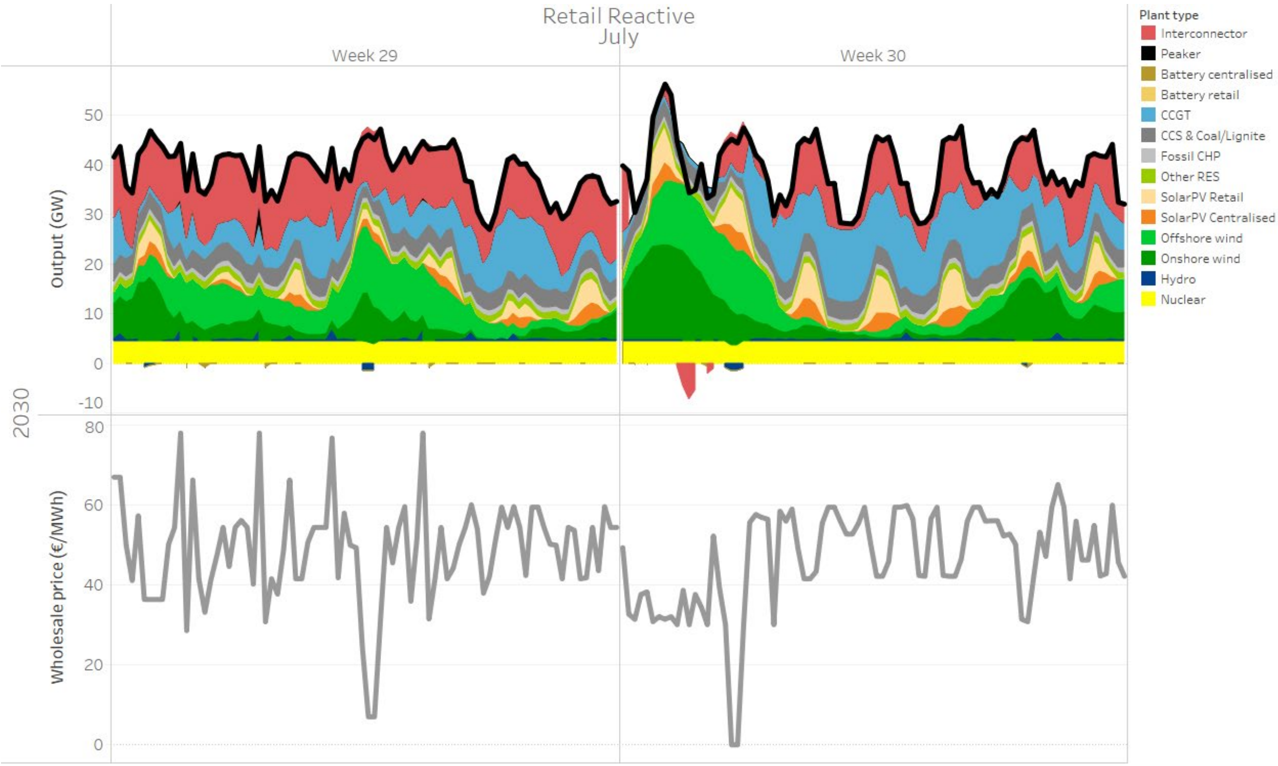



In the ‘Tariff Reform’ world, the lower amounts of solar mean a much less volatile system, which in turn leads to much flatter wholesale prices. Prices do not follow a systematic day-night pattern due to the flexibility of electric vehicle charging which changes dynamically in response to prices.

In both the scenarios, interconnectors import from the Continent most of the time due to higher GB prices resulting partly from higher carbon prices in GB.

**Exhibit 4.3 – Current tariffs: hourly generation and prices**

*Reforming tariffs leads to flatter demand, more stable generation and less volatile prices.*



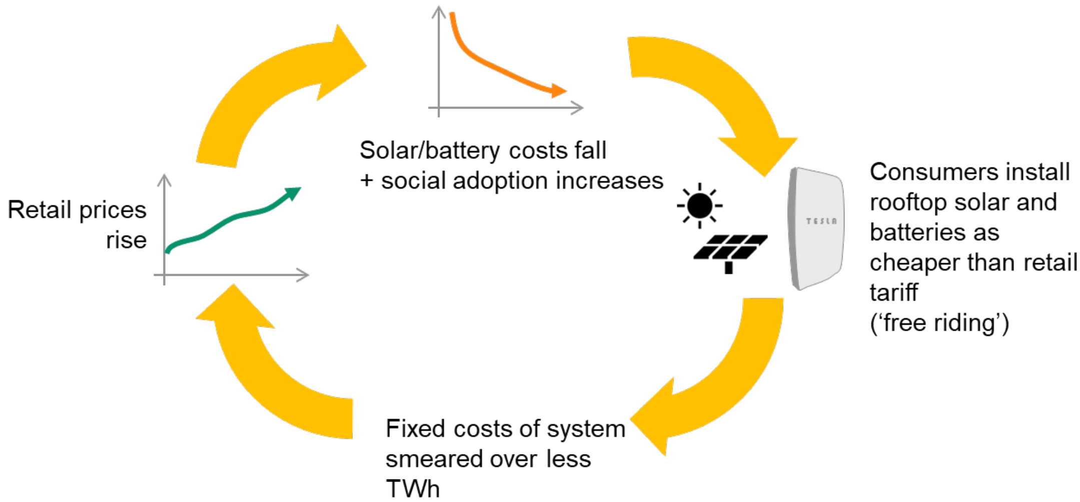

So overall, different tariff regimes could lead to remarkably different futures for the flexibility of demand and the impact on hourly electricity prices. Currently flat residential prices with high variable charges could lead to a lot of solar and inflexible charging of electric vehicles – leading to highly volatile prices with zero priced periods and high peaks. However, enabling demand to match supply via smart meters, whilst removing the incentive on behind-the-meter solar creates a more flexible system with less volatile prices.

# 5. Could a Tipping Point emerge?

*One of the concerns from policy makers is that the avoidance of grid and policy support costs by rooftop solar could lead to a vicious circle. The 'free riding' from individual customers, who generate most of their own energy but still rely on a grid connection for times when there isn't enough sun, leads to falling revenues for grid costs.*

However, someone still has to pay for the fixed costs of the grid and committed policy support costs such as renewable subsidies. So other customers have to pay more for their electricity, which incentivises them to install solar on their rooftop. This leads to a further shortfall in recovery of grid costs, and hence further rises in retail tariffs, which encourages more up take of solar. This vicious circle has also been dubbed the 'Death Spiral', as shown below.

The Tipping Point vicious circle has also been dubbed the 'death spiral'




So the key question is whether a Tipping Point – the point at which a majority start to install solar and the issue becomes uncontrollable – will emerge. This Tipping Point is the point at which the current regime of paying for electricity bills ceases to work.

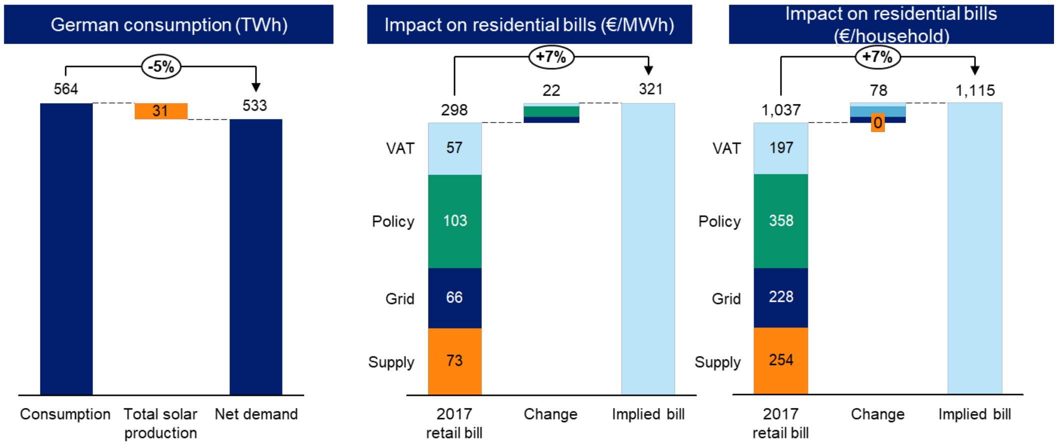
## What happens if half of all residential and commercial customers install solar?

To test the idea of a Tipping Point, we've analysed what happens if half of all residential and commercial customers install solar on their rooftops. We've assumed a typical household consumption of 4MWh, and typical solar panel size of 3.5kW, implying annual generation of about 3MWh (72% of demand of each household that builds solar). In the commercial sectors we've assumed varying panel sizes depending on the commercial premises.

In Germany, as shown below, demand falls by 31TWh, or 5%, as a result of household solar generation. In turn, electricity bills to non-solar households rise by about 7%, as the grid and policy support costs have to be paid across a smaller share of metered demand (note that supply costs – mainly generation – do not change). This leads to a rise in bills of €78 per household. Although €78 per household increase in bills would certainly be unfortunate for those affected, it is unlikely to lead to those household deciding to install solar (with an install cost of a couple of thousand Euros).

**Exhibit 5.1 – German consumption and residential bills with 50% take-up of solar**

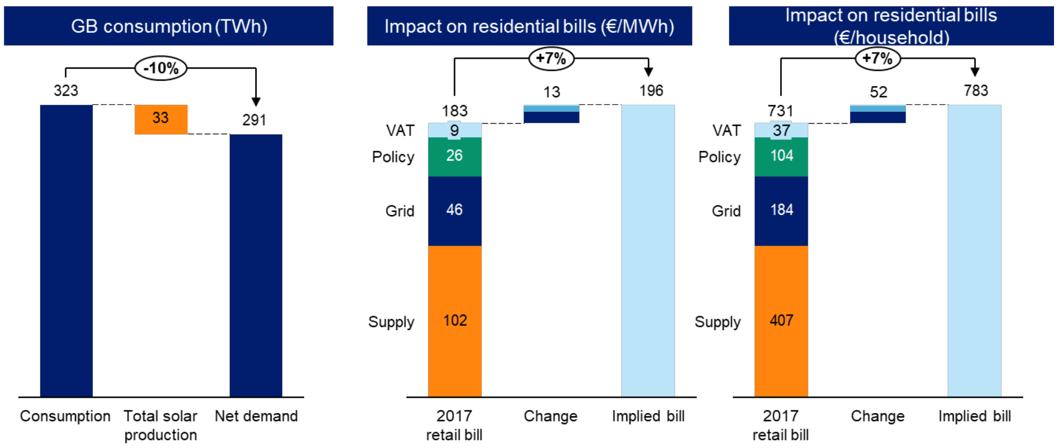
*Assuming half of all households in Germany install solar implies a 7% increase in retail bills.*




In GB, the supply of supply, grid and policy costs is very different to Germany, with much lower subsidies paid to renewables, but much higher wholesale prices and hence higher supply costs. A similar analysis leads to a smaller rise in household bills of €52 – coincidentally about 7% increase. Again, a definite impact, but unlikely to be large enough to slew consumer behaviour and lead to a complete adoption of rooftop solar.

**Exhibit 5.2 – GB consumption and residential bills with 50% take-up of solar**

*If half the households in GB install solar retail bills rise by 7% increase in retail bills.*




## Could a Tipping Point emerge in any European country?

Although retails bills increase, it probably isn't enough to cause a Tipping Point

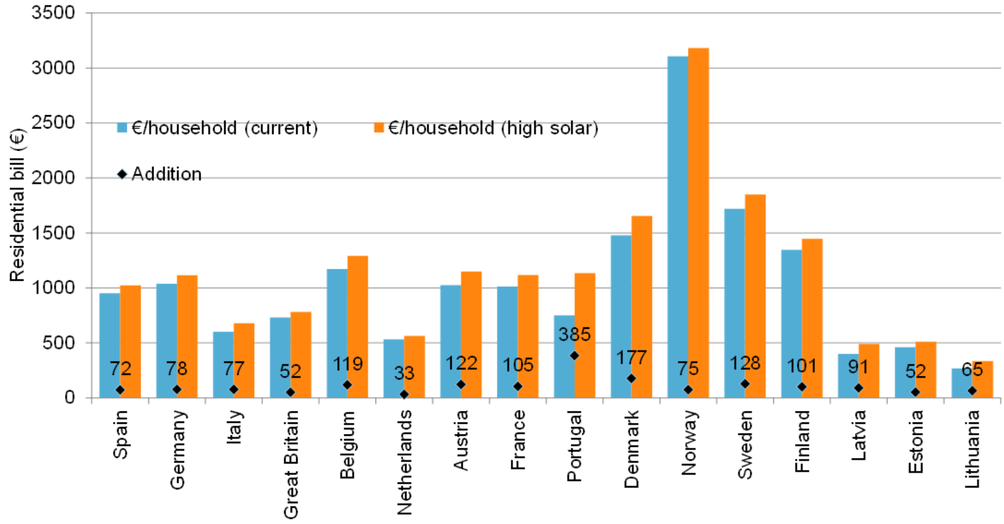
Since all European countries are different – with varying solar yields, different consumption per household and different tariffs – we've looked at all European countries to see if there are any countries where this effect might be more evident than others.

The chart below compares the current residential electricity bill (without solar) with the bill on a non-solar house if half of all households installed solar. The typical increase in bill faced by the non-solar houses varies between €30 and €100. Rooftop solar in Portugal has the biggest impact on bills, due to high solar irradiation (so each roof top panel generates a lot more energy), plus relatively high policy support costs and network costs that can be avoided by installing solar. Equally the Netherlands is one of the countries with lowest impact, owing to low solar irradiation and low policy support costs and network costs.

Overall, in most countries the typical values of €30-€100 per household per year are not insubstantial, but certainly not enough to create the runaway effect of a Tipping Point.

**Exhibit 5.3 – Pan-Europe residential bills with 50% take-up of solar**

*The increase in bills faced by non-solar households is unlikely to drive a Tipping Point in European countries*




So, although rapid adoption of rooftop solar may lead to rising bills for those without rooftop solar, it appears unlikely that a runaway Tipping Point would emerge.

# 6. Future capture prices for renewables

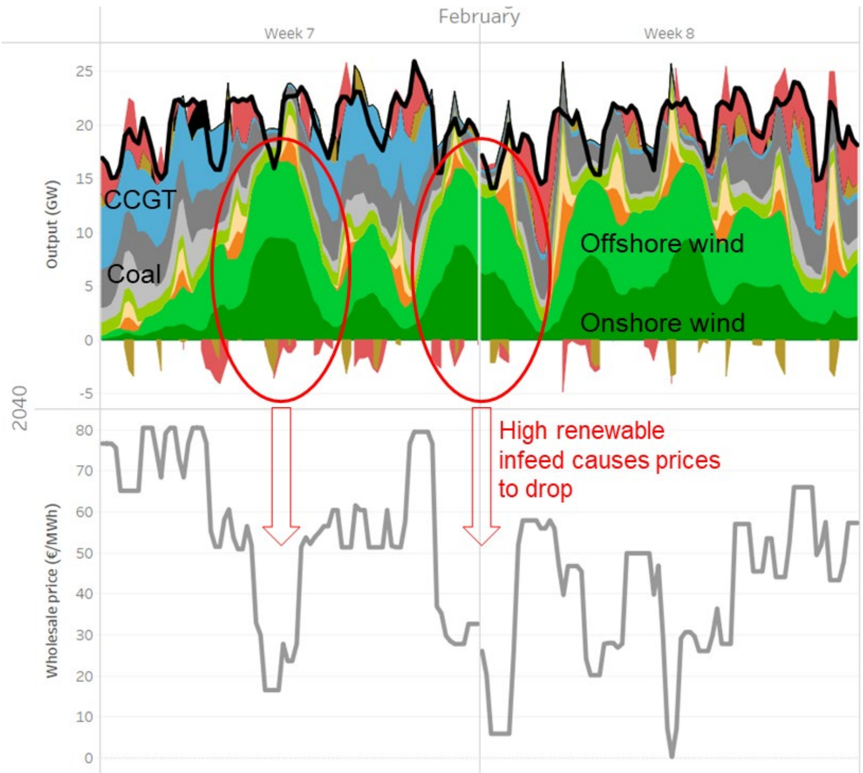
*Most renewables in Europe have been built based on fixed government subsidies or Feed-In Tariffs. These have given a high degree of certainty of revenues to developers. However, with renewables now a mature technology and many older solar and wind farms coming to the end of their subsidy period, renewables have to increasingly cope with 'merchant' risk: fluctuating hourly prices for the electricity they generate.*

## What is the capture price and cannibalisation?

Since renewables do not generate at baseload continuously, but rather fluctuate variably, the price they 'capture' is different from the baseload wholesale price. In the recent past, wind tended to earn more than the baseload price as it generates more in winter when prices are higher on average. Equally solar used to earn more than the baseload price as it generates during the day when prices are higher than at night.

**Exhibit 6.1 – Hourly generation and price in the Netherlands (2040)**

*High renewable output causes dips in wholesale price, leading to low revenues (capture prices) for generators ('cannibalisation')*




However, with increasing solar and wind penetration, both technologies are tending to drive prices down due to 'cannibalisation': where increasing volumes of renewables drives returns down as they tend to generate when prices are low.

## Why is this important?

Although most renewables are currently on subsidy mechanisms including Feed-In Tariffs, many are now coming to the end of their subsidy period. This means that future revenues, rather than being fixed by a government subsidy regime, will now be exposed to fluctuating hourly market prices and hence falling capture prices. This creates a level of market risk that generators have previously not been exposed to.

In addition, new renewables being built may be 'subsidy free' and fully merchant – i.e. their only source of revenue will be the wholesale market price.

The simplistic view of future capture prices assumes that the discount to baseload wholesale price gets greater and greater over time, leading to capture prices steadily falling as more renewables get built. In reality, the interaction is more complicated as falling capture prices lead to less incentive to build.

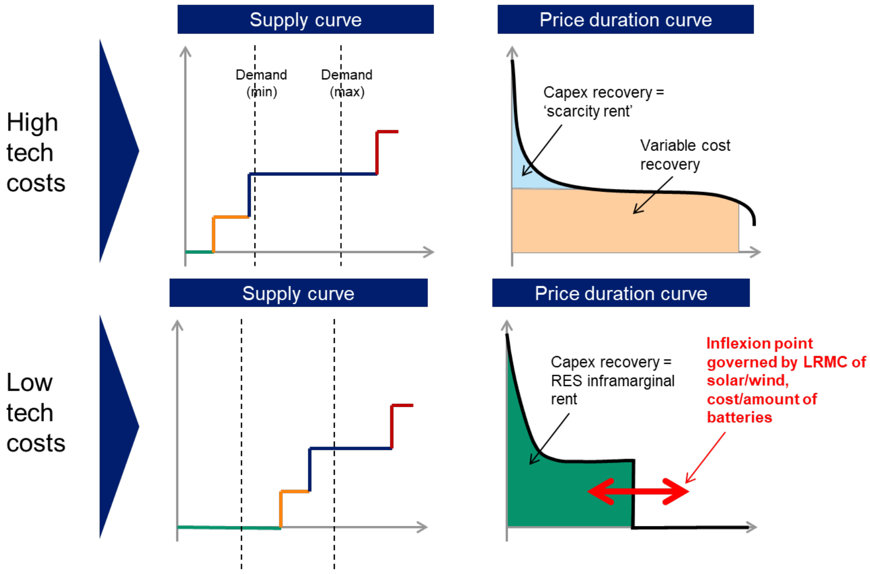
## How supply curves and price duration curves will change

The chart below illustrates how the supply curve and price duration curves may evolve from today's thermal dominated system to one where large amounts of renewables and thermal co-exist, and both are merchant (i.e. built without subsidies).

In a thermal dominated world, prices are set by high variable cost plant – in this example CCGTs in blue. This leads to a price duration curve that is flat, with plenty of variable cost recovery. Capex recovery is provided by peak prices.

**Exhibit 6.2 – Changing shape of supply curves and price duration curves**

*The traditional supply curve and price duration curve will morph into a curve with more zero prices.*



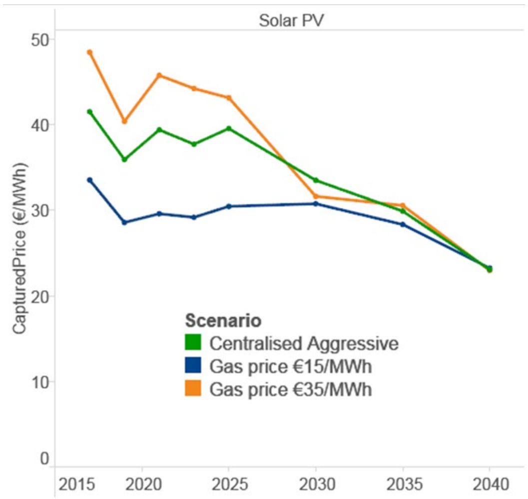

With rapidly falling renewable technology costs, the most profitable new build (the 'marginal new entrant') becomes wind or solar, rather than coal or gas. Since these technologies are uncontrollable and zero variable cost, it creates a very different price dynamic. There are two fundamental price levels – that of thermal plant and that of zero cost renewables. As a result, the capture price moves towards the levelized cost (long run marginal cost) of the new entrant – for example wind or solar.

There is an inflexion point where the price duration curve jumps from high prices (set by thermal plant) to low prices (set by renewables). The location of this inflexion point is governed by the cost of renewables: cheaper renewables will lead to more build, leading to more zero-priced hours and hence less incentive to build. Assuming investors are rational and there are no government subsidies, prices become self-limiting with capture prices stable at the levelised cost of new renewables.

To illustrate this, we have run three different scenarios with widely differing gas prices, at €15/MWh, €25/MWh and €35/MWh. All other assumptions are identical. In France in the early 2020s, high gas prices (in orange) lead to high capture prices for solar plant, and low gas prices lead to low capture prices. However, by 2040 this relationship disappears: high gas prices allow more solar to be built, reducing capture prices; whilst lower gas prices prevent build of solar. As a result, capture prices end up at very similar levels despite widely differing gas prices.

**Exhibit 6.3 – PV capture price in France with varying gas prices**

*Renewables capture prices will be increasingly influenced by the cost of new renewables – and less and less by commodity price movements.*




This is also shown in the price duration curves (all hourly prices stacked from highest to lowest). In the 2020s, high gas prices raise the price duration curve at the top end, whilst there is no impact at the bottom end. But by the 2040s, with large amounts of merchant solar and wind potentially being built, a high gas price leads to higher electricity prices at the top of the price duration curve, but more lower prices set by renewables at the bottom of the curve. Equally a lower gas price outlook leads to less renewables build and hence less low-priced periods.

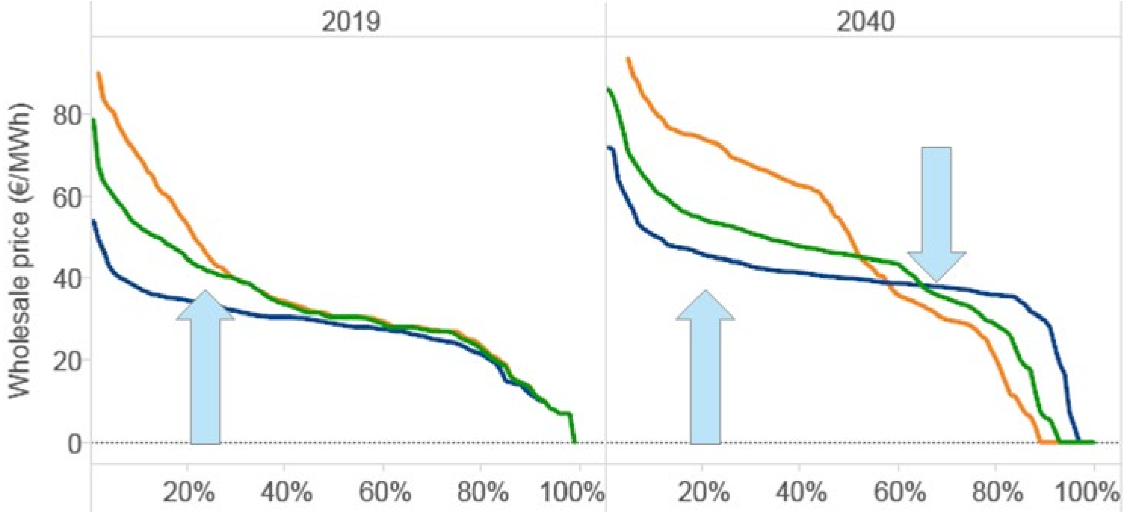
It should be noted that although the capture prices become equal, baseload wholesale prices may still be different, although they will become heavily influenced by the long-run marginal costs of new renewables.

As a result, the future cost of building renewables (the levelised cost) becomes a large factor in future wholesale prices, although this will vary by market: in northern Europe the future cost of wind will be the important driver, whilst in southern Europe the future cost of solar will be key.

Of course, markets do not have perfect foresight of the future. In our modelling we do not simulate the impact of over-investment, bubbles or herd mentality; all of which mean the underlying drivers described here could be overlaid by investment cycles and periods of over- or under-shooting. But nonetheless, the drivers of prices we describe are likely to shape electricity market prices for decades to come.

**Exhibit 6.4 – Price duration curves**

*Increasing gas prices currently increases electricity prices. In the future, it will also act to increase renewable build, acting to 'twist' the price duration curve, and impacting prices less.*



# 7. Price volatility and batteries

*The prevailing wisdom in the energy sector is that rising renewables will lead to substantially increased price volatility. At first blush, this seems reasonable: renewables are highly variable in their output and do not follow demand, which means there can be periods of excess and shortage. In addition, given that their variable cost is zero (or negative if subsidised), this leads to a sudden drop in the electricity price from €30-60/MWh to zero. So, given that rising renewables has the potential to increase the variability in prices, why won't this happen? The answer is simple: batteries.*

## The return of the batteries

Rising renewables results in volatility, right?

Wrong!

Battery technology, in particular Li-ion batteries, make their profit on the spread between prices, so the higher the price volatility, the more money they make. As a result, rising renewables leads to greater battery deployment, which in turn acts to cap price volatility.

In the last 10 years, this effect has not been visible as the cost of storage technologies (including batteries, but also pumped storage, compressed air storage etc.) have been more expensive than the spreads that have resulted from renewable build. However, with the very rapid falls in Li-ion battery costs, we are now at a stage where economic battery deployment can act to cap price volatility.

We have illustrated this by running two scenarios. In the 'Conservative' scenario, where battery costs fall slowly, and an Aggressive technology costs scenario, with more rapid drops in costs of batteries and renewables. In the chart below we show price volatility (measured as the absolute change in hourly price, averaged across the year). In the Conservative scenario, price volatility rises, driven by rising renewables. However in the Aggressive scenario, volatility drops rapidly.

In this case, price volatility is (in effect) set by the long-run cost of batteries. Further reductions in battery costs leads to greater deployment, which in turn flattens prices and prevents additional deployment.

**Exhibit 7.1 – Price volatility – Germany**

*Price volatility drops rapidly in Germany and GB if battery costs continue to decrease.*

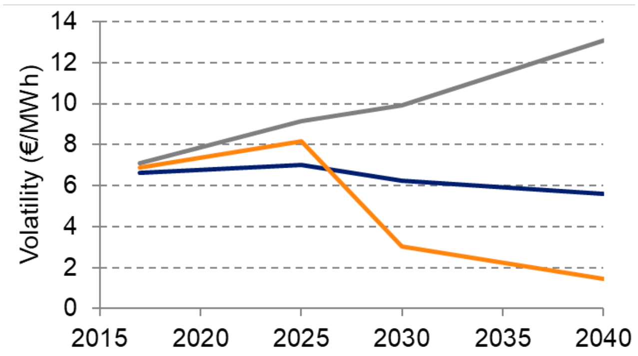
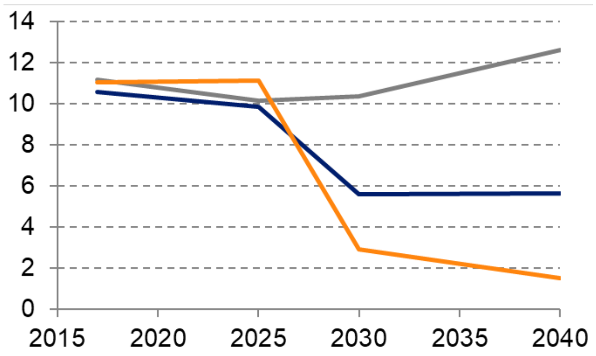



**Exhibit 7.2 – Price volatility – GB**




Notes: Price volatility measured as the standard deviation of the change in price.

## How electric vehicles could disrupt the battery business

Finally, with rapidly growing numbers of electric vehicles, disposing and recycling of old Li-ion batteries will become an issue. One proposed solution is to reuse the batteries in stationary storage – although the batteries are no longer useful in a car due to the loss in storage capacity, stacking them up for grid storage means they can be reused for another 10 years.

So we asked the question: "What happens if electric vehicle batteries are recycled into the power sector?" The answer is dramatic: price volatility drops radically.

In this scenario, we have assumed half of all EV batteries are recycled as storage after 10 years of use. This leads to 193GW of 8-hour batteries being installed across NW Europe, with 60GW in Germany and 30GW in GB.

In this scenario, the value of storage collapses completely, and existing storage projects (whether pumped storage or batteries) rapidly lose most of their value.

So although rising renewables leads to rising volatility, falling battery costs may act as a cap, and the threat from redeployed EV batteries could lead to a dramatic change.

# 8. Conclusions

*The Tipping Points study was a highly detailed study which. for the first time ever, integrated retail market behaviour with the wholesale market. This has allowed us to gain unparalleled insights into the future evolution of the electricity sector in Europe. Given the study covered 10 countries and 15 scenarios, there are a large number of conclusions, in many cases varying by country, so we have highlighted a few important ones below.*

### *The power price is highly influenced by the levelised cost of renewables*

Given the assumption of rapidly falling technology costs in this study, renewables are competitive without subsidies[1] within the next few years, starting with wind in the Nordics and solar in France by the early 2020s. As a result, renewables investment continues until the 'captured price' is less than the LCOE (Levelised Cost of Energy). Where levelised costs fall, renewables investment increases, bringing wholesale prices back down to equilibrium. Equally if commodity prices rise (increasing wholesale prices), renewables investment rises bringing prices back to equilibrium.

As a result, the LCOE of wind and solar (and indeed batteries) has a very strong influence on the wholesale price. In turn, this means that the influence of fossil fuel prices on long-run wholesale prices begins to weaken.

### *RES-on-RES competition is just starting*

All generation on the power system is competing against each other, but the idea that renewables are competing against each other has never been a factor given the relatively low penetration of renewables. However, with rapid falls in technology costs, we see rapid deployment of renewables. This in turn means the main threat to existing renewable investment is new (cheaper) renewables. The new (cheaper) renewable investment lowers returns to existing investors, who may have built with the expectation of higher returns in the long-run. Since renewables are the main source of new build, the amount of 'RES-on-RES' competition will become a key determinant of future returns. In turn, it may harm renewables deployment if future expectations of returns are reduced.

### *Batteries are coming*

For providing peaking capacity, Li-ion batteries could become cheaper than gas turbines (per MW of firm capacity) in the next 10 years. This leads to 5-20GW of build across NW Europe by 2040. However, batteries do not completely replace gas turbines, as periods of tightness become longer than the duration of economic-sized batteries. If tariff reform fails to materialise, and large amounts of rooftop solar emerge, the volume of batteries will increase substantially to manage the increased intermittency.

### *European markets may diverge in prices and generation mix, rather than converge, due to the influence of renewables, tariffs and heating*

Traditionally, market studies tend to see the world converging – a combination of increased interconnection and dominant technologies tend to drive similar outcomes in all European markets. However, in the Tipping Points study, we observe the opposite: differences in solar

[1] Without subsidies in this context means fully merchant – no subsidies, no PPAs and no hidden support costs, such as transmission connections or pre-permitted sites.

irradiation, electricity consumption, tariff charges and space available act to create different investment patterns in different countries. For example, a Norwegian house with electricity consumption of 20MWh and low solar irradiation has very different incentives to a French house with high solar irradiation. Equally differences in retail tariff structures and speed of smart meter deployment all impact which technologies are built.

Finally, northern Europe is generally a lot more windy than the south, so we foresee a general difference with wind in the North and solar in South as the key long-term price setters.

### *Solar ‘behind the meter’ could spur uneconomic build without tariff reform*

Where current retail tariffs are dominated by variable ‘per kWh consumed’ charges to recover grid/policy costs, this means that ‘behind the meter’ solar helps households avoid these charges. As a result, this avoidance of policy and grid charges creates a strong economic incentive to install rooftop solar.

This avoidance of grid/policy cost, or ‘free riding’, could spur 130GW of rooftop solar PV deployment by the early 2020s across Western Europe. Although this is a large amount of capacity, it is often built in the wrong places or where it is not needed, as the signal to build is retail tariff structure, rather than wholesale prices.

### *Variable ‘per kWh’ retail charges can lead to expensive decarbonisation*

Variable charges for grid and policy make distributed solar investments profitable in countries even with low solar resource. In the long term, a ‘per kWh’ retail tariff delivers a very significant amount of solar PV, replacing cheaper wind resource and requiring more than 60GW of batteries to balance the system in NW Europe.

The dual impact of displacing cheaper wind and necessitating the build of gigawatts of grid-scale batteries to balance the solar intermittency mean that high costs are incurred unnecessarily.

### *Retail pricing reform is necessary in most European countries*

Charging for grid and policy support costs on a ‘per household’ or ‘per kW’ basis, or through a dynamic Time of Use tariff would avoid costly distortions in the power market. It would avoid uneconomic build of rooftop solar and in turn avoid costly network and system reinforcements including gigawatts of batteries.

This reform process has started in some countries but must be continued quickly in order to avoid a rapid rise in uneconomic solar capacity.

# Annex A – Modelling approach

*To accurately capture the interactions between the wholesale market and the retail market, the Tipping Points study had to invent a whole new type of electricity market modelling, building on our existing BID3 power market model.*

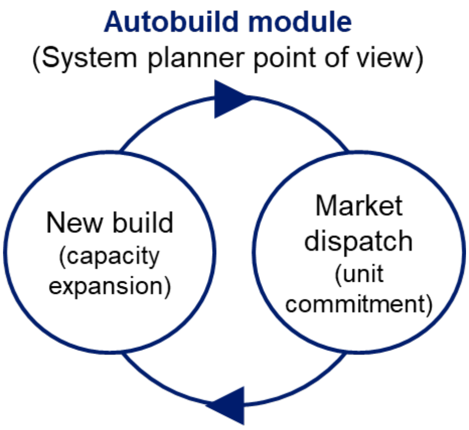
## A1 BID3 modelling framework

Conventional electricity market modelling focuses on the wholesale market: modelling large scale generators and demand, and looking to accurately reflect the dispatch and operation of each unit on the system. In addition, the 'new build' decision on when to build new power stations, and what type to build, also has to be captured.

These interactions are carried out in the **Autobuild module**, which runs a market dispatch as a mathematical optimisation (a linear program) for all hours of the year and all future years to minimise the variable costs of the system (mainly fuel and carbon costs). It then decides on the optimal new build, looking to minimise the capex and opex of the system. Since the new build affects the dispatch, an iteration is then carried out between the market dispatch and the new build using a Benders Decomposition.

**Exhibit A.1 – Autobuild structure**

*Autobuild optimises both the dispatch and new build of plant.*



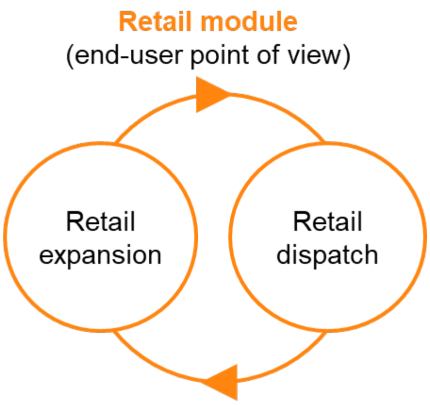

However, for this study, we also needed to capture the retail side of the market, to understand how residential and commercial businesses would interact with the wholesale market. Again, this covers the 'dispatch' and operation of electric vehicles and behind-the-meter batteries: when should these charge and discharge. And again, it also covers the 'new build' decision – this time the decision on when a customer should buy a solar panel or battery.

These interactions are carried out in the **Retail module**. The Retail dispatch minimises the costs to an individual customer (**not** to the entire system), which means that customers will charge their vehicles or operate behind-the-meter batteries to minimise their costs of supply. Since customers do not 'see' the wholesale market price, but rather their own retail tariff, this means they may carry out sub-optimal actions, such as charging their vehicles at peak hours, rather than off-peak, or using their behind-the-meter batteries to maximise their on-site usage of solar (rather than generating when the system is short of power).

For retail customers, their 'new build' decision is whether to buy a solar panel or battery, which is based on the savings on their retail bill. If the savings exceed the cost of purchase, they will buy, subject to meeting a required hurdle rate.

**Exhibit A.2 – Retail module**

*Retail module optimises both the retail dispatch (batteries and EVs) and new build (installation of rooftop solar or batteries).*

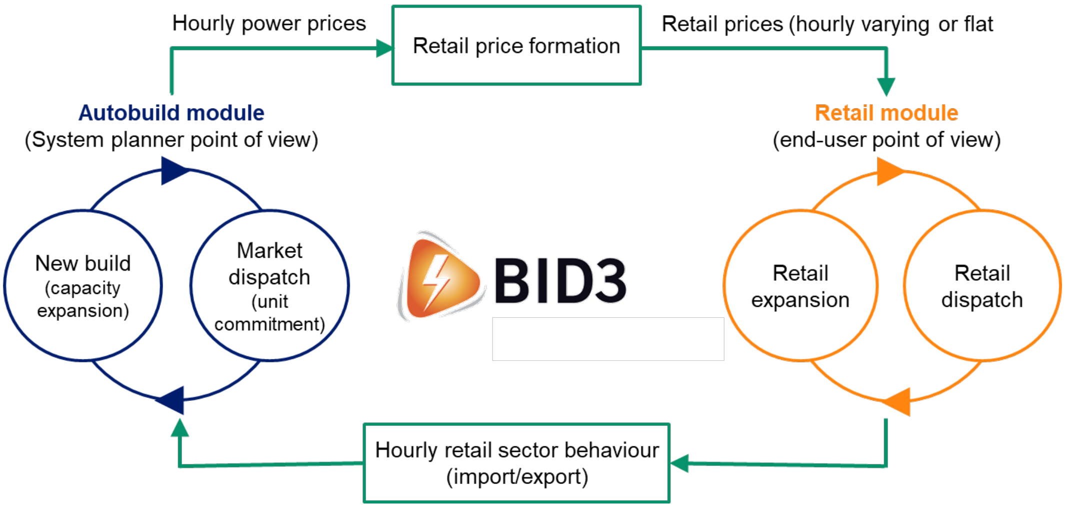



Finally, the two parts of the modelling need to be brought together, as decisions taken at the retail level (for example installing large numbers of rooftop solar panels) impacts decisions taken at the wholesale level (for example building ground mounted solar or batteries). In addition, whether retail prices are flat for the entire year (which is the current situation for most customers) or whether they vary hourly, can also be captured accurately. The variations between flat annual retail tariffs, and hourly varying tariffs, are a key part of the results from this study.

The modelling framework is shown in the diagram below, and illustrates this interaction.

**Exhibit A.3 – Combined Retail and Autobuild modules**

*Combining both the Retail and Autobuild modules together allows modelling of the different interactions and incentives on the system.*




The resulting model is iterated between the Autobuild module and the Retail module until convergence is reached: in other words, both large-scale investments and retail investments all meet their required rates of return.

## A2 Retail expansion – what should a customer buy?

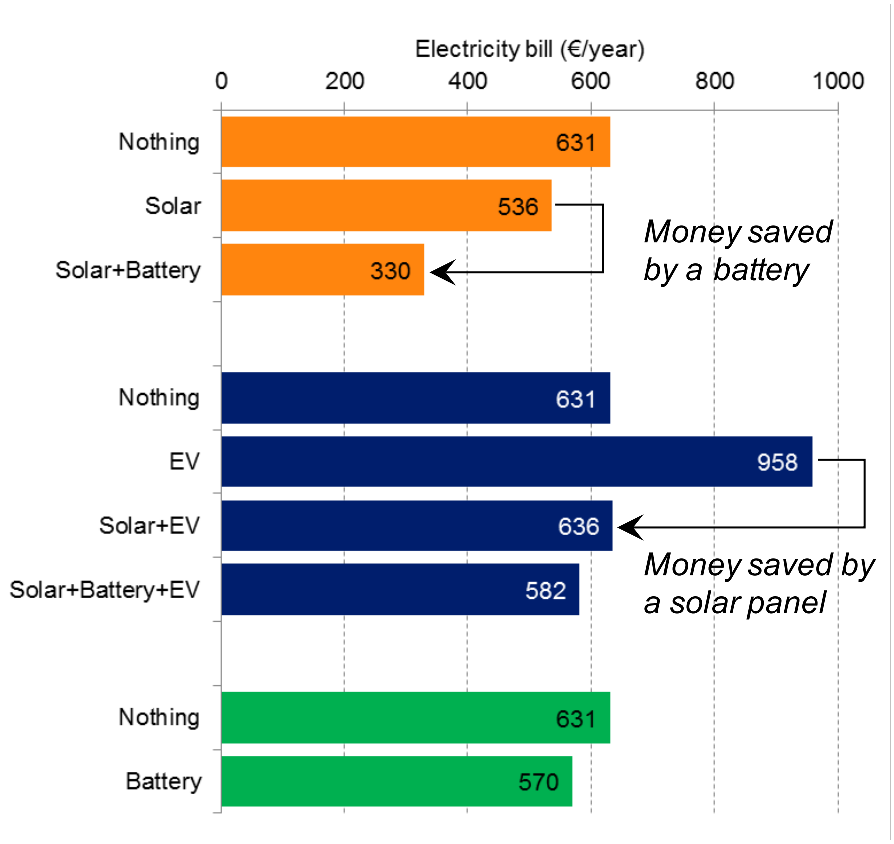
For this study, we assume that retail customers are driven by their desire to save money on their electricity bill, and hence are ‘rational’ players. By installing solar on their rooftops, they can reduce their electricity bill by reducing the amount they buy from their supplier, and potentially earn money by selling electricity back to the system. Also by installing a battery, they may be able to increase their own-consumption and avoid buying electricity at expensive times.

We assume that the decision to buy an electric vehicle is an independent decision and the rate of take-up of EVs is hence an exogenous assumption. We do not try to model this dynamically as it depends on other factors such as petrol and diesel prices which are not trying to capture in this study.

A sample calculation is illustrated below (Germany, 2040), showing how the bill savings vary depending on the starting point (whether a customer has ‘nothing’ or has already bought an electric car), and what they choose to buy.

**Exhibit A.4 – Typical customer bill with varying technologies**

*Savings from installing new technologies vary depending on the choices made.*




Not all customers are the same: some may be keen on new technologies, some may have more or less disposable income etc. To capture this range, we have assumed four customer categories There are four types of customer categories of Early Adopters, Early Majority, Late Majority and Laggards with different required rates of return (between 5% and 30%), giving a range of investment costs.

# Table of Exhibits


Exhibit 1.1 – Reductions in costs of new technologies ........ 4
Exhibit 1.2 – The transformation of the wholesale and retail markets in Central-West Europe. 5
Exhibit 2.1 – Typical retail tariff savings from a solar panel ........ 6
Exhibit 2.2 – Installed capacity from now to 2040 ........ 8
Exhibit 2.3 – Grid scale battery build ........ 8
Exhibit 3.1 – Current tariff structure: share of customers by technology type ........ 11
Exhibit 3.2 –Tariff reform structure: share of customers by technology type ........ 12
Exhibit 4.1 – Hourly generation and demand for wholesale and retail markets ........ 14
Exhibit 4.2 – Current tariffs: hourly generation and prices ........ 15
Exhibit 4.3 – Current tariffs: hourly generation and prices ........ 16
Exhibit 5.1 – German consumption and residential bills with 50% take-up of solar ........ 18
Exhibit 5.2 – GB consumption and residential bills with 50% take-up of solar ........ 18
Exhibit 5.3 – Pan-Europe residential bills with 50% take-up of solar ........ 19
Exhibit 6.1 – Hourly generation and price in the Netherlands (2040) ........ 20
Exhibit 6.2 – Changing shape of supply curves and price duration curves ........ 21
Exhibit 6.3 – PV capture price in France with varying gas prices ........ 22
Exhibit 6.4 – Price duration curves ........ 23
Exhibit 7.1 – Price volatility – Germany ........ 25
Exhibit 7.2 – Price volatility – GB ........ 25
Exhibit A.1 – Autobuild structure ........ 28
Exhibit A.2 – Retail module ........ 29
Exhibit A.3 – Combined Retail and Autobuild modules ........ 29
Exhibit A.4 – Typical customer bill with varying technologies ........ 30

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