INTEGRATE TO ZERO

Identifying opportunities for commercial consumer savings with distributed energy systems

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Executive Summary

Governments across the world are trying to tackle climate change, with 196 countries signed up to the legally binding Paris Agreement to keep global warming well below 2 degrees. Buildings and surface transport accounts for a significant portion of those emissions, and electrification of heating, cooling and transport can help reduce emissions . Distributed energy systems (DES), involving small scale renewables and storage, can complement grid-scale electricity decarbonisation. DES can help cut emissions, increase energy security and can reduce the need to reinforce grids.

DES allow customers to deploy their own energy systems, using equipment such as solar panels, batteries, heat pumps, and electric vehicles (EV). Our report develops case studies to demonstrate where customer-owned DES can save customers money. We look at three commercial customer archetypes: supermarkets, dairy farms, and fast food restaurants, in five countries: Australia, Kenya, Mexico, Spain, and the UK. We find that all of our customer archetypes could save money from converting to owning a DES in each of the countries that we consider. We look at different combinations of DES equipment – solar photovoltaics (PV), battery, heat pump, EV – and we find that any combination saves customers money.

Our analysis of the customer benefits of DES is based on a model that we developed to compare customer costs under centralised energy systems (CES) and customer-owned DES. This model brings together bottom-up estimates of customer demand, calculations of customers' potential own-production of solar electricity, and country-specific prices.

Analysis of our case studies results in the five key findings of this report:

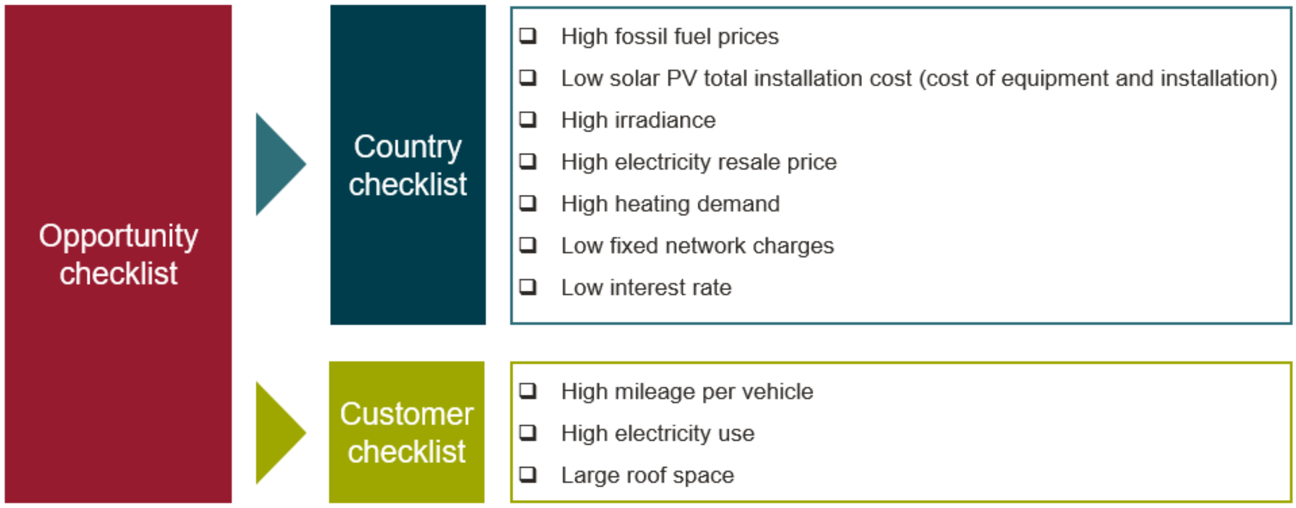
1. DES presents economic opportunity in all the countries and all archetypes that we analysed.
2. All combinations of DES equipment save customers money in these situations. If full DES conversion is considered, the maximum absolute total annualised net savings (TANS) of £56,962 is seen in Mexico and the minimum TANS of £8,306 is seen in Australia (both for dairy farms). In the case of Mexico this means dairy farmers save more than 100% of their costs (i.e. the revenue they earn annually more than covers their total annualised net costs [TANC]) and Australian dairy farmers are saving 25% of their CES TANC.
3. Mexico and Kenya present the largest economic opportunity among countries that we considered. In full DES conversion, the TANS in Mexico are between £18,109 (34% of CES TANC) to £56,962 (more than 100% of CES TANC) across customer archetypes and TANS in Kenya are between £14,348 (24% of CES TANC) to £47,207 (more than 100% of CES TANC).
4. The customer savings associated with choosing an EV rather than an internal combustion engine (ICE) vehicle depend on mileage and the petrol or diesel price. TANS are between £1k-£10k (2-20% of CES TANC) across countries and archetypes.
5. Specific country conditions lead to modest increases in savings from purchasing a heat pump instead of a gas boiler. In Spain and Australia, purchasing a heat pump instead of a boiler have modest increase in TANS up to £2.5k (up to 6% of CES TANC).

Box 1: Report scope

As outlined above, our analysis finds that DES could present significant economic opportunities for customers in some countries and sectors. However our results may underestimate some of the benefits because certain features – behavioural change, bi-directional energy flow, dynamic pricing – were out of scope for this study. These are described in greater detail throughout the main report and annex, but incorporating them into the analysis could increase the savings to customers beyond those found here.

We have summarised our findings in a checklist of country-specific and customer-specific factors that are likely to lead greater customer savings from converting to owned DES. These are outlined in Figure 1 below.

Figure 1 Opportunity checklist



Source: Frontier Economics

1. Introduction

There is a need for rapid action to decarbonise buildings and surface transport

Governments around the world are acting to tackle climate change. Over 70 countries, including China, the United States, the European Union and the UK, have set a net-zero target. The UN estimates this covers about 76% of global emissions[1]. The Paris Agreement saw 196 countries sign a legally binding international treating limiting global warming to well below 2 degrees.[2]

Buildings and surface transport are responsible for a significant proportion of total emissions: the International Energy Agency (IEA) estimates transport accounted for 37% of emissions from end use sectors[3], and that buildings account for 27% of energy sector emissions[4]. The decarbonisation of these sectors will therefore be crucial in meeting international and domestic climate goals.

To be able to achieve these decarbonisation goals, increased electrification of buildings and surface transport will be required, and the electricity sector will need to be decarbonised. In its latest World Economic Outlook, the International Energy Agency (IEA) states that 8 TW of additional capacity of renewable electricity generation capacity is needed each year across the globe in the build up to 2030.[5] However nationally determined contributions (NDCs) for annual additions currently total only at 3.7 TW.[6] As well as needing to generate more zero-carbon electricity, decarbonising buildings and surface transport will increase peak demand on transmission and distribution grids. Current grids around the world may struggle with increased electrification, and may either fail to keep pace or require significant upgrades.

Hence, the scale of emissions from building and transport presents a problem, as well as the lack of renewable generation and grid capacity that would be needed to electrify them. However, distributed energy systems (DES) are currently commercially available and can make a substantial contribution to decarbonising these sectors in the build up to 2030, as well as in the years beyond. DES can do this while reducing both the amount of grid-level renewable generation capacity required and potentially reducing the strain on the electricity grid, by reducing peak demand. What's more, DES have to the potential to bring financial benefits to customers alongside the decarbonisation benefits.

These distributed energy technologies, and the near-term benefits that they can bring to customers, are the focus of our report. While the decarbonisation benefits of these technologies have been explored in depth, our work concentrates on the potential financial benefits to customers and highlights these through illustrative case studies. System benefits – such as balancing benefits – are

[1] https://www.un.org/en/climatechange/net-zero-coalition

[2] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[3] https://www.iea.org/topics/transport

[4] https://www.iea.org/topics/buildings

[5] https://www.iea.org/reports/world-energy-outlook-2022/executive-summary

[6] ibid

out of scope, even though these could potentially represent additional savings.[7] Exploring the other potential non-financial benefits of DES to customers – such as improved reliability – is also outside the scope of our quantitative analysis (see Box 1 for a brief discussion of these potential benefits).

We focus on commercial customers, and distributed energy systems as a near-term solution

This report focuses on changes that commercial customers can make on an individual level, rather than looking into changes on a systems level. We focus on DES, which are defined as any energy system that does not source its energy predominantly from the centralised gas or electricity grids. This in itself represents a broad range of options. For the purpose of our work, we have defined DES to mean commercial customers installing solar PV on their roof, as well as the option to integrate this with other zero-carbon equipment including installing a battery, converting a gas boiler to a heat pump, and exchanging an internal combustion engine (ICE) vehicle for an electric vehicle (EV).

The combination of all of these pieces of equipment are what we refer to as ‘full DES’, though we also look at these changes individually (incrementally to installing solar PV) to consider the benefits of ‘partial DES’.

Importantly, we assume customers are still connected to the grid, which means they produce as much solar electricity as they can, but they can use grid electricity to make up any shortfalls and provide emergency protection in case their equipment fails. This avoids the need to overbuild capacity as a back-up, which can be costly, but customers continue to bear the bill impacts of staying connected to the grid. It also creates an opportunity for customers to earn revenue by generating more electricity than they need and selling the surplus back into the grid.

We develop illustrative case studies to demonstrate the potential financial benefits of DES

The purpose of this report is to demonstrate the potential opportunity of DES in terms of saving customers money. We do this through developing a series of case studies that focus on three commercial customer archetypes in five countries. These customers and countries have been deliberately chosen to demonstrate the potential benefits of DES, that is, we have focussed on the countries and customer types with high potential.

We focus on industries related to the food sector, as electrification could lead to significant carbon benefits for these industries, and they generally present opportunities for electrification given low-temperature heat requirements, which are relatively easy to electrify.[8] We therefore take three customers from different parts of the chain in that sector: a supermarket, a fast food restaurant, and a dairy farm. Further details on the selection process for our customer archetypes is in Annex B.

In terms of our country selection, we wanted to be able to present a range of countries in terms of geographic location and stage of development, to be able to show the variety and diversity of

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[7] Catapult (2022), *Location, location, location : Reforming wholesale electricity markers to meet Net Zero.*

[8] Climact (2022), *Opportunities to get EU industry off natural gas quickly.*

situations where DES can show benefits. Given again that these countries are meant to show the potential benefits of DES, there are similarities between these countries such as relatively high fossil fuel prices. The list of selected countries is: Australia, Kenya, Mexico, Spain and the UK. More information on our country selection process is in Annex B

We use these case studies to pull together key findings

We present the full results of the case studies in Annexes C to E. In the main report, we focus on the five key findings from our work, on where DES presents economic benefits.

To do this we look at the overall picture, as well as taking a separate lens to look at the country characteristics, customer characteristics, and combinations of owning DES equipment that we find increase the relative savings from DES.

The majority of the results in our key findings and annexes are found using our base case assumptions. These are outlined in Annex A. However, throughout the report, we also include sections where we change some of these assumptions individually, and present the findings. We call these ‘what if’ boxes, as each one looks at the impact on results if a single element were changed. These are helpful in exploring the potential impact of policy or philanthropy, however they are not necessarily recommendations for future changes. As these are merely demonstrations of possible effects, we do not explore impacts in every country and on every customer archetype.

Box 2 : Reliability benefits

As explained above, the focus of this report is looking at the financial benefits to customers, in terms of cost savings. Alongside the environmental effects of decarbonisation, there could be other non-financial benefits to customers from switching to DES, including air quality benefits and increases in the reliability of customers’ electricity supply. This is because customers are still connected to the grid. Therefore if their own DES equipment fails, or their store of renewable energy is insufficient, they can automatically use electricity from the grid. If the grid fails, then customers are likely to be able to use their own electricity, either directly from solar PV if during the day, or from their battery if at night. So to experience a break in power there would need to be simultaneous failures in both their own DES system and the wider electricity grid, which is less likely than a failure in grid electricity alone.

However this additional reliability benefit is not likely to be equally spread across countries. Countries such as Australia, Spain and the UK have reliability targets above 99.99% for grid electricity that are generally met, meaning average loss of power for around 30 minutes in a year. Therefore additional reliability benefits for customers in these countries installing DES equipment are likely to be small. However grid reliability is much worse in Mexico,[9] and in Kenya 23% of people said that their grid connection did not work half the time.[10] Therefore the additional reliability benefits to customers in these countries is likely to be significantly higher. We have not attempted to monetise the benefits of reliability as they are likely to vary considerably.

[9] https://mexicobusiness.news/energy/news/mexico-takes-step-toward-grid-stability100-percent-renewables

[10] https://www.brookings.edu/blog/africa-in-focus/2019/12/12/figure-of-the-week-progress-toward-reliable-energy-access-in-africa/

2. Key Findings

We present our results using two different metrics

We look at the benefits of DES in this report by comparing investment and use of DES technologies to a counterfactual world where customers continue to rely on a centralised electricity system (CES). We assume that in the counterfactual CES world, the customer's current equipment has come to the end of its life, and needs replacing. Therefore we are comparing the upfront and running costs of purchasing new DES equipment (heat pump, EV, solar PV, battery) with the upfront and running costs of replacing old CES equipment (gas boiler, air conditioner, ICE vehicle) with new CES equipment. Instead of focussing on the variable payment stream of customers, which would vary each year, we look at two different measures to understand whether customers save money overall in the DES or CES worlds by looking at average costs.

These two measures are total annualised net savings (TANS) and the payback period, with their definitions in Figure 2 and TANS looks at the total level of savings customers receive over the lifetime of the equipment, from purchasing DES equipment instead of CES equipment, taking into account the time value of money (i.e. interest rates). This is then evenly distributed over the lifetime of the equipment, so it is presented as annual savings. Nominal interest rates are used because the model and its results are all in nominal terms.

Figure 3 respectively.

Figure 2 Definition of total annualised net costs and savings (TANC and TANS)

Total annualised net savings (TANS) for a given snapshot year

Total net costs are absolute costs and are presented for a given year. These represent the average costs customers will be paying over the lifetime of the equipment. These costs take into account:

- The upfront capex from purchasing equipment and installation cost,
- Maintenance costs,
- Fuel costs, and
- Any customer revenues from selling back to the grid.

Most of these costs are annual, but the upfront capex only occurs in one year. To make sure upfront capex is captured in our results, we split out the upfront capex evenly over the lifetime of the equipment, using the interest rate as a country-specific discount rate, meaning financing costs are included.

TANC are absolute costs and can be calculated in the CES and DES worlds. TANS represents the savings from DES,

i.e. TANS = CES TANC – DES TANC.

Source: Frontier Economics

TANS looks at the total level of savings customers receive over the lifetime of the equipment, from purchasing DES equipment instead of CES equipment, taking into account the time value of money (i.e. interest rates). This is then evenly distributed over the lifetime of the equipment, so it is presented as annual savings. Nominal interest rates are used because the model and its results are all in nominal terms.[11]

Figure 3 Definition of payback period

Payback period
Generally DES equipment involves higher upfront costs than CES equipment, but leads to annual savings on maintenance and fuel. The payback period is an accounting concept and looks at the amount of time it takes to recover an investment. In this case how many years a customer would need to own a piece of DES equipment before the annual savings (compared to CES) had 'paid back' the greater upfront costs compared to the equivalent piece of CES equipment. It is not a measure of how quickly someone pays back a loan in real life, because it is assumed that the equipment is bought upfront rather than taking out a loan. Therefore, in line with accounting practice, no discounting or interest rates are taken into account.

Source: Frontier Economics
Note: Definition of payback period comes from here.

The payback period measures the amount of time it would take to recover an investment. For example, if a customer bought an EV that was £1,000 more expensive than the equivalent ICE vehicle, but they saved £500 a year in ongoing costs – fuel and maintenance – then their payback period would be 2 years.

Generally we would expect these two measure to move in the same direction, however we present both because that is not always the case, given that the TANS measure factors in financing costs, while the payback period does not.

We have five key findings

Using these measures of benefits, we have five key findings in this report, and look at each in turn in the following sections. They are:

- Finding 1: DES present economic opportunities in all countries and all archetypes that we analysed
- Finding 2: All combinations of DES equipment save customers money

[11] Assuming constant O&M costs in nominal terms is effectively assuming that average efficiency gains are the same in for both CES and DES, and that this is equal to the rate of inflation. This is a slightly conservative assumption for DES, as it is likely that efficiency gains for newer technologies would be greater than for older technologies.

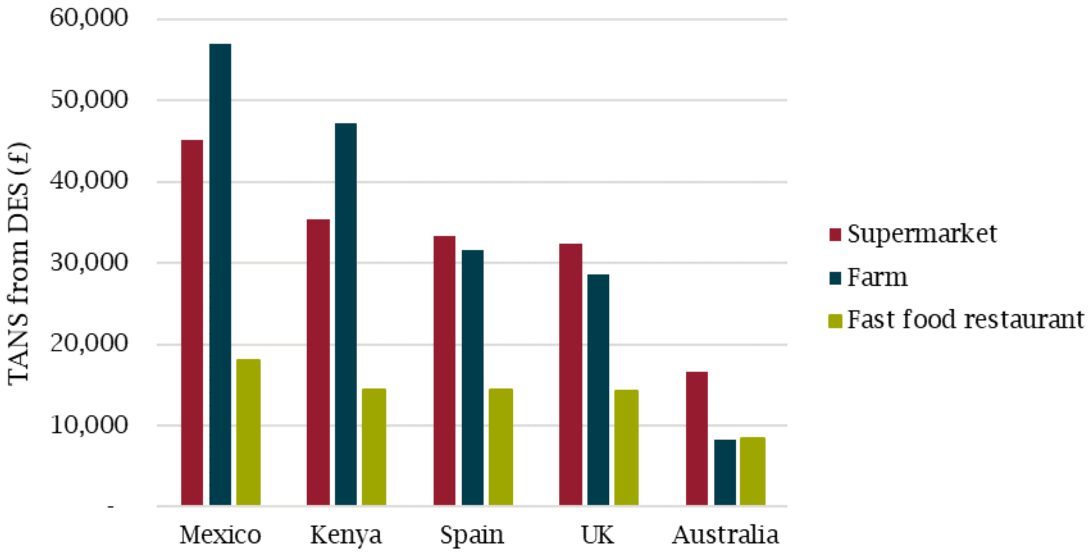
- Finding 3: Mexico presents the highest economic opportunity of the countries we considered
- Finding 4: Purchasing an EV leads to customer TANS compared to purchasing an ICE, with the extent of the TANS depending on mileage and transport fuel prices
- Finding 5: Specific country conditions lead to modest increases in TANS from purchasing a heat pump instead of a gas boiler

Finding 1: DES present economic opportunities in all countries and all archetypes analysed

Converting from CES to DES leads to TANS in each of the five countries we analysed and for each of the three customer archetypes we were looking at.

Figure 4 below shows TANS for customers that fully convert to DES. 'Fully converting' to DES means that customers purchase and install solar PV and a battery as well as converting their fossil fuel equipment to a heat pump and an EV. This chart shows that for all customer types and countries that we looked at, customers gain TANS from fully converting to DES.

Figure 4 TANS for customers that fully convert to DES



Source: Frontier Economics

Note: The minimum lifetime of an equipment in our model which is 14 years. For some equipment this can go up to 25 years.

The figure above looks at TANS from full DES conversion, however, this may not necessarily be the optimum combination of equipment. Table 1 below looks at the payback period of customers in different countries who fully convert to DES, and demonstrates that across all countries and customers, the upfront cost of fully converting to DES will be 'paid back' to customers in terms of annual savings within 3-9 years.

Table 1 Payback period for customers who fully convert to DES

	Supermarket	Dairy farm	Fast food restaurant
Mexico	4	3	4
Kenya	3	3	4
Spain	6	6	6
UK	7	7	6
Australia	8	9	7

Source: Frontier Economics

Note: The payback period can be compared to the minimum lifetime of an equipment in our model which is 14 years. However, the lifetime of equipment used in our analysis varies between 14-25 years.

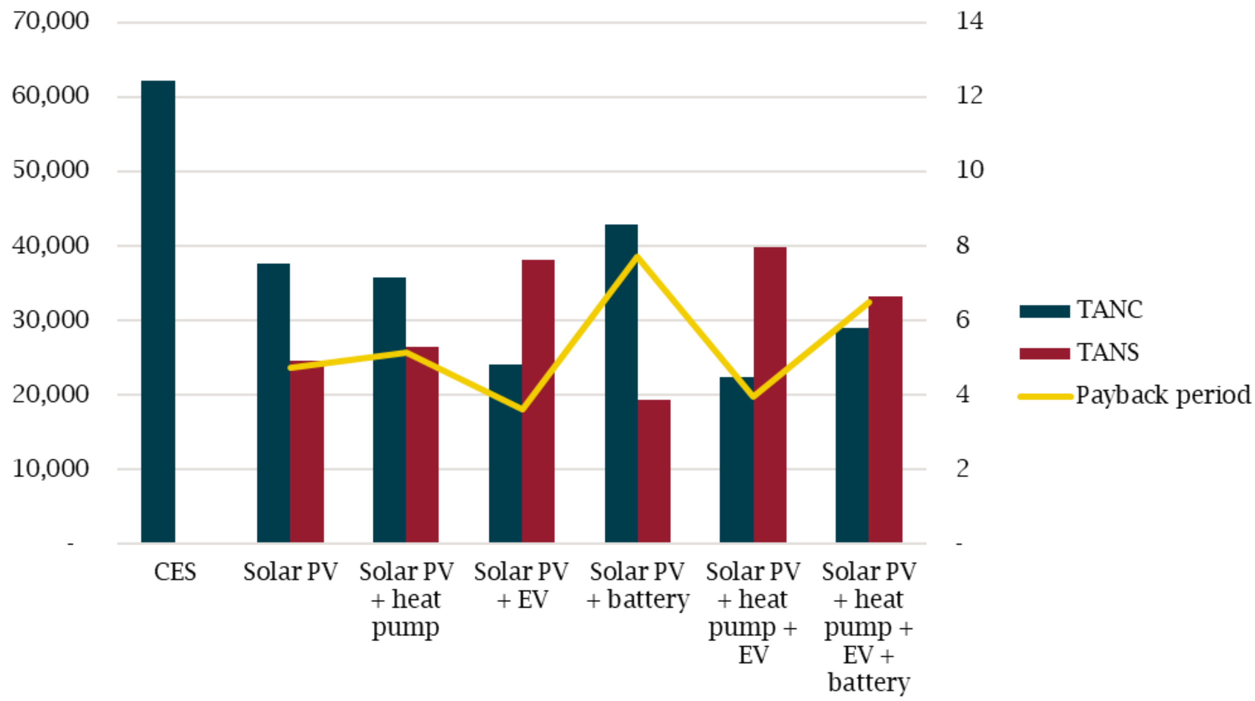
There is variation across countries and archetypes, which will be explored in later findings and in Annexes C to E.

Finding 2: All combinations of DES equipment save customers money in our case studies

Customers in our case studies can gain TANS from converting any amount of DES equipment – i.e. from just getting solar PV to installing heat pumps, EVs and batteries. We also find that greater savings can be generated when optimising the combination of DES equipment to a given archetype for a specific country.

For each country, our model produces a chart that looks at the incremental total annualised net costs (TANC) (see Figure 2 for the definition) of converting additional pieces of equipment from CES to DES for a given country and customer archetype. As explained in the definition of TANC, TANC includes both the costs customers pay and any revenues that they generate from selling surplus electricity back to the grid. Figure 5 below shows an example for supermarkets in Spain. The payback period is also shown on the chart by the yellow line. This shows that under our assumptions any combination of DES equipment has lower TANC than CES for supermarkets in Spain. Further, it can be seen that TANS is positive in all combinations of DES. The highest TANS of £39,884 and lowest TANC of £22,335 is seen in the scenario with Solar PV + Heat pump + EV.

Figure 5 Incremental analysis for supermarkets in Spain



Source: Frontier Economics

Note: The minimum lifetime of an equipment in our model which is 14 years. For some equipment this can go up to 25 years. The coloured bars use the left-hand axis and the yellow line measures the payback period on the right-hand axis.

The same finding remains when looking at any country and archetype in our selection – see more details in Annexes C to E of this report. The payback period shows that for supermarkets in Spain, annual savings are high enough for customers to be 'paid back' for their upfront capex within 4-8 years.

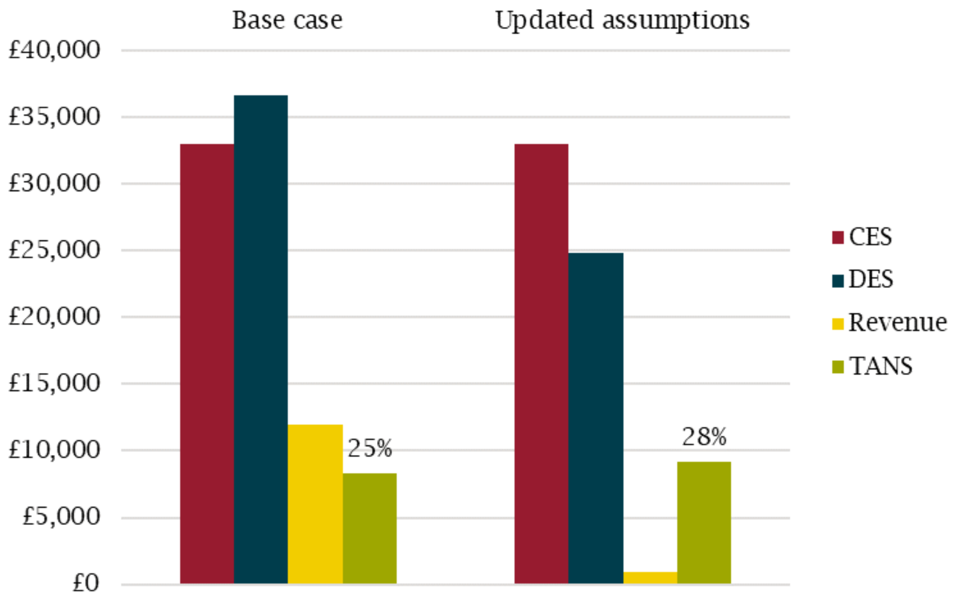
In the case of supermarkets in Spain, the lowest TANC combination of equipment is when customers have solar panels, a heat pump, and an EV. This is driven by factors described in more detail in findings four and five below, but the increased efficiency of EVs and the heating demand in Spain play a significant role. However the chart demonstrates that customer savings are possible without a full customer-specific optimisation, because all DES combinations lead to lower TANC than CES, and therefore trying to find the optimum combination of DES for a given customer shouldn't prevent customers switching to *some* combination of DES, given that all combinations will save them money.

While our model looks at different combinations of DES equipment, it does not generally look at different sizing of DES equipment. The size of the battery, heat pump, and EV is fixed at the smallest size required to fit the individual customer's needs. However, for solar PV we assume that customers install as many panels as they can fit on their roof. In other words, installed capacity of the DES equipment is not optimised. In the 'what if' box below, we explore one example of customers varying the amount of solar PV they install – dairy farms in Australia. This shows that optimisation could lead to additional DES benefits.

Box 3: 'What if' dairy farms installed less solar PV?

Changing our base case assumptions to assume dairy farms install less solar PV leads to modest increases in TANS from DES in Australia.

Figure 6 Comparison of DES TANS in Australia using 30% roof space for PVs



Source: Frontier Economics

As can be seen in more detail in Annex E, our modelling assumptions have dairy farms produce significant surplus electricity. Installing excessive solar PV – in terms of own-demand - may not be the most profitable course of action for dairy farms in all countries. In Kenya and Mexico, where solar PV is cheap and the electricity resale price is high, this may be a sensible decision. However in countries such as Australia, where DES revenues are low and capex costs are greater, it may increase TANS for them to install only the amount of solar PV they need to cover their own demand, rather than installing more to generate a surplus.

We therefore change our assumption on solar capacity here, such that solar PV is only installed on 30% of roof space in Australia rather than 80% – reflected in Figure 6. This reduces both costs and revenues for DES, but reduces costs by more meaning there is an increase in TANS.

This strategy reduces upfront capex by more than £77,000. It also reduces DES revenues by £11,000, because the farm does not have the same surpluses to sell back to the grid. This is overall a net benefit to dairy farms in Australia, reducing their TANS and speeds up the payback period from 10 to less than 8 years.

Finding 3: Mexico and Kenya are the most promising of the countries we considered

Mexico and Kenya both have the lowest payback periods from converting to DES for all the archetypes we look at. Table 2 below looks at the payback period for an example archetype: fast food restaurants, across each country and possible combination of DES equipment analysed. Results are that Mexico and Kenya have the fastest payback periods (between two and four years) followed by Spain, and then payback periods are slower in Australia and the UK (four to eight years).

Table 2 Payback period for fast food restaurants for different DES equipment

Country	PV	PV + heat pump	PV + EV	PV + battery	PV + heat pump + EV	Full DES
Mexico	**2**	**2**	**2**	**4**	**4**	**4**
Kenya	**2**	**2**	**2**	**4**	**4**	**4**
Spain	4	4	4	7	4	6
UK	5	6	4	6	5	6
Australia	4	5	4	8	5	7

Source: Frontier Economics

Note: Mexico and Kenya are highlighted in bold as the most promising countries. As customers in Kenya and Mexico would not typically install heating equipment due to the weather in those countries, the results that include a heat pump are replaced by the same combination without a heat pump. For example, the results for PV + heat pump are the same as the results for solar PV.

There are three main drivers behind this result:

1. **High irradiance** in Mexico and Kenya means customers are able to generate a lot of electricity with their solar panels, reducing the levelised cost of electricity (£/kWh) generated by increasing the quantity of electricity produced (kWh).
2. **Low total installation costs for solar PV** reduces levelised cost again. Both Mexico and Kenya have relatively low upfront total installation costs compared to the other countries we consider.
3. **High electricity resale price** means the revenue customers in Mexico and Kenya generate with surplus energy is higher than in the other countries.

Spain presents the next best opportunity as the irradiance is high and electricity resale price is high compared to the grid electricity price. However upfront total installation costs for solar PV are higher in Spain than Mexico and Kenya.

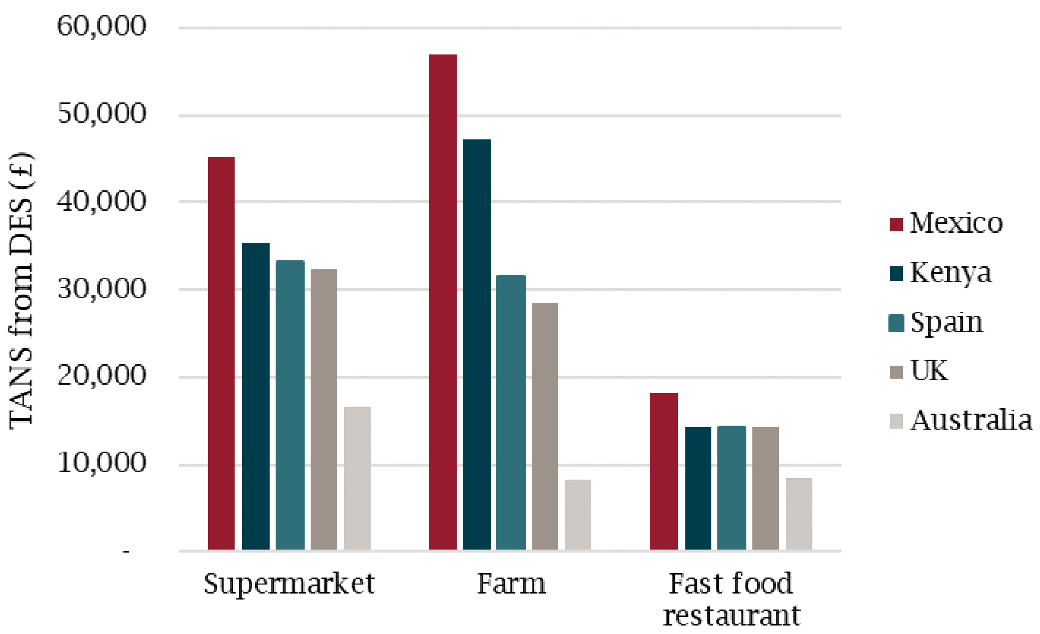
Compared to Mexico, Kenya and Spain, the payback period is slower in the UK. This is because there is lower irradiance, so for some archetypes own-production does not cover demand. However our analysis finds that upfront DES costs are still paid back within 7 years.

While Australia has high irradiance and inexpensive solar PV, the fixed cost for being connected to the grid is high at £50/kW. Hence DES customers still connected to the grid have to pay a high annual cost, increasing their costs and slowing down the payback period.

Kenya has the highest commercial interest rates among the countries that we consider. Interest rates impact TANS but do not affect the payback period. This means that when looking at TANS as a measure of savings, Kenya performs less well than Mexico, because the higher interest rate means that the annualised costs of the upfront capex and installation is greater. The effect of interest rates is explored in greater detail in the 'what if' box at the end of this section.

Figure 7 shows for each customer archetype we look at, customers gain the greatest TANS from fully converting to DES in Mexico, and savings in Kenya are lower. This pattern continues for all other combinations of DES equipment.

Figure 7 TANS for customers converting to full DES



Source: Frontier Economics

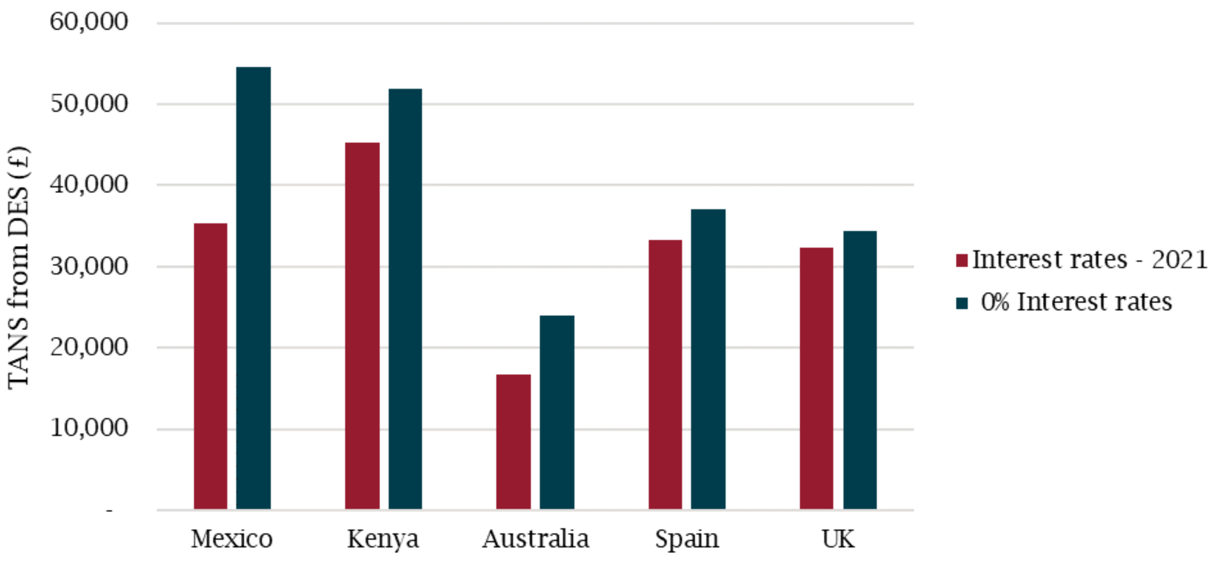
Box 4: 'What if' interest rates were 0%?

If interest rates were 0%, DES becomes more promising across all countries and archetypes, but we see the biggest change in Kenya.

When reducing interest rates to 0%, we see an increase in TANS in all countries and across all archetypes. Interest rates affect CES TANC and DES TANC, but the higher upfront costs of DES mean DES TANC are affected to a greater degree. This means countries with higher interest rates will see a more drastic increase in TANS from DES when we reduce interest rates to 0%. Figure 8 shows the impact of reducing interest rates to 0% on TANS for supermarkets.

As expected, it dramatically improves TANS in Kenya, such that Kenya becomes the most promising country. A lower but significant increase in TANS from DES is seen for Mexico and Australia, as their interest rates are 4.9% and 4.3% respectively. Low interest rate countries, Spain and the UK, see the least change.[12]

Figure 8 Comparison of TANS for supermarkets with different interest rates



Source: Frontier Economics

We see similar patterns across dairy farms and fast food restaurants, but they are not presented here.

[12] Data is taken form December 2021.

Finding 4: Purchasing an EV leads to customer TANS compared to purchasing an ICE vehicle, with the extent of the savings depending on mileage and transport fuel price

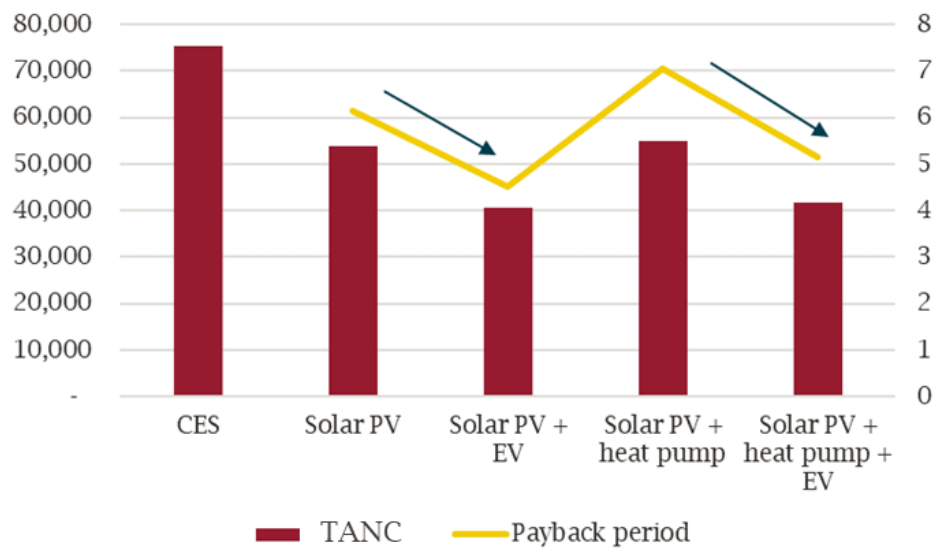
Mileage is the most important factor determining whether customers benefit from purchasing an EV instead of an ICE vehicle, followed by the price of the relevant transport fuel.

We assume that the upfront costs of purchasing an EV are higher than the upfront costs of purchasing an ICE vehicle. But converting to an EV allows customers to avoid (potentially high) transport fuel costs, and increases the efficiency of their vehicles. Two conditions determine whether these positive effects outweigh the upfront capex and purchasing an EV instead of an ICE vehicle leads to TANS:

1. If customers have **high mileage**, purchasing an EV instead of an ICE vehicle leads to TANS.
2. If mileage is lower but **transport fuel prices are high**, customers will experience a decrease in TANC from purchasing an EV instead of an ICE vehicle.

As an example, Figure 9 below shows customer savings from purchasing an EV instead of an ICE. In the case of supermarkets in the UK, TANC reduces by over £10,000 a year (20% of CES TANC), and the payback period speeds up by about two years compared to the equivalent combination without an EV. This pattern continues across countries – as can be seen in Annexes C to E. The reason for the significant and consistent reductions in TANC for supermarkets is because supermarkets have high mileage per vehicle.

Figure 9 TANC for supermarkets in the UK for different DES equipment



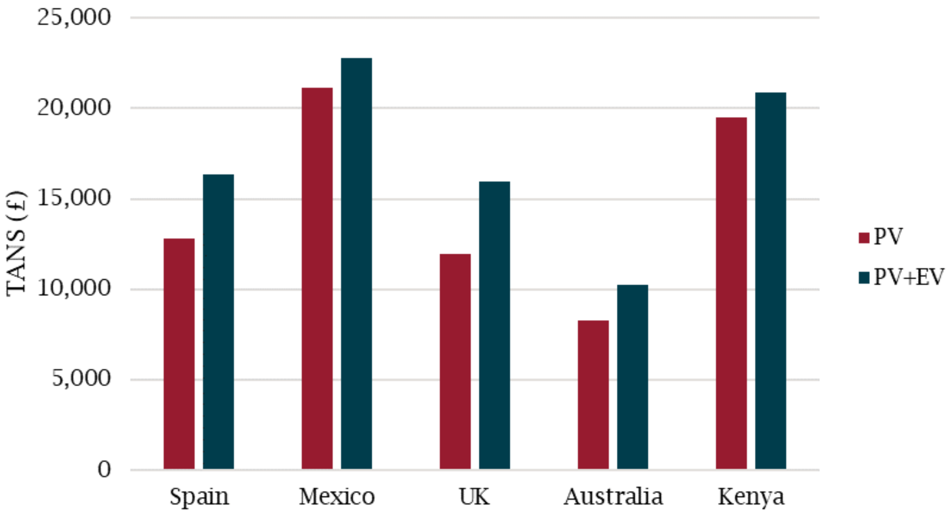
Source: Frontier Economics

Note: The TANC – once any customer revenues have been taken into account – for all combinations of DES equipment are represented by the red bars. This includes the possibility of no DES equipment – i.e. CES – on the far left. The payback period for each combination of DES equipment – compared to the CES world – is represented by the yellow line.

The second column in the chart above shows a customer's TANC if the only DES equipment they purchased was solar PV, but they also purchase an ICE vehicle and a gas boiler alongside. The third column shows a customer's TANC if the DES equipment a customer purchases is solar PV and an EV, and then they purchase a gas boiler alongside. Hence the difference in TANC between these two columns demonstrates the customer TANS from purchasing an EV instead of an ICE vehicle. The same principle applies when comparing customer TANC in the fourth and fifth column.

Customers also experience savings when purchasing EVs instead of ICE vehicles in the case of fast food restaurants, because they too have relatively high mileage per vehicle. However their mileage is lower than that of supermarkets, and therefore their TANS are also lower. Customers could expect TANS of £1,000-4,000 (2-7% of CES TANC) depending on the country, as seen in Figure 10.

Figure 10 TANS for fast food restaurants who purchasing an EV instead of an ICE vehicle in addition to installing solar panels



Source: Frontier Economics

Note: The TANS for 2 combinations of DES equipment are represented – In red we look at DES when only Solar PVs are installed while in blue we have a DES world with Solar PVs and EVs. It can be seen that for all countries, adding EVs increase TANS for fast food restaurants.

Where mileage is lower, TANS are gained in some countries but not all of them. Dairy farms have lower mileage per vehicle than supermarkets and fast food restaurants. This means that purchasing an EV instead of an ICE vehicle also shows benefits for dairy farms in Australia, Spain and the UK, but not Kenya and Mexico.

This is because high retail petrol and diesel prices in Australia, Spain and the UK mean that the fuel savings outweigh the increased upfront capex from purchasing an EV tractor compared to an ICE tractor, and hence TANC declines. Hence also because retail petrol and diesel prices are low in Kenya and Mexico, dairy farms do not experience an increase in TANS from purchasing an EV instead of an ICE tractor, compared to the TANS they receive from just installing solar PV.

These results are driven by the fuel price assumptions that we have used. We explore the impact of changing these assumptions in the following 'what if' box.

Box 5: 'What if' current fuel prices persist?

Changing our base case assumptions to assume current prices and interest rates persist affect DES TANS in opposite directions. The overall effect differs across archetypes.

In our base case, we assume the current energy crisis and wider economic issues do not persist over the 15-25 year lifetimes of the DES assets. Current (late 2022) parameters are affected by the fact that:

- *Europe is in an energy crisis since the Russia-Ukraine war.*
- *Supply chain issues have increased DES appliance costs.*
- *Many countries are experiencing higher interest rates than they have in decades.*

Our analysis looks over the lifetime of DES assets, which can be 15-25 years. In the base case, we aim to use prices that could be realistic over that horizon. Instead of using the higher prices from late 2022, we have used December 2021 fuel prices for our base analysis,[13] as well as December 2021 interest rates, and a range of total installation costs from 2020-2022 (depending on data availability).

However, we also look at the effects of current prices and interest data on our model. Updating price assumptions to use current data (reflecting the energy, supply chain and interest rate effects) has a number of effects that work in opposite directions:

- *Updating fossil fuel prices increases CES TANC, and therefore DES TANS.*
- *Updating the total installation costs of CES and DES equipment increases the price of both, but reduces DES TANS overall as prices of DES equipment increase by more than prices of CES equipment.[14]*
- *Updating the interest rate, increases annualised capex for both CES and DES, but more for DES because upfront costs are higher, reducing DES TANS.*

The dominating effect differs across archetypes. Figure 11 *compares the base case and updated values for DES TANS in the UK. The following effects can be seen:*

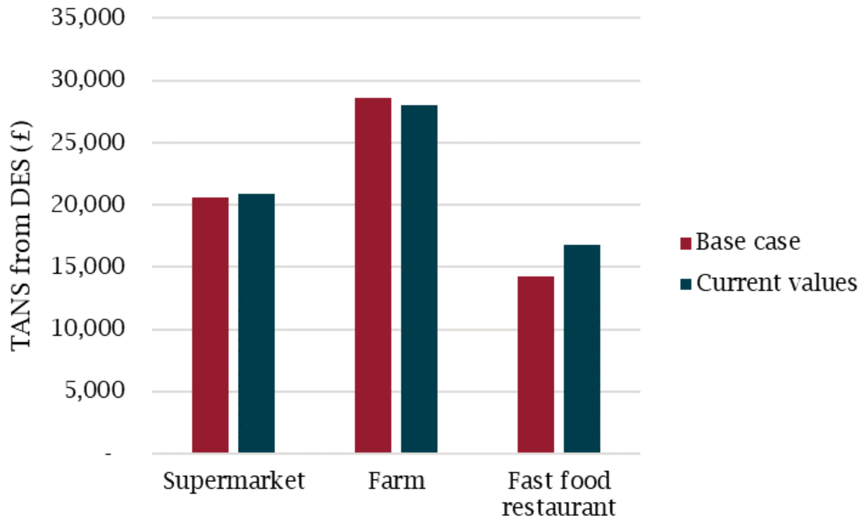
- *For supermarkets, increase in price of fossil fuels outweighs increase in total installation costs and interest rates resulting in higher TANS.*
- *For farms, energy demand is low, hence total installation costs and interest rates effect dominate, resulting in lower TANS.*

For fast food restaurants, increase in fossil fuel prices dominate because restaurants buy such a significant amount of electricity from the grid in the CES world.

[13] Fuel prices have not historically moved with inflation, and justifies assuming a constant fuel price in nominal terms.

[14] The sector is exposed to supply chain issues given 90% of solar PV panels made in China. Guardian (2022), *Solar panels: how to fix your energy bills while the sun shines.*

Figure 11 Comparing TANS for DES in the UK with different prices assumptions



Source: Frontier Economics

Note: We compare TANS from DES using base case assumptions of energy prices, interest rates and CAPEX in the UK - seen in red - with current values (September 2022) in blue.

Finding 5: Specific country conditions lead to modest increases in TANS from purchasing a heat pump instead of a gas boiler

For customers to experience any benefit from a heat pump, they need to have a reasonable heat demand[15] and to be able to cover a lot of that demand with own-production.

A heat pump can lead to increase in TANS for customers. However, two conditions need to be met, and these tend to be country-specific:

1. Customers must have a reasonable heating demand. Heating demand is so low (on average) in Kenya and Mexico that they are unlikely to have heating equipment in either the CES or DES world. It would therefore not make sense for them to install a heat pump.
2. Customers must be able to cover a high proportion of demand by own-production. If expensive grid electricity is used to make up the shortfall, this can be more expensive than powering 100% of heat through natural gas.

Out of the countries we consider, these conditions can only be found for Australia and Spain, as customers in Kenya and Mexico would not have heating equipment and the UK has low irradiance, meaning own-production is lower. Low irradiance in the UK, combined with a large differential

[15] Differences in heat demand for each country is determined by the number of heating degree days (definition: here), which can then be converted into a measure of heat demand per metre squared (kWh/m^2). Kenya and Mexico's heat demand is 2kWh/m^2 and 17kWh/m^2 respectively, which is not enough to justify heating equipment. Heating demand in Spain is 63kWh/m^2, in Australia is 83kWh/m^2 and in the UK is 94kWh/m^2.

between retail electricity and gas prices, means that taking some electricity from the grid outweighs the benefit from reducing total fuel demand.

Table 3 shows that modest TANS of £2,000-3,000 a year (up to 6% of CES TANC) can be made for supermarkets in Australia and Spain if they purchase a heat pump instead of a gas boiler. This pattern continues across all customers where the TANS range between £0.5k and £0.6k (roughly 1% of CES TANC) for fast food restaurants, and £0.5k and £0.9k for dairy farms (1-3% of CES TANC).

Table 3 TANC for supermarkets in Australia and Spain

		Solar PV	Solar PV + EV
Australia	No heat pump	£50k	£41k
	With heat pump	£47k	£39k
Spain	No heat pump	£38k	£24k
	With heat pump	£36k	£22k

Source: Frontier Economics

Note: This table compares TANC for supermarkets in Australia and Spain for 2 combinations of DES equipment – solar PV only and solar PV + EV – when there is no heat pump and when a heat pump is added to the current combination of DES equipment.

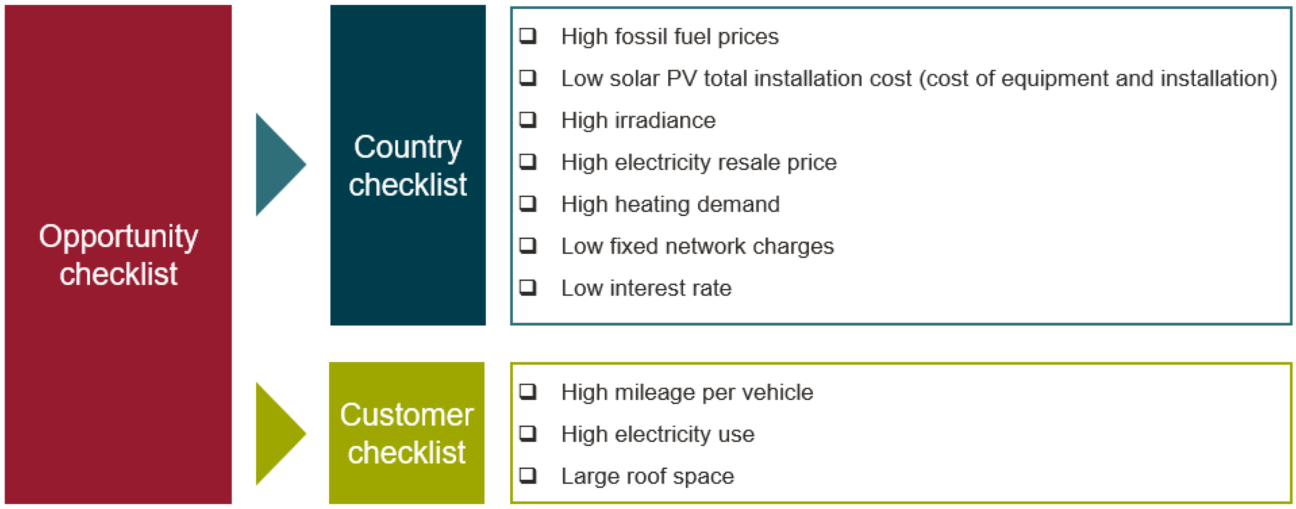
Our analysis in terms of heating degree days has been at the country level, meaning we have excluded all of Kenya and Mexico for the heat pump analysis. However it is possible that mountainous regions in these high irradiance countries – where heating equipment may be needed - could present more promising results for heat pumps. We discuss this in greater detail as part of our recommendations for further work.

Opportunity checklist

While not a key finding of the report in the sense of the five findings above, our analysis allows us to distil a list of characteristics – both customer and country – that are more likely to lead to TANS from converting to DES equipment compared to replacing CES equipment. We term this an ‘opportunity checklist’ (Figure 12).

These characteristics, and the reasons why they lead to greater DES TANS, can be found in the rest of this chapter as well as Annexes B to E. This is not to say that countries and customers without all of these features cannot experience TANS from converting to DES, but that these are helpful starting points for narrowing the scope of where DES is likely to be useful.

Figure 12 Opportunity checklist



Source: Frontier Economics

Box 6: What does 'high' mean?

The opportunities checklist above and in the Executive Summary does not include thresholds for the different criteria (for example, we do not define the exact level of fossil fuel prices that would be required to drive customer benefits). This is because multiple factors drive the results, and with multiple moving parts, it is not possible to assign a MW/MWh figure to the level of irradiance required or a km/year figure to the mileage per vehicle, without making assumptions on all of the other factors.

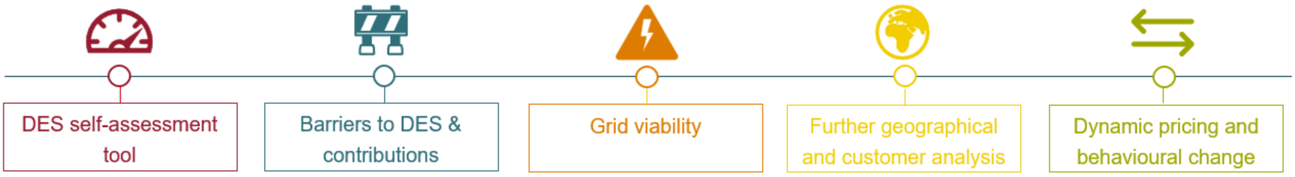
However, we provide some descriptions below of the ranges used in our modelling for the different features, in case they are useful. We do not provide this description for all features, as in some cases our case studies don't present a range – i.e. they all have high fossil fuel prices and large roof space. These bullets are accompanied by a full list of the modelling assumptions used in Annex G.

- *We considered Kenya and Mexico as having low cost solar PV at £430/kW and £435/kW respectively. Others in our same had prices of £525-790/kW.*
- *Only the UK was considered a low irradiance country with 3.59 kWh/kW/day in summer and 1.64 kWh/kW/day in winter. Other countries had between 4.95-5.17 kWh/kW/day in summer and 3.66-4.71 kWh/kW/day in winter.*
- *High heating was described earlier in the text as high enough such that countries would have a central heating system. Customers in Kenya and Mexico tend not to have such systems and their heat demand is 2 kWh/m^2 and 17 kWh/m^2 respectively.*
- *Australia was the only country considered to have high fixed network charges at £49.75/kW. The next largest network charges were £17.40 in the UK.*
- *We considered Kenya as a high interest country with lending rates in December 2021 of 12%. All other countries were between 1-5%.*
- *Supermarkets and fast food restaurants were considered customers with high mileage per vehicle, with 140,000 km/year and 70,000 km/year respectively. Farms were considered low mileage customers with 30,000 km/year.*
- *Fast food restaurants have exceptionally high electricity use at 872 kWh/m2, but this should not be considered a required threshold as this is very high.*

3. Recommendations for further work

Our analysis has presented some interesting and helpful findings, but there is room for further work in the area. Below we outline five different areas for further work.

Figure 13 Five recommendations for further work



Source: Frontier Economics
Note: [Insert Notes]

Research to enable take up of DES:

1. **DES self-assessment tool - o**ur primary recommendation is to produce a tool that could make it easier for customers to make the decision on whether to take up DES. This tool would allow customers to assess the benefits and optimal configuration of DES depending on their demand patterns and local conditions.
2. **Barriers to DES and contributions** – we would suggest key barriers for DES adoption at the country level – including taxes and subsidies – be investigated, and discussions be had on how policy and philanthropy can efficiently help overcome them.

Further investigation into the benefits of DES

1. Grid viability - network upgrades and reinforcements are being undertaken in many countries to allow bi-directional flows of electricity and allow changes in the size and location of demand. Further work on optimal DES locations should take this into account.
2. Further geographical and customer analysis - looking at a wider set of countries and on a more granular regional level may open up opportunities in a wider variety of countries.[16] Also, looking for additional archetypes is likely to lead to a broader set of customers who can benefit from DES.
3. Dynamic pricing and behaviour change - allowing for dynamic daily and seasonal pricing for both purchase and resale of electricity would better reflect the value of batteries in systems with variable retail pricing, where some places are moving towards. Behavioural change after installing DES to maximise its benefits could lead to additional TANS beyond what we have found.

[16] As already mentioned, looking at more granular data for Kenya and Mexico may find areas where heating equipment is needed and therefore heat pumps could reduce costs compared to gas boilers. Another example of regional variation is that payback periods for electrifying home appliances varies between 5 and 19 years in Australia, depending on the region. Guardian (2022), *Give up the gas: switching to electric appliances could save Australians up to $1,900 a year, report says.*

Annex A - Methodology

Model design

In our analysis we try to demonstrate the potential savings to customers of DES. We develop case studies for customers and countries. These are illustrative examples and specific findings cannot necessarily be applied to all customers and countries. However they are helpful in sharing where potential opportunities for DES may be.

Customer archetypes and country selection

The food industry contributes to about 40% of global greenhouse gas emissions which has a huge impact on climate change.[17] We select customer archetypes within the food industry to recommend ways of reducing emissions and make the industry more sustainable as a whole.

We chose three customer archetypes that have high electricity demand during the day and potentially high levels of roof space. If there is more demand during the day, when rooftop solar produces electricity, more of that production can be used and less needs to be sent back to the grid at a reduced (or even zero) price, increasing benefits for DES customers. Further, the ability to install more PVs helps one cover more energy needs with their own production. Hence, having enough roof space is important.

We select the following three customer archetypes for our analysis:

- Supermarkets - have relatively flat demand during opening hours which coincides for a large period of time with solar production. In addition, depending on the location of the supermarket, it is possible to install additional PV capacity in the parking lot and increase own-production.
- Dairy farms - have the advantage of covered cattle shelters and milking parlours providing enough space to install PVs, without increasing heating or cooling demand that would likely be required in other larger buildings.
- Fast food restaurants – demand peaks during meal times, but is still high enough during the day to benefit from DES. Similar to supermarkets, there is often the potential for additional PV capacity in parking lots.

We pick five countries where DES systems are likely to be promising because of high costs of grid electricity. Within this, we choose countries that varied across other factors such as PV costs, irradiance, and commercial interest rates, as well as geography and stage of development. The five countries we use in our analysis are Australia, Kenya, Mexico, Spain and the UK.

[17] Source : https://www.newscientist.com/article/2290068-food-production-emissions-make-up-more-than-a-third-of-global-total/

Model Structure

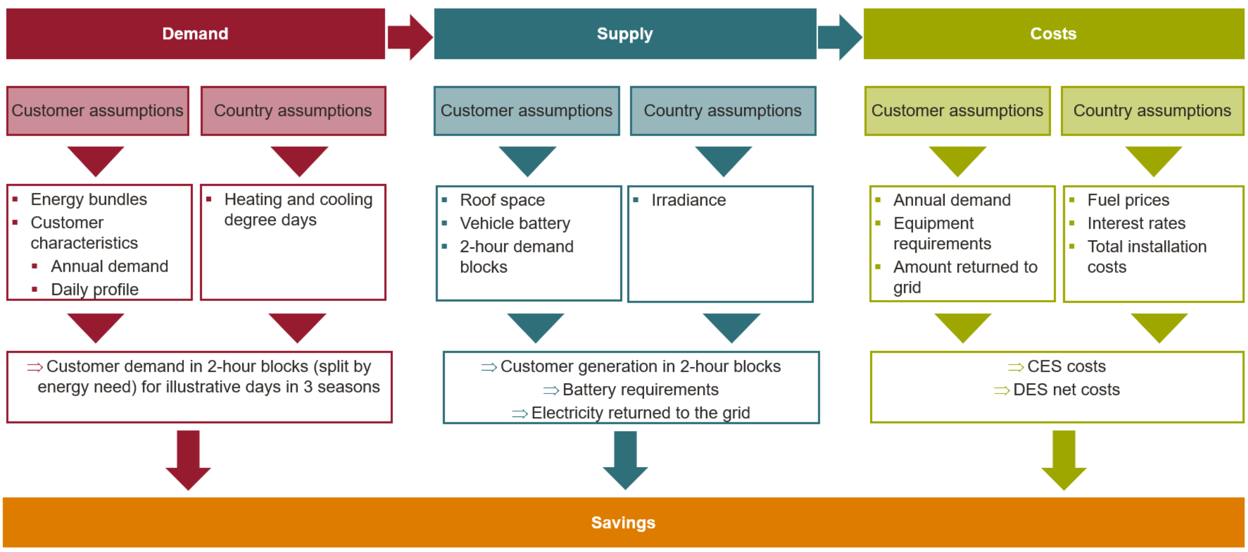
We have built an Excel model that constructs bottom-up demand and supply volumes to estimate the costs and benefits of converting CES equipment to DES. The model is divided into three main sections – Demand, Supply and Costs and Revenues. Within each of this section, we have made customer and country specific assumptions that can be seen in Annex G. We calculate daily customer energy demand requirements and estimate daily solar electricity generation. Figure 11 provides a snapshot of the model. This model is editable by the user, so our default assumptions can be easily changed and reverted to see impacts on results.

We model costs and savings in terms of TANC and TANS respectively. These are defined in Figure 2. Most of the costs in our analysis are annual (O&M, fuel, grid costs), but the upfront capex only occurs in one year. To make sure upfront capex is captured in our results, we split out the upfront capex evenly over the lifetime of the equipment, using a country-specific discount rate.

TANC are absolute costs and can be calculated in the CES and DES worlds. TANS represents the savings from DES, i.e. TANS = CES TANC – DES TANC.

When estimating DES we calculate TANC for full DES conversion (from CES to PV + Heat pump + EV + Battery) as well as incremental TANC of different combinations of DES equipment. This assists in analysing the best combination of DES for each customer across all countries.

Figure 14 Model Schematic



Source: *Frontier Economics*
Note: *[Insert Notes]*

Methodological assumptions

Our detailed assumptions and sources are available in Annex G. However we discuss our key theoretical assumptions here.

As described above, our Excel model uses a bottom-up approach to calculate the demand, supply, costs and revenues for each customer type across all countries. We make the following key assumptions in our analysis:

Demand

Equipment

As previously mentioned, heating, cooling, transport, and electricity use are the energy demand components used in our analysis. We assume the quantity of energy demanded under both CES and DES remains the same. In other words, we are not modelling for any behavioural change for customers when they switch to DES.

Box 7: Behavioural change

In practice, some level of behaviour change is likely, as customers would be able to respond to more salient incentives to reduce their energy costs. Obvious examples include households choosing to wash their clothes or dishes during the day time when they can use their own electricity rather than at night when they would need to buy it from the grid.

Modelling this level of behavioural change was beyond the scope of this work, and in assuming no change we are being conservative and potentially underestimating the TANS of DES. However there is reason to believe that there would be less behaviour change amongst commercial customers than households.

For example, a restaurant that serves evening meals will need electricity when the sun is not shining. It is therefore not possible for them to shift all of their activities to only during the daytime as household may be able to do, even if that would save the restaurant money by reducing their reliance on the grid or the size of battery they require. This is not to say that behavioural change is impossible amongst commercial customers, but that it is likely to be less readily available than to households, and therefore simplifying our analysis to remove behavioural change is likely to underestimate the TANS of DES by a smaller degree.

As an example, customers' *heat* demand depends on the size of the space that needs heating and the outside temperature; it does not depend on the equipment used. However their *fuel* demand does depend on the equipment used because different pieces of equipment have different efficiencies. Equipment used for each demand component in the DES and CES settings are listed in Table 4.

Table 4 Technology assumptions

SERVICE	CES	DES
Electric appliances	Electricity	Electricity
Cooling	Air Conditioning	Heat pump
Heating	Gas boiler	Heat pump
Transport	Internal combustion vehicle	Electric vehicle

Time periods for energy demand

Some types of energy demands are seasonal – for example, heating and cooling. Based on heating degree days (HDD) and cooling degree days (CDD) in each country, we divide the year into 3 seasons – summer, winter and other. We assume customers only demand cooling in summer and only demand heating in winter. In other months they demand neither.

We treat Kenya and Mexico differently because they are predominantly hot countries. Desktop research shows heating equipment is uncommon in both countries[18], and hence, we assume that these countries have no heating demand in either CES or DES scenario. They therefore do not purchase heating equipment.

Within each season, energy demand is converted from annual totals to daily totals. Annual heating and cooling demands are evenly divided across the days in the relevant season, whereas annual demand for electricity and transport are evenly divided throughout the entire year. This is a simplifying assumption that may not reflect reality in some cases, for example in countries with fewer sunlight hours in the winter electricity use tends to be higher.

Within each day, we use daily demand profiles to split demand for each energy use into 2-hour blocks, and consider how demand varies during the day and night.

Supply

In our model, supply of electricity is synonymous to self-production of solar electricity generation. We assume that all countries and archetypes have the infrastructure and technology to be able to install solar PVs. In our analysis, we assume that the customer’s key requirement is to meet own demand. This means that while we allow customers to sell surplus electricity back to the grid, we do not assume that maximising revenue generation is a key incentive. When selling surpluses back to the grid, all additional electricity generated is sold back to the grid immediately.

Roof space

In our model, we do not optimise the number of PVs required to meet demand and minimise costs. Rather we assume that PVs are installed in the entire usable roof space.

All of our consumer archetypes are assumed to be standalone buildings with flat roofs available to install solar PVs. We assume buildings have flat roofs due to limited data availability on roof size, so we can use floor area as a suitable proxy. We take into account potential limitations around the amount of roof space that could be viable for solar panel installations in practice, and therefore assume 80% of the available roof space is usable for solar panels. Further, we assume all customers have the legal right to install PVs and are not required to share the electricity generated with other occupants. This is reflective of a vast majority of buildings in our chosen archetypes.

[18] Source: https://blog.dwellworks.com/no-heat-no-ac-no-big-deal-this-is-mexico-city2 ;

Through desktop research, we found that in some countries parking lots have roofs and therefore provide additional PV installation capacity.[19] We have thus assumed supermarkets and fast food restaurants have car parks with additional roof space, since they tend to have parking spaces. For the dairy farm we instead assume that rather than a car park, the additional solar PV can be installed on the roof of the animal pen.

Irradiance profiles

Sunlight received across countries has a broad range. This varies across seasons. For each country in our analysis, we use daily PV power potential in summer and winter to calculate solar electricity generated each day[20]. We assume the daily PV power potential in the 'other' season to be an average of summer and winter values.

Along with variation across countries and seasons, solar potential also varies throughout the day depending on the intensity of sunlight. We use daily irradiance profiles in 2-hour blocks to calculate solar electricity generated at different times of day.

Battery characteristics

Batteries play an important role in the DES world as they provide a way to store solar electricity generated during the day for later use. In our analysis, battery size is assumed to be the smallest battery required to cover a customer's daily demand. If demand cannot be fully covered because self-production is smaller than demand, then the battery size is large enough to store all of the surplus electricity generation from different points throughout the day. Similar to energy demand and electricity generation, we calculate battery size separately for summer, winter and other months - the largest battery size demanded across the seasons is chosen. We assume that battery efficiency and depth of battery discharge are less than 100%.

We take into account that EV batteries can be used to meet other energy demands. In our model, we assume a small portion of battery capacity requirements are met by the EV battery, acting as a substitute for a stationary battery. Since EVs are in use throughout the day, we assume only 10% of its battery store can be used for meeting other energy demand. If a customer's battery requirements are very small, then it's possible that only the EV battery would be needed.

Solar electricity generated in any given two-hour slots is first used to fulfil current demand. If any surplus electricity remains, it is stored in batteries for future demand. If there is electricity generation in excess of battery capacity, it is immediately sold to the grid. As we assume the resale value of electricity is constant throughout the day, there is no incentive to temporarily store additional electricity and sell it back to the grid later. We also assume there to be no cap on the electricity that can be sold back to the grid.

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[19] Source : https://knovhov.com/covering-parking-lots-with-solar-panels/

[20] Source: https://globalsolaratlas.info/global-pv-potential-study

Costs and revenues

We assume that customers own all equipment and model costs for both DES and CES scenarios. We consider annualised total installation costs (including capex), operations and maintenance costs, fuel costs and costs to remain connected to the grid. We assume all our costs are constant per unit with no economies of scale. In the DES world, customers can generate revenue from selling their excess electricity supply to the grid.

Total installation costs

We use costs in the commercial to be in line with realistic prices faced by our customer archetypes. Due to limited data availability, we assume per unit total installation costs for appliances are the same across countries, apart from solar PV.

Our base case assumption is that customers are buying new equipment at the end of the lifetime of their current assets. This means that in the CES scenario customers are buying new CES equipment to replace current assets at the end of their life, just as in the DES scenario customers are purchasing new DES equipment.

As mentioned above, costs and revenues are calculated on an annual basis for a snapshot year. Upfront costs are only paid in one period. If this is assumed for the snapshot year, it will disadvantage technologies with initial upfront costs such as DES. Thus, in our model, total installation costs have been evenly distributed over each year of the lifetime of the equipment (annualised) using country specific interest rates for discounting. We use nominal interest rates here, because our model is in nominal terms.

In our analysis, we include total installation costs for both CES and DES settings. For the CES world this represents the costs for a customer at the end of the life of their current CES equipment. We provide a caveat in our model by which a user can exclude these costs.

We assume constant per unit total installation and O&M costs without any economies of scale O&M, fuel and grid costs

O&M costs vary widely across countries. In our analysis, we assume annual O&M costs to change across countries in proportion to the daily median income in each country. However we assume constant O&M costs over time. As the model is in nominal terms, assuming constant O&M costs is effectively assuming that expected efficiency gains over time are equal in the CES and DES world, and that this is equal to the rate of inflation. This is a slightly conservative assumption in terms of the savings from DES, as we would expect newer technologies to have a fast rate of efficiency gains than older technologies.

In our analysis, we are trying to look at the lifetime costs of DES which range between 15 and 25 years depending on the type of equipment. Hence, we try to use prices that could be realistic over this horizon. Given current economic turmoil, the fuel costs and interest rates used in our analysis are from December 2021, as they are not as extreme as the current prices and interest rates. We then assume these prices are held constant over the lifetimes of the assets.[21]

Total installation costs come from between 2020-2022, based on data availability. This means that installation costs, fuel prices, and interest rates used in our work are lower than we currently see in the world today. In the main body of the report we have a 'what if' box that looks at the effect of using current prices instead.

We assume the grid electricity price and the electricity resale price are both constant throughout the day, and do not fluctuate with demand. This is a simplifying assumption as with flat electricity price, customers would not adapt their demand profiles to use electricity at different times of the day.

We assume the consumer incurs fixed costs to remain connected to the grid, in line with the current retail changes.

Payback period

Payback period is the number of years required to recover the cost of an initial investment.[22] See TANS looks at the total level of savings customers receive over the lifetime of the equipment, from purchasing DES equipment instead of CES equipment, taking into account the time value of money (i.e. interest rates). This is then evenly distributed over the lifetime of the equipment, so it is presented as annual savings. Nominal interest rates are used because the model and its results are all in nominal terms.

Figure 3 for a full definition. In this case, it is calculated by dividing the initial investment by the amount of net annual savings, without taking into account financing costs. In our analysis we compare the costs in the DES and CES setting. DES normally requires a higher initial investment but leads to net annual savings due to lower fuel costs and any revenue earning from the sale of excess electricity back to the grid (doesn't apply to every archetype and country). In line with accounting practice, no discounting or interest rates are taken into account in this calculation.

[21] Assuming constant fuel prices in nominal terms assumes that fuel prices do not rise with inflation. This is a reasonable assumption given that fuel costs are a raw input and historically changes in fuel costs have not been correlated with inflation.

[22] https://www.investopedia.com/terms/p/paybackperiod.asp

Annex B - Selection

This annex sets out our process for selecting case studies.

Drivers of DES

Initially, we undertook our analysis on a prototype version of the model - without countries or customer archetypes selected. This allowed us to understand the drivers that were more likely to lead to customer TANS for DES. At a high level, DES TANS depend on:

- The TANC of the existing CES;
- The TANC of the DES system that satisfies the same energy needs as the CES.

We analyse the cost structure of CES and DES, and look at the relative importance of each cost element as well as looking at if and how the size of each cost element changes across customer types and countries. Table 5 shows the cost structure of energy systems, classifying costs into capex, O&M, and fuel. For each of these cost elements the table shows:

1. Their relative size for CES and DES. This is done on a qualitative basis using ranges to reflect that the relative sizes depend on fuel prices and the ability of a DES system to self-supply.
2. Whether the size of these cost elements changes across countries. This analysis is divided into two:
   - Does the unit cost - for example, the cost of a kW of equipment or a unit of fuel - change across country?
   - Does the quantity - amount and size of the equipment and fuel demand - change across country? If so, what factors affect the quantity of energy demanded.
3. Whether the size of these cost elements changes across customers, again split into unit cost and quantity elements.

Table 5 shows that the most important cost elements for determining DES TANS are fossil fuel costs for CES, capex for DES, and electricity resale prices for DES (included in 'fuel'). To reiterate what is in the main body of the report in Section 1, we deliberately chose case studies that are showing opportunities benefits of DES. Hence we use these important cost elements to choose customers and countries where DES is likely to lead to TANS for consumers.

Table 5 Cost structure

COST ELEMENT	SHARE OF COSTS		COST VARIABILITY ACROSS COUNTRIES		COST VARIABILITY ACROSS CUSTOMERS	
	CES	DES	(UNIT) COST	QUANTITY	(UNIT) COST	QUANTITY
Capex	Small-Medium	**Medium-Large**	Yes – solar PV mainly	Yes - heating/cooling	No	Yes
O&M	Small-Medium	Small	Yes	Yes - heating/cooling	No	Yes
Fuel	**Large**	**Medium**	Yes	Yes - heating/cooling and own-production	No	Yes

Source: Frontier Economics

Notes: The costs highlighted in bold represent the cost elements that have the most significant impacts, and therefore should be considered the drivers of potential DES TANS.

Country selection

To select the five countries for our case studies we first developed a shortlist of ten countries, and then refined this shortlist to the final five countries. To develop the initial shortlist we looked at fossil fuel prices – as a key determinant of DES TANS outlined above – as well as ensuring geographic and developmental diversity within the shortlist. Once the set of countries had been narrowed down to the shortlist, we were then able to look at a number of other factors, such as DES capex, irradiance, and lending rates which will also impact the levelised cost of electricity (LCOE) using DES. Data availability constraints meant that we could not use these factors when creating the initial shortlist.

Developing the shortlist

Table 5 outlines that fossil fuel costs, DES capex, and electricity resale costs are key drivers of DES. Due to data availability, out of these three factors we could only consider fossil fuel prices when making the shortlist. However we did overlay this criteria with the desire for diversity in both the geography and the stage of development of our shortlisted countries.

- **Fossil fuel prices** change significantly depending on taxes and other country-specific costs included in the natural gas and electricity tariffs. This means that fuel prices are likely to be the key factor to select countries.
  - Countries with high **petrol and natural gas prices** will lead to higher TANS from electrifying the transport and heating needs, respectively.
  - In terms of **electricity**, a high retail price favours the installation of solar panels and batteries but will reduce the benefits of switching heating and transport to electricity if own-production is insufficient. These two effects work in opposite directions, however the first

effect dominates for our case studies, and therefore we looked at countries with relatively high electricity prices.

- **DES capex** is a significant cost component, and in reality this is a key driver of DES TANS. However for the purpose of our analysis we assume that capex tends to be similar across countries - apart from in the case of solar PV - and Table 5 shows that. While we did find variation in solar PV capex and installation,[23] solar PV only represents 45% of total installation costs for full DES. Given this, and the difficulty in collecting this data for a larger number of countries, we did not use solar PV capex and installation costs as a measure to shortlist countries, but did use it later as a measure to pick between shortlisted countries.
- As we choose case studies where significant solar generation is possible, customers will likely be able to sell their electricity back to the grid at certain times of day. A high **electricity resale price** is therefore very beneficial to reduce the levelised cost of solar electricity by offsetting the costs of the equipment. This differs significantly across countries, and could therefore be used as a significant criteria for country selection. However electricity resale price is a live issue in many countries, and is therefore exposed to significant policy risk in the near-term. Moreover the lack of data availability made this a difficult factor to research for a large number of countries. Electricity resale price therefore does not form a core criteria for country selection.
- We want to show the **diversity** and flexibility of DES, that it can lead to customer TANS in a variety of countries.

After an initial research and high-level analysis of the above criteria, our initial country selection was the following: Spain, UK, Mexico, Brazil, Egypt, South Africa, Kenya, Japan and South Korea.

Finalising countries

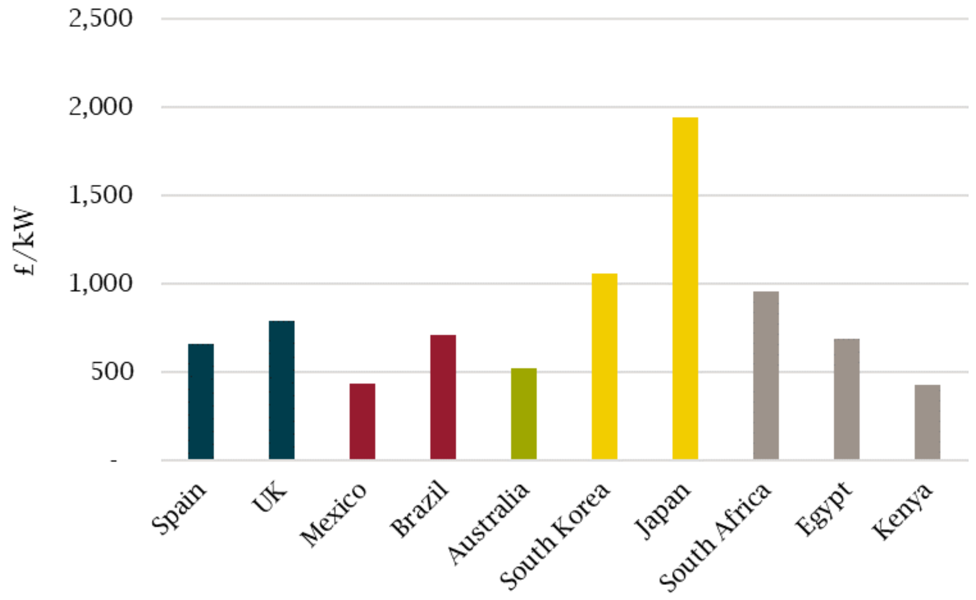
Our next step was to narrow down the initial list to a selection of 5 countries. As we had a shorter list of countries to assess, we could bring in additional data that it was not possible to use for the initial shortlisting process. We therefore looked at the following three factors, as these will drive the difference between the cost of network electricity and the average cost of solar electricity (also known as LCOE):

- Total installation costs for solar PV installations for the commercial sector (Figure 15): The lower the capex and cost of installation – together making the total installation cost – the lower the upfront costs of DES.
- Irradiance Figure 16): The higher the irradiance, the greater the amount of electricity produced that customers can consume, and therefore the lower the cost per unit.
- Lending rate (Figure 17): The lower the lending rate the lower the cost of the capex once it has been annualised, and therefore the lower the levelised cost.

The results of our analysis are represented in the following three charts. The bars are coloured differently according to geographic diversity, so that this can be overlaid.

[23] The lowest price we found was £560/kW for Mexico and the highest was £890/kW for Australia.

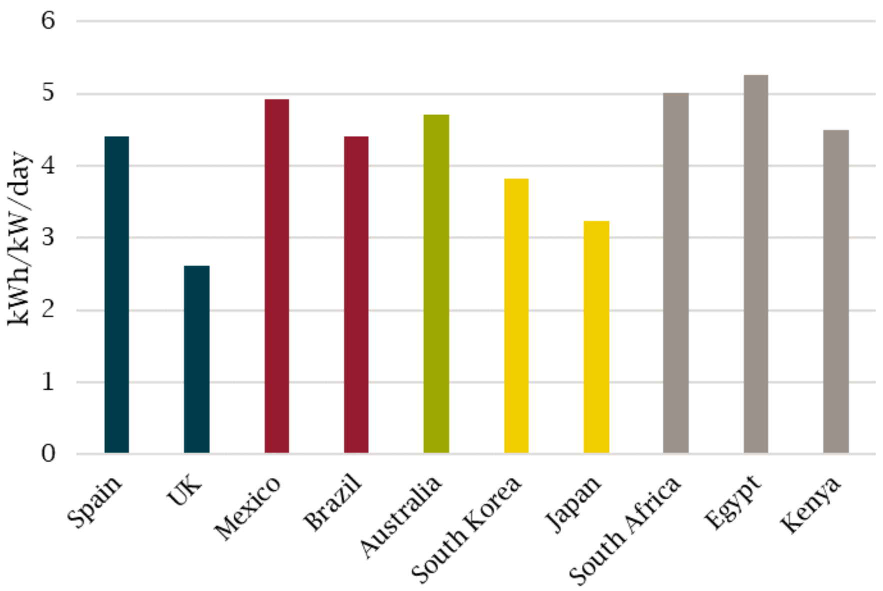
Figure 15 Costs of installed PV for commercial customers (in £/kW)



Source: IRENA, 2021 and own calculations

Note: Each colour represents a different continent.

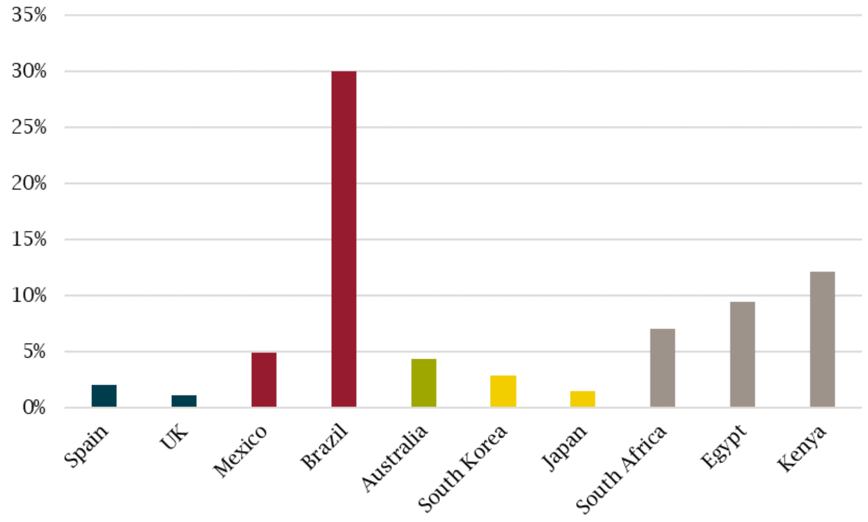
Figure 16 Average Irradiance – the amount of electricity solar panels can generate in each country (in kWh/kW/day)



Source: Global Solar Atlas

Note: Each colour represents a different continent.

Figure 17 Nominal interest rates (%)



Source: World Bank and country-specific sources when the World Bank did not provide data for 2021
Note: Each colour represents a different continent.

The charts show that a few countries have low total installation costs, high irradiance, and low lending rates. These are Spain, Mexico, Australia and Kenya, and also represent a geographically and developmentally diverse set of countries. We chose the UK as the final country for our final group to show a relevant comparator, given that the audience of this report is predominantly UK. Moreover the data was more readily available for the UK than for South Korea, which would have been the other choice. With all this in mind, we suggest to select Spain, UK. Mexico, Australia, and Kenya.

Table 6 Summary of final country selection

COUNTRY	COST OF INSTALLED PV	IRRADIANCE	NOMINAL INTEREST RATES	COST OF NETWORK ELECTRICITY	SELECTION
Spain	Low	High	Low	High	✓
UK	Medium	Low	Low	High	✓
Mexico	Low	High	Low	High	✓
Brazil	Low	High	Very high	High	×
Australia	Medium	High	Low	High	✓
Japan	High	Low	Low	High	×
South Korea	Medium	Medium	Low	Medium	×
South Africa	Medium	High	Medium	Low	×
Egypt	Low	High	Medium	Low	×
Kenya	Low	High	Medium	High	✓

Source: Frontier Economics

Box 8: Carbon emissions

As outlined in the introduction, the focus of this report is not looking for opportunities for DES to lead to the greatest carbon emissions. It is looking into where and for whom DES can lead to the greater customer TANS. However there are environmental motivations behind installing DES equipment, as well as financial ones. Therefore, while we did not take carbon emissions into account in selecting our countries, the summary below shares some information on which countries DES would likely have the most environmental benefit.

This summary looks only at the carbon intensity of the electricity grid. This is because we assume that the carbon emissions of petrol and diesel, as well as the embedded carbon of the production and installation of solar PV and other DES equipment is the same across countries. While this is not necessarily the case in practice – differing transport emissions being one example – it is beyond the scope of this work to compare these.

Table 7 Average grid intensities (gCO2/kWh) of our short-list countries (2020)

Country	Grid intensity
Brazil	140
Spain	151
UK	172
South Korea	183
Kenya	189
Mexico	198
Egypt	211
Japan	218
Australia	253
South Africa	332

Source: *Our World in Data - https://www.icos-cp.eu/science-and-impact/global-carbon-budget/2021*
Note: *2020 data was missing for Kenya, so 2019 data is used instead.*

Looking at average grid intensities allows us to see where emissions are highest per unit of electricity. This is not strictly a measure of where DES would lead to most emissions savings, as for that we would need to look at the marginal grid intensity. This data is not so easily available and therefore we use average grid intensities as a proxy. Table 7 shows that the electricity grids in South Africa, Japan and Egypt are currently the most polluting, and the least polluting is Brazil. According to the same dataset, the unweighted average for the world in that year was 199gCO2/kWh in 2020. And the weighted average was 225gCO2/kWh in 2020.

Given the final five countries in we consider – Australia, Kenya, Mexico, Spain and the UK – we can see that the majority of these countries are at or under the world average in terms of average grid intensity. This implies that the electricity grids in our countries are less polluting than the average.

Customer type

Selection

We focus on the food sector, as a significant emitter of carbon emissions, as electrification could lead to significant carbon benefits for these industries, and they present opportunities for electrification given low-temperature heat requirements, which are relatively easy to electrify.[24] We therefore choose three archetypes within the food sector.

As shown in Table 5, we assume that (unit) costs don't change significantly across archetypes, but that quantities of equipment and duel will change significantly. Quantities have two significant dimensions: size and timing.

Size and timing of energy demand are the main factors we used to choose our customer archetypes:

- In terms of **size**, the higher the demand the higher the TANS from DES. This happens because the upfront costs and efficiency of electric appliances is higher, meaning that quantity has a significant impact on per unit costs for DES. This is a general result, though can create a tension if large energy requirements compared to own-production means that electricity from the network may be needed.[25]
- In terms of **timing**, the higher the correlation between demand and own-production, the lower the battery requirements and therefore the lower the TANC for DES.[26]

On the basis of this analysis, we choose archetypes with high energy demands for the capacity of the equipment they use, and with energy demand mostly during the day so that demand profiles broadly match irradiance profile. However, as we did with country selection, we also overlap two other factors in the choice of our customer archetypes:

1. Just as we wanted an element of diversity and variety in our country selection, we would like the same for our customer archetypes, meaning that we wanted to choose customers in different parts of the food sector value chain, to show the diversity and flexibility of DES.
2. While we want diversity between archetypes, we want homogeneity within archetypes. Our case studies are purely illustrative, and are not meant to be representative of an 'average' customers within an archetype. However for the results of our analysis to be as helpful as possible in indicating customers that are likely to experience DES TANS, we wanted to choose archetypes where the customers within each archetype is reasonably homogenous.

Bringing all of these together, the three archetypes we choose are:

[24] Climact (2022), *Opportunities to get EU industry off natural gas quickly.*

[25] This is discussed in Section 2 of the main report, as the UK is not able to cover its own demand for supermarkets and fast food restaurants.

[26] However, it's worth noting that that the relative impact of battery costs on DES TANS falls the more energy uses are electrified, as these require buying a heat pump and an electric vehicle.

- Supermarkets
- Fast food restaurants
- Dairy farms

Supermarket demand is relatively flat during opening hours and coincides for a large period of time with solar production, which reduces TANC. In addition, in some countries they can install additional PV capacity in the parking lot and increase own-production without increasing the capacity of equipment needed to provide heating or cooling. Delivery vans also have high mileage, which is good for electric efficiency and reducing transport TANC.

Fast food restaurants have a significant amount of kitchen equipment that is already electrified. Their electricity use is very high, which means they will use all of the electricity they generate, and they don’t need to purchase additional DES equipment to load shift. Mileage is also reasonably high for delivery motorbikes, and they would also likely have a parking lot for additional PV capacity.

Farms have the advantage of being widespread, but their heterogeneity (for example, a cereal farm is very different from a cattle farm) makes it hard to find a common archetype or even a core. Therefore, we focus on **dairy farms**, which have a relatively common structure and have the advantage of having the roof that protects the cattle. This additional extra own-production of solar energy could favour the electrification of heating of the other buildings and the passenger/light duty vehicles.

Annex C - Case studies: Supermarket

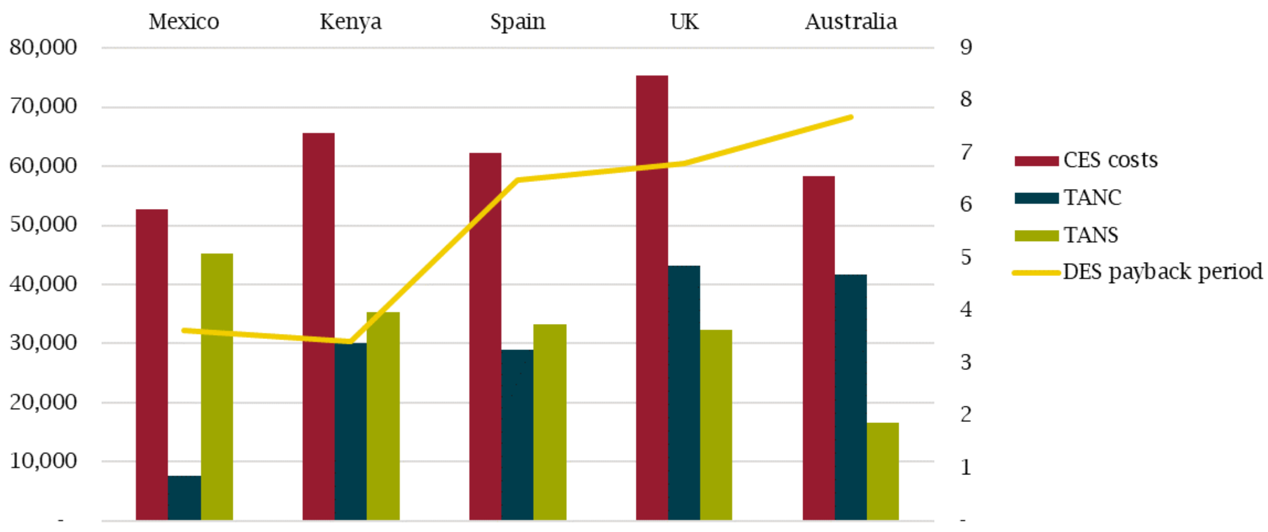
Summary

All five countries demonstrate that it is possible for a supermarket to achieve TANS by switching to DES. These TANS can be achieved by installing solar PV on its own, or by installing any combination of a battery, a heat pump, or an EV. Not all combinations lead to the same TANS or payback period however, and this is outlined in the trends and annex sections below.

Country comparison

Our model compares the TANS to supermarkets across countries from **fully converting to DES**. This means installing a heat pump, battery, and EV alongside solar PV. This is shown in Figure 18, where it can be seen that the payback period ranged from 4 to 8 years.

Figure 18 Comparison of DES TANS across countries



Source: Frontier Economics

Note: The yellow line representing the payback period uses the right-hand axis, all other measures use the left-hand axis.

Mexico and Kenya present the largest economic opportunities across the five countries

Mexico and Kenya are the most promising countries in terms of the payback period – both between three and four years. A significant driver of this is the relatively cheap solar PV in these countries,[27] as well as the fact that the electricity resale price is equal to the electricity purchase price.[28] However,

[27] Solar PV capex (£/kW) in Mexico and Kenya is half what it is in the UK and two-thirds what it is in Spain.

[28] In Spain the resale price is 75% of the purchase price, in the UK it's less than 50%, and in Australia it's one-third.

Mexico and Spain have the lowest TANC after installing DES - £8k and £29k respectively – and Mexico represent the biggest TANS.[29]

Low irradiance makes DES TANS in the UK more modest

The UK presents more modest TANS because of the relatively low irradiance, meaning that solar panels generate less electricity per unit, and supermarkets cannot cover all of their electricity demand with their own-production.

High network costs in Australia also reduce the benefits of DES

Australia also has relatively smaller DES TANS. High network costs in Australia mean that supermarkets would pay around £6k a year to be connected to the grid, even if DES production covered all of their expected demand. This closes the gap between CES and DES TANC, and slows down the payback period for DES equipment.

Trends

For each country, our model can produce a chart that looks at the incremental effect on TANC of converting additional pieces of equipment from CES to DES. This is shown for Mexico in Figure 19.

Using this analysis, we can see that countries seem to be affected by the same key trends. We highlight three of them:

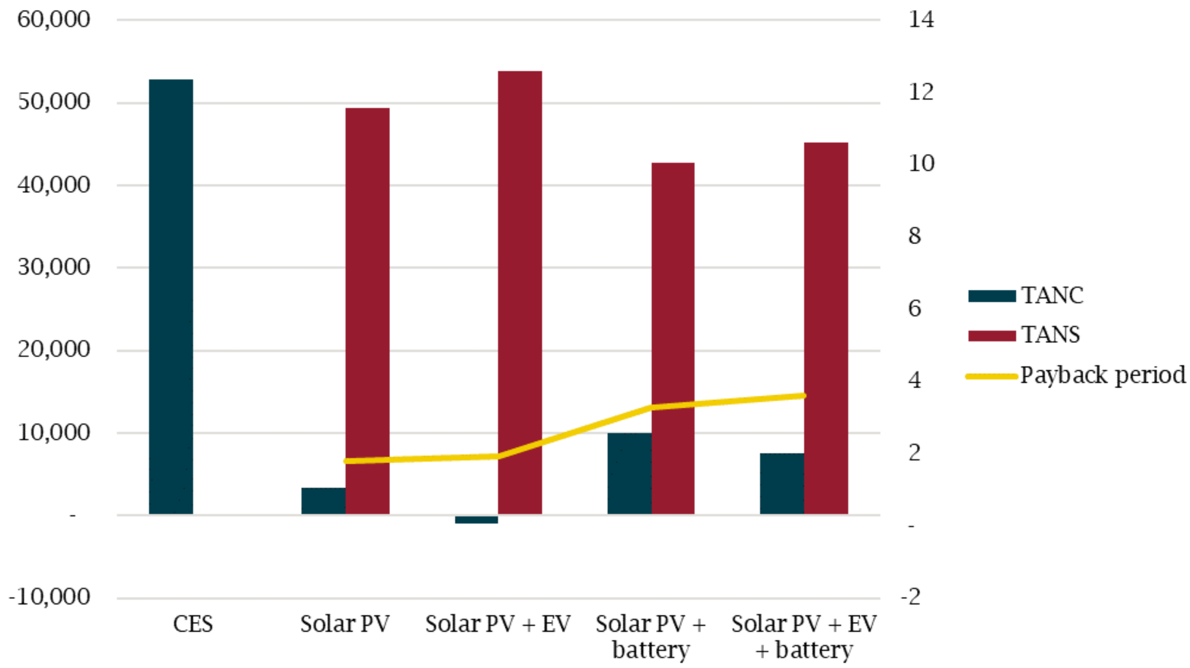
1. Purchasing an EV van instead of an ICE substantially reduces TANC across all countries.

This is because converting transport to DES removes expensive transport fuel TANC. An EV van is three times as efficient as an ICE van, and this significantly reduced energy demand can be fully covered by a supermarket’s own production for all countries apart from the UK (due to lower irradiance).[30]

[29] The reason that Kenya has higher TANC than Spain – despite a faster payback period – is that interest rates are high in Kenya meaning that the annualised capex is higher. The higher interest rate increases annualised capex for CES and DES equipment similarly, and therefore does not reduce the TANS from DES for supermarkets in Kenya. If interest rates in Kenya were lower, then Kenya would have higher DES TANS than Spain and lower DES TANC.

[30] Even for the UK – where only 80% of demand is covered by own-production – electricity and petrol prices are similar enough, that purchasing 20% of energy from electricity does not outweigh 80% own-production.

Figure 19 Incremental analysis for Mexico



Source: Frontier Economics

Note: The yellow line representing the payback period uses the right-hand axis, all other measures use the left-hand axis.

2. Installing a heat pump instead of a gas boiler reduces TANC modestly in Australia and Spain.

In Kenya and Mexico, heating demand is so low that it is unlikely supermarkets in these countries would have heating equipment in either the CES or the DES world. They are therefore not included in this analysis.

In the UK, heating demand is high and solar production is low. Hence not all heating demand is covered by own-production – only 80% is. Therefore the TANS that are made from 80% of heat demand being met by (free) own-production rather than (cheap) gas are largely undone by the remaining 20% being met by (expensive) grid electricity. [31]

Australia and Spain are in a sweet spot where irradiance is high, so it covers heating demand, but heating demand is high enough that these countries would have heating equipment and the increased efficiency of a heat pump has a greater effect than the increased capex. The TANS in these countries are between £0.5k and £2.6k across all customers.

3. Batteries increase TANC for all countries.

Even in the UK where batteries have the smallest impact on TANC, the effect is still negative. This is because while installing a battery decreases fuel costs in the UK by £10.5k, it reduces revenue by

[31] The gas price used is less than 25% of the electricity price, in the UK.

£6k and includes an additional maintenance cost of £1.4k a year[32]. The remaining £5k in annual savings does not outweigh the £6k in annualised capex.

Detailed results

Table 8 outlines for each country and combination of DES equipment:

- What TANC supermarkets would be facing each year [left];
- The payback period – how many years of annual savings of DES are required before the upfront capex is paid off (assuming no interest rate) [right].

A number of factors make up TANC. In the CES scenario this includes:

- The upfront capex (and installation) from purchasing CES equipment, annualised over the lifetime of the asset using the country's interest rate. CES equipment includes gas boiler, air conditioning, and ICE vehicle;
- The O&M costs for each piece of equipment;
- The fuel costs for each piece of equipment.

In the DES scenario, TANC include:

- The upfront capex (and installation) from purchasing DES equipment, annualised over the lifetime of the asset using the country's interest rate. DES equipment includes solar PV cells, battery, heat pump, EV vehicle;
- The O&M for each piece of equipment;
- The fuel cost for any remaining fuel that is not produced using solar PV panels;
- The revenue that is generated from selling surplus electricity back into the grid.

Table 8 TANC and payback periods for supermarkets

	MEXICO		KENYA		SPAIN		UK		AUSTRALIA	
CES	*£53k*	-	*£66k*	-	*£67k*	-	*£83k*	-	*£61k*	-
Solar PV	£3k	1.8yrs	£20k	1.7yrs	£42k	4.7yrs	£61k	5.8yrs	£52k	7.2yrs
PV + heat pump					£42k	5.5yrs	£63k	7.0yrs	£51k	7.9yrs
PV + EV	**-£1k**	**1.9yrs**	**£16k**	**1.8yrs**	**£25k**	**3.3yrs**	**£42k**	**3.9yrs**	**£42k**	**4.8yrs**
PV + battery	£10k	3.3yrs	£31k	3.1yrs	£47k	7.6yrs	£61k	7.1yrs	£55k	10.1yrs
PV + heat pump + EV					**£24k**	**3.9yrs**	£44k	4.6yrs	**£40k**	**5.5yrs**

[32] Own calculations using Lazard, Levelised Costs of Storage (2021)

	MEXICO		KENYA		SPAIN		UK		AUSTRALIA	
PV + heat pump + EV + battery	£8k	3.6yrs	£30k	3.4yrs	£31k	6.3yrs	£46k	6.3yrs	£44k	7.8yrs

Source: Frontier Economics

Note: The costs expressed on the left are the TANC, where capex has been annualised over the lifetime of the asset. The payback period is then expressed on the right. CES TANC are in italics as a reference, and the best option(s) for each country is in bold. As Kenya and Mexico would not install heating equipment, for these countries the results that include a heat pump are replaced by the same combination without a heat pump. For example, the results for PV + heat pump are the same as the results for solar PV.

Annex D - Case studies: Fast food restaurant

Summary

All 5 countries demonstrate that it is possible for a fast food restaurant to experience TANS by switching to DES. These TANS can be achieved by installing solar PV on its own, or by installing any combination of a battery, a heat pump, or an EV. Not all combinations lead to the same TANS or payback period however, and this is outlined in the trends and annex sections below.

Country comparison

Our model compares the TANS to fast food restaurants across countries from **fully converting to DES**. This means installing a heat pump, battery, and EV alongside solar PV. This is shown in Figure 18, where it can be seen that the payback period ranged from 4 to 7 years.

Figure 20 is ordered with the largest TANS from DES in the countries on the left, and the smallest in the countries on the right.[33]

Mexico, Spain and Kenya again present the most promising countries

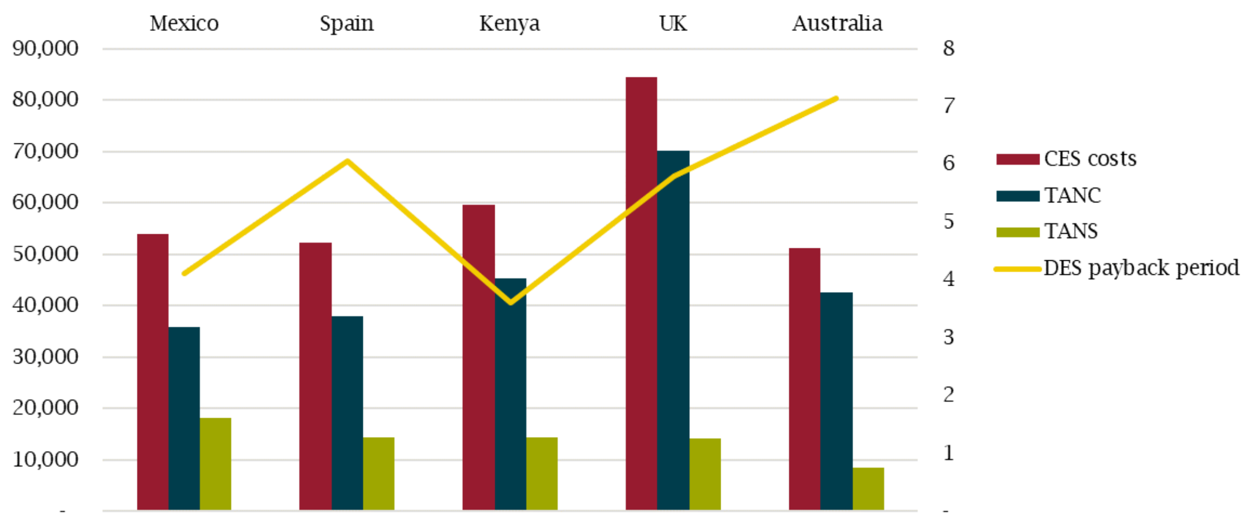
Mexico and Kenya are the most promising countries in terms of the payback period – both 4 years. This is driven by the relatively cheap solar PV. However, the high electricity resale prices that made Mexico and Kenya even more promising for supermarkets, do not affect for fast food restaurants because, given their high energy intensity, they do not sell electricity back to the grid.

High network charges in Australia again reduce the benefits of DES

The DES TANS are smaller for Australia – DES TANC are only £8k lower than with CES and the payback period is 7.2 years. The high fixed network charges mean that a smaller proportion of grid electricity costs are variable, and therefore replacing grid electricity with own-production leads to lower TANS.

[33] TANC are correlated with payback period but not exactly the same, which is why the chart is not ordered in both TANC and payback period.

Figure 20 Comparison of DES TANS across countries



Source: Frontier Economics

Note: The yellow line representing the payback period uses the right-hand axis, all other measures use the left-hand axis.

DES TANS are higher in Spain than in UK

Extremely high electricity use in fast food restaurants mean that the majority of own-production is used to replace grid electricity, rather than replacing other fuels. This is true even in the full DES case. Due to high energy demand, a significant proportion of electricity is bought from the grid. The higher electricity prices in the UK – 22p/kWh - mean that the TANS from own-production are less than they are in Spain (where grid electricity is 12p/kWh).

Trends

For each country, our model can produce a chart that looks at the incremental costs and benefit to TANC of converting additional pieces of equipment from CES to DES. This is shown for Mexico in Figure 21, where a significant feature of fast food restaurants is the high electricity use.

Using this analysis, we can see that countries seem to be affected by the same key trends. We highlight four of them:

3. Only a portion of fast food restaurants' energy needs can be met by DES

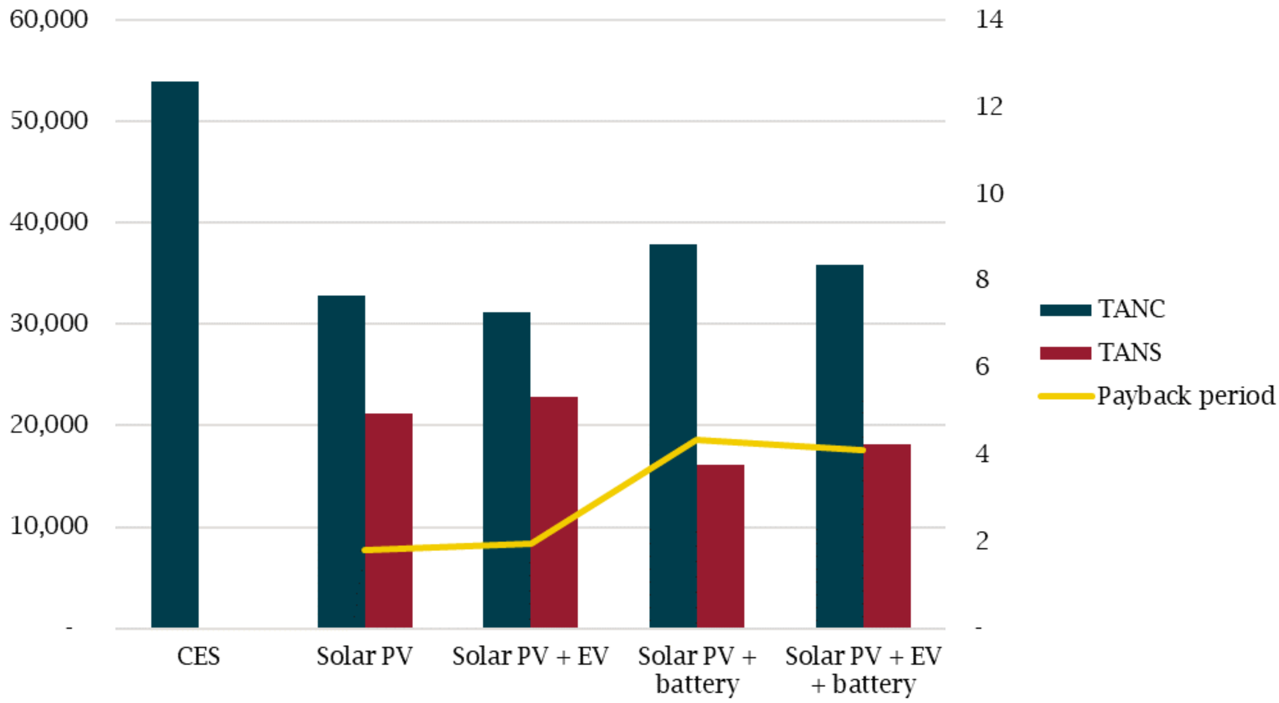
Across the different countries, between 25-50% of the energy required by fast food restaurants can be met by DES. The remaining must be collected from the grid. This reflects what is currently seen in the real world, where fast food restaurants can have energy intensities as high as 800kBTU/sq ft.[34] This means that at present most zero carbon kitchens use DES for 20-30% of their electricity, and

[34] AIA California (2022), *Webinar – Induction cooking: the all-electric kitchen of today and zero net carbon design for food service.*

then use offsets for the remaining emissions.[35] It would be possible for kitchen to be zero-carbon without using offsets were the grid supplied electricity is also from renewables.

As electricity demand is high in almost every hour that the solar panels are producing electricity, there is very little spillover at any time of day. 'Spillover' is the term used in the model to describe when electricity generation is greater than demand, and there is excess electricity that can be either stored in a battery or sold back to the grid. This means that electricity resale price is not a differentiator between countries, whereas it is for other customer archetypes.

Figure 21 Incremental analysis for Mexico



Source: Frontier Economics
Note: The yellow line representing the payback period uses the right-hand axis, all other measures use the left-hand axis.

4. Batteries increase TANC across all countries

The low levels of spillover mean that adding a battery makes little difference to the proportion of demand that can be met by DES. As batteries do increase upfront capex and annual maintenance costs however, they increase TANC for fast food restaurants across all countries.

5. Purchasing an EV instead of an ICE vehicle leads to increased TANS in all countries

Purchasing an EV instead of an ICE saves fast food restaurants £1-4k per year in TANS across all countries. This is because the mileage of a fast food restaurant motorbike is lower than that of a

[35] AIA California (2022), *Webinar – Induction cooking: the all-electric kitchen of today and zero net carbon design for food service.*

supermarket van, but still high enough for the efficiency benefits to outweigh the increased upfront capex of an EV motorbike compared with an ICE motorbike.

6. Installing a heat pump reduces TANC modestly in Australia and Spain.

In Kenya and Mexico, heating demand is so low that it is unlikely fast-food restaurants in these countries would have heating equipment in either the CES or the DES world. They are therefore not included in this analysis.

In the UK, heating demand is high and solar production is low. Hence not all heating demand is covered by own-production – only 86% is. Therefore, the savings that are made from 86% of heat demand being met by (free) own-production rather than (cheap) gas are largely undone by the remaining 14% being met by (expensive) grid electricity. [36]

Australia and Spain are in a sweet spot where irradiance is high, so it covers heating demand, but heating demand is high enough that these countries would have heating equipment and the increased efficiency of a heat pump has a greater effect than the increased capex. TANS in these countries are between £0.5k and £0.6k.

Detailed results

Table 9 outlines for each country and combination of DES equipment:

- What TANC fast food restaurants would be facing each year [left];
- The payback period – how many years of annual savings of DES are required before the upfront capex is paid off (assuming no interest rate) [right].

A number of factors make up TANC. In the CES scenario this includes:

- The upfront capex (and installation) from purchasing CES equipment, annualised over the lifetime of the asset using the country's interest rate. CES equipment includes gas boiler, air conditioning, and ICE vehicle;
- The O&M costs for each piece of equipment;
- The fuel costs for each piece of equipment.

In the DES scenario, TANC include:

- The upfront capex (and installation) from purchasing DES equipment, annualised over the lifetime of the asset using the country's interest rate. DES equipment includes solar PV cells, battery, heat pump, EV vehicle;
- The O&M for each piece of equipment;
- The fuel cost for any remaining fuel that is not produced using solar PV panels;
- The revenue that is generated from selling surplus electricity back into the grid.

[36] The gas price used is less than 25% of the electricity price, in the UK.

Table 9 TANC and payback periods for fast food restaurants

	MEXICO		KENYA		SPAIN		UK		AUSTRALIA	
CES	*£54k;*		*£60k;*		*£52k;*		*£85k;*		*£51k;*	
Solar PV	**£33k;**	**1.8yr**	**£40k;**	**1.7yr**	£39k;	4.1yr	**£73;**	**5.0yr**	£43k;	4.5yr
PV + heat pump					£39k;	4.5yr	£73k;	6.0yr	£42k;	5.0yr
PV + EV	**£31k;**	**1.9yr**	£39k;	1.9yr	**£36k;**	**3.6yr**	**£69k;**	**4.3yr**	**£41k;**	**4.2yr**
PV + battery	£38k;	4.4yr	£47k;	3.8yr	£42k;	7.0yr	£74k;	6.4yr	£45k;	8.0yr
PV + heat pump + EV					£35k;	4.0yr	£69k;	5.0yr	£40k;	4.6yr
PV + heat pump + EV + battery	£36k;	4.1yr	£45k;	3.6yr	£38k;	6.1yr	£70k;	5.8yr	£43k;	7.2yr

Source: Frontier Economics

Note: The costs expressed on the left are the TANC, where capex has been annualised over the lifetime of the asset. The payback period is then expressed on the right. CES TANC are in italics as a reference, and the best option(s) for each country is in bold. As Kenya and Mexico would not install heating equipment, for these countries the results that include a heat pump are replaced by the same combination without a heat pump. For example, the results for PV + heat pump are the same as the results for solar PV.

Annex E - Case studies: Dairy farm

Summary

All five countries demonstrate that it is possible for a dairy farm to experience TANS by switching to DES. These TANS can be achieved by installing solar PV on its own, or by installing any combination of a battery, a heat pump, or an EV. Not all combinations lead to the same TANS or payback period however, and this is outlined in the trends and annex sections below.

Country comparison

Our model compares the TANS to dairy farms across countries from **fully converting to DES**. This means installing a heat pump, battery, and EV alongside solar PV. This is shown in Figure 18, where it can be seen that the payback period ranged from three to nine years.

Figure 20 is ordered with the largest TANS from DES in the countries on the left, and the smallest in the countries on the right.[37] In all countries DES produces more electricity than the farms demand. This makes resale value of electricity an important factor for DES savings.

Mexico and Kenya again present the most promising countries

The results for dairy farms mirror other archetypes, as Mexico and Kenya again have the fastest payback period. This is driven by the relatively cheap solar PV along with high electricity resale prices. This second factor has a huge effect for dairy farms in the full DES case, because they sell a substantial amount of electricity back to the grid due to their large space for installing rooftop solar PV. In fact, these countries earn so much from reselling electricity back to the grid that their TANC are negative, meaning that dairy farms in these countries would earn money every year from installing solar panels. This can be seen in Figure 22 as the blue bar representing DES net costs is negative.

Low resale value of electricity in Australia reduces the benefits of installing PVs on all available roof space

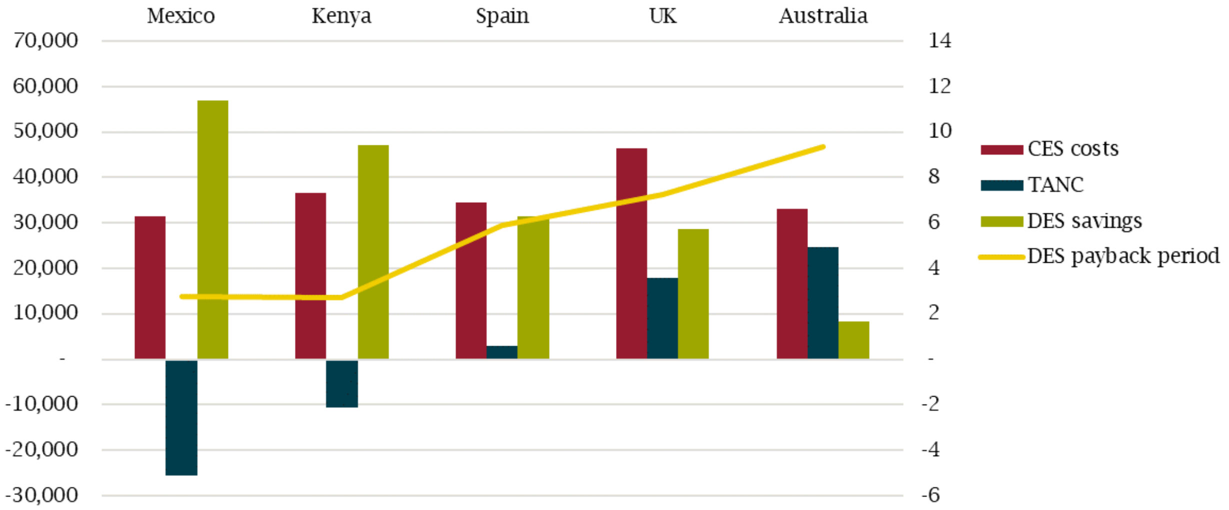
The DES TANS are smaller for Australia – DEC TANC are only £8k lower for full DES than with CES, and the payback period is 9 years. This is due to low electricity resale price and therefore DES revenue – compared with high upfront capex of the solar PV because of the sizable roof space. In Australia's case, not installing PVs on all available roof space would make DES likely more profitable.

DES TANS are higher in Spain than in the UK

Spain and UK have similar TANS but UK's higher O&M and network costs makes Spain marginally more profitable for dairy farms.

[37] TANC are correlated with payback period but not exactly the same, which is why the chart is not ordered in both TANC and payback period.

Figure 22 Comparison of DES TANS across countries



Source: Frontier Economics

Note: The yellow line representing the payback period uses the right-hand axis, all other measures use the left-hand axis.

Trends

For each country, our model can produce a chart that looks at the incremental costs and benefit on TANC of converting additional pieces of equipment from CES to DES. This is shown for Mexico in Figure 21, where a factor of note is the high surplus electricity generation on a farm.

Using this analysis, we can see that countries seem to be affected by the same key trends. We highlight four of them:

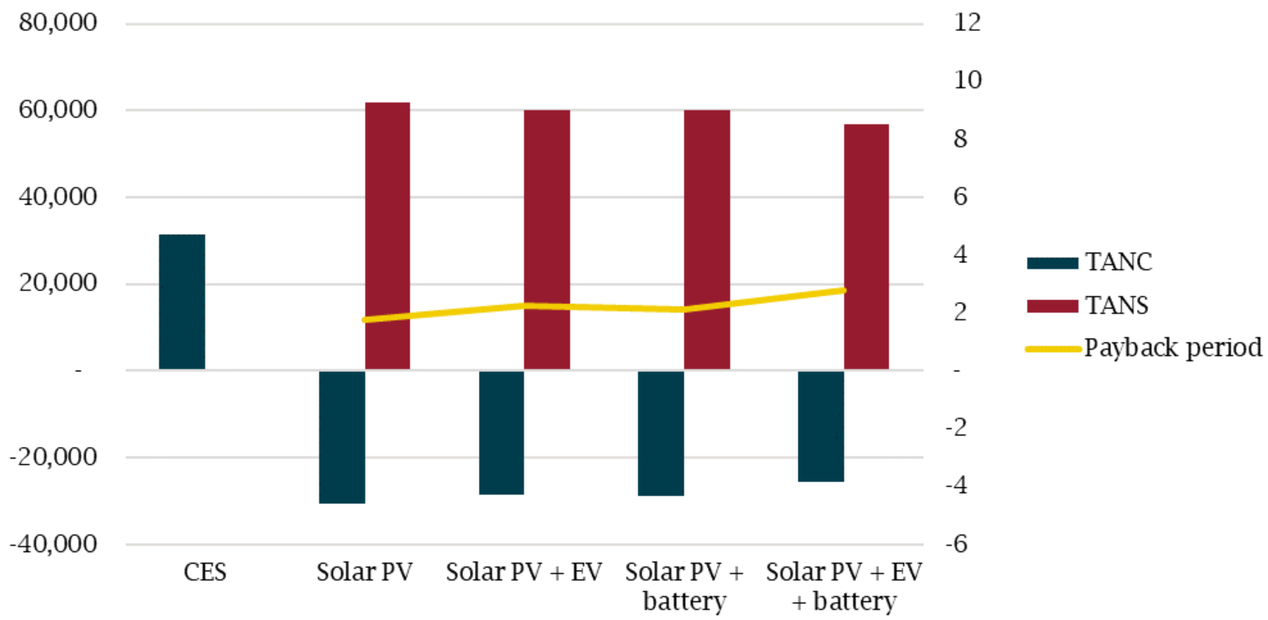
1. **100% of dairy farms' energy needs can be met by DES and substantial surplus is sold back to the grid**

Across the different countries, 100% of the energy required by dairy farms can be met by DES. This is different from supermarkets where UK customers could not cover all of their needs with DES, and differs significantly from fast food restaurants where no country was able to. This means for farms a significant amount of surplus is sold to the grid.

As electricity supply is high in almost every hour that the solar panels are producing electricity, there is a lot of spillover at any time of day. 'Spillover' is the term used in the model to describe when electricity generation is greater than demand, and there is excess electricity that can be either stored in a battery or sold back to the grid. The follow-on from this is that electricity resale price is a major differentiator between countries, as has been described already in the section above.

For Kenya and Mexico – as can be seen below – the combination of significant surplus generated and high electricity resale price means that customers would even make a net profit from switching to DES when the upfront capex costs are annualised (which represents a leasing model).

Figure 23 Incremental analysis for Mexico



Source: Frontier Economics

Note: The yellow line representing the payback period uses the right-hand axis, all other measures use the left-hand axis.

2. Batteries increase TANC across all countries

The high levels of spillover mean that almost all demand is being met by the electricity produced during the day. While dairy farms do require some energy when the sun is not shining, this is a relatively small proportion and therefore adding a battery makes little difference to the level of demand that can be met by DES. The small changes in TANC in Figure 21 between DES combinations with and without a battery in Mexico demonstrate that the cost of purchasing grid electricity when the sun is not shining is small for dairy farms.[38]

In fact, what Figure 21 also shows is that the TANC of installing a battery is greater than the TANC of buying that small amount of electricity from the grid.

In some combinations of DES such as PV + heat pump + battery, a battery can be beneficial but this isn't the case in across all countries.

3. Purchasing an EV instead of an ICE vehicle leads to TANS in some countries

Converting tractors from ICE to EV saves dairy farms £4-6k per year in TANS across Australia, Spain and the UK. This is because the mileage of a dairy tractor is much lower than that of a supermarket van, and therefore the efficiency benefits from an EV are less pronounced even though an electric tractor is 2.5 times as efficient as an internal combustion engine one. However, in these countries the

[38] DES revenues (without a battery) are higher in all countries

diesel price is high, and therefore reducing the amount of diesel purchased outweighs the additional upfront capex from buying an EV tractor compared to buying an ICE tractor.

In Mexico and Kenya, however, the diesel price is low and therefore the additional upfront capex is the stronger effect, and purchasing an EV tractor instead of an ICE tractor increases TANC for dairy farms.

4. **Installing a heat pump reduces TANC modestly in Australia and Spain.**

In Kenya and Mexico, heating demand is so low that it is unlikely dairy farms in these countries would have heating equipment in either the CES or the DES world. They are therefore not included in this analysis.

In farms, the area requiring heating demand is low. For countries like the UK, when there is no battery, the heat demand isn't met by own-production. The capital costs incurred in installing heat pumps along with high electricity costs undoes any savings from cheap gas. However, if a battery is installed, 100% heat demand in the UK is met by own-production which leads to greater TANS.

Australia and Spain are in a sweet spot where irradiance is high, so it covers heating demand, but heating demand is high enough that these countries would have heating equipment and the increased efficiency of a heat pump has a greater effect than the increased capex. The TANS are between £0.5k and £0.9k for these countries.

Detailed results

Table 1 outlines for each country and combination of DES equipment:

- What TANC dairy farms would be facing each year [left];
- The payback period – how many years of annual savings of DES are required before the upfront capex is effectively paid off [right].

A number of factors make up TANC. In the CES scenario this includes:

- The upfront capex (and installation) from purchasing CES equipment, annualised over the lifetime of the asset using the country's interest rate. CES equipment includes gas boiler, air conditioning, and ICE vehicle;
- The O&M costs for each piece of equipment;
- The fuel costs for each piece of equipment.

In the DES scenario, TANC include:

- The upfront capex (and installation) from purchasing DES equipment, annualised over the lifetime of the asset using the country's interest rate. DES equipment includes solar PV cells, battery, heat pump, EV vehicle;
- The O&M for each piece of equipment;

- The fuel cost for any remaining fuel that is not produced using solar PV panels;
- The revenue that is generated from selling surplus electricity back into the grid.

Table 10 TANC and payback periods

	MEXICO		KENYA		SPAIN		UK		AUSTRALIA	
CES	*£31k;*		*£37k;*		*£46k;*		*£58k;*		*£43k;*	
Solar PV	**-£31k;**	**1.8yr**	**-£21k;**	**1.7yr**	**£10k**	**4.2yr**	£27;	5.5yr	**£31k;**	**7yr**
PV + heat pump					£11k;	5.2yr	£28k;	6.6yr	£32k;	8.6yr
PV + EV	-£29k;	2.3yr	-£16k;	2.2yr	£6k;	4.4yr	**£23k;**	**5.5yr**	£30k;	7.3yr
PV + battery	-£29k;	2.1yr	-£18k;	2.0yr	£14k;	5.4yr	£30k;	6.9yr	£34k;	9.2yr
PV + heat pump + EV					£7k;	5.2yr	£24k;	6.4yr	£31k;	8.5yr
PV + heat pump + EV + battery	-£26k;	2.8yr	-£11k;	2.7yr	£9k;	5.9yr	£24k;	7.2yr	£33k;	9.6yr

Source: Frontier Economics

Note: The costs expressed on the left are the TANC, where capex has been annualised over the lifetime of the asset. The payback period is then expressed on the right. CES TANC are in italics as a reference, and the best option(based on payback period) for each country is in bold. As Kenya and Mexico would not install heating equipment, for these countries the results that include a heat pump are replaced by the same combination without a heat pump. For example, the results for PV + heat pump are the same as the results for solar PV.

Annex F - Key tables and charts

Summary of TANC and payback periods across countries and archetypes

Table 11 TANC and payback periods for supermarkets

	MEXICO		KENYA		SPAIN		UK		AUSTRALIA	
CES	*£53k*	-	*£66k*	-	*£67k*	-	*£83k*	-	*£61k*	-
Solar PV	£3k	1.8yrs	£20k	1.7yrs	£42k	4.7yrs	£61k	5.8yrs	£52k	7.2yrs
PV + heat pump					£42k	5.5yrs	£63k	7.0yrs	£51k	7.9yrs
PV + EV	**-£1k**	**1.9yrs**	**£16k**	**1.8yrs**	**£25k**	**3.3yrs**	**£42k**	**3.9yrs**	**£42k**	**4.8yrs**
PV + battery	£10k	3.3yrs	£31k	3.1yrs	£47k	7.6yrs	£61k	7.1yrs	£55k	10.1yrs
PV + heat pump + EV					**£24k**	**3.9yrs**	£44k	4.6yrs	**£40k**	**5.5yrs**
PV + heat pump + EV + battery	£8k	3.6yrs	£30k	3.4yrs	£31k	6.3yrs	£46k	6.3yrs	£44k	7.8yrs

Source: Frontier Economics

Note: The costs expressed on the left are the TANC, where capex has been annualised over the lifetime of the asset. The payback period is then expressed on the right. CES TANC are in italics as a reference, and the best option(s) for each country is in bold. As Kenya and Mexico would not install heating equipment, for these countries the results that include a heat pump are replaced by the same combination without a heat pump. For example, the results for PV + heat pump are the same as the results for solar PV.

Table 12 TANC and payback periods for fast food restaurants

	MEXICO		KENYA		SPAIN		UK		AUSTRALIA	
CES	*£54k;*		*£60k;*		*£52k;*		*£85k;*		*£51k;*	
Solar PV	**£33k;**	**1.8yr**	**£40k;**	**1.7yr**	£39k;	4.1yr	**£73;**	**5.0yr**	£43k;	4.5yr
PV + heat pump					£39k;	4.5yr	£73k;	6.0yr	£42k;	5.0yr
PV + EV	**£31k;**	**1.9yr**	£39k;	1.9yr	**£36k;**	**3.6yr**	**£69k;**	**4.3yr**	**£41k;**	**4.2yr**
PV + battery	£38k;	4.4yr	£47k;	3.8yr	£42k;	7.0yr	£74k;	6.4yr	£45k;	8.0yr
PV + heat pump + EV					£35k;	4.0yr	£69k;	5.0yr	£40k;	4.6yr
PV + heat pump + EV + battery	£36k;	4.1yr	£45k;	3.6yr	£38k;	6.1yr	£70k;	5.8yr	£43k;	7.2yr

Source: Frontier Economics

Note: The costs expressed on the left are the TANC, where capex has been annualised over the lifetime of the asset. The payback period is then expressed on the right. CES TANC are in italics as a reference, and the best option(s) for each country is in bold. As Kenya *and Mexico would not install heating equipment, for these countries the results that include a heat pump are replaced by the same combination without a heat pump. For example, the results for PV + heat pump are the same as the results for solar PV.*

Table 13 TANC and payback periods for dairy farms

	MEXICO		KENYA		SPAIN		UK		AUSTRALIA	
CES	*£31k;*		*£37k;*		*£46k;*		*£58k;*		*£43k;*	
Solar PV	**-£31k;**	**1.8yr**	**-£21k;**	**1.7yr**	**£10k**	**4.2yr**	£27;	5.5yr	**£31k;**	**7yr**
PV + heat pump					£11k;	5.2yr	£28k;	6.6yr	£32k;	8.6yr
PV + EV	-£29k;	2.3yr	-£16k;	2.2yr	£6k;	4.4yr	**£23k;**	**5.5yr**	£30k;	7.3yr
PV + battery	-£29k;	2.1yr	-£18k;	2.0yr	£14k;	5.4yr	£30k;	6.9yr	£34k;	9.2yr
PV + heat pump + EV					£7k;	5.2yr	£24k;	6.4yr	£31k;	8.5yr
PV + heat pump + EV + battery	-£26k;	2.8yr	-£11k;	2.7yr	£9k;	5.9yr	£24k;	7.2yr	£33k;	9.6yr

Source: Frontier Economics

Note: The costs expressed on the left are the TANC, where capex has been annualised over the lifetime of the asset. The payback period is then expressed on the right. CES TANC are in italics as a reference, and the best option(based on payback period) for each country is in bold. As Kenya and Mexico would not install heating equipment, for these countries the results that include a heat pump are replaced by the same combination without a heat pump. For example, the results for PV + heat pump are the same as the results for solar PV.

Table 14 TANS for supermarkets

	MEXICO		KENYA		SPAIN		UK		AUSTRALIA	
Solar PV	49k	94%	46k	70%	25k	40%	22k	29%	8k	14%
PV + heat pump					26k	42%	21k	27%	11k	19%
PV + EV	54k	102%	49k	75%	38k	61%	35k	46%	17k	29%
PV + battery	43k	81%	35k	53%	19k	31%	22k	29%	5k	9%
PV + heat pump + EV					40k	64%	34k	45%	20k	34%
PV + heat pump + EV + battery	45k	86%	35k	54%	33k	53%	32k	43%	17k	29%

Source: Frontier Economics

Note: The savings expressed on the left are the TANS, where capex has been annualised over the lifetime of the asset. The TANS expressed on the right is as a % of CES costs. As Kenya and Mexico would not install heating equipment, for these countries the results that include a heat pump are replaced by the same combination without a heat pump. For example, the results for PV + heat pump are the same as the results for solar PV.

Table 15 TANS for fast food restaurants

	MEXICO		KENYA		SPAIN		UK		AUSTRALIA	
Solar PV	21k	39%	20k	33%	13k	25%	12k	14%	8k	16%
PV + heat pump					13k	26%	11k	13%	9k	17%
PV + EV	23k	42%	21k	35%	16k	31%	16k	19%	10k	20%
PV + battery	16k	30%	12k	21%	10k	19%	11k	13%	6k	11%
PV + heat pump + EV					17k	32%	15k	18%	11k	21%
PV + heat pump + EV + battery	18k	34%	14k	24%	14k	27%	14k	17%	8k	17%

Source: Frontier Economics

Note: The savings expressed on the left are the TANS, where capex has been annualised over the lifetime of the asset. The TANS expressed on the right is as a % of CES costs. As Kenya and Mexico would not install heating equipment, for these countries the results that include a heat pump are replaced by the same combination without a heat pump. For example, the results for PV + heat pump are the same as the results for solar PV.

Table 16 TANS for dairy farms

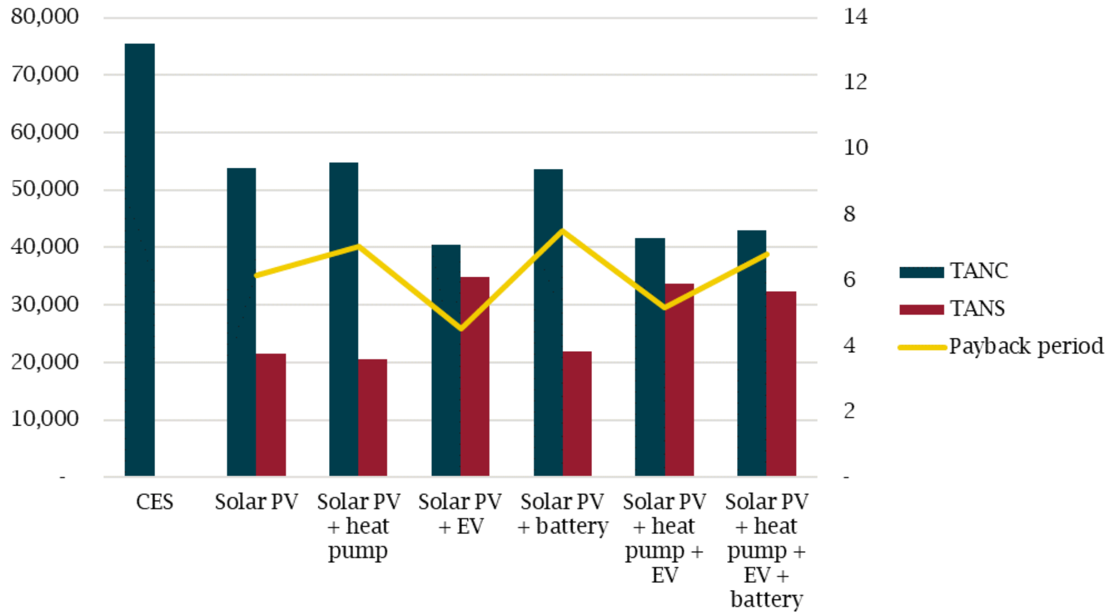
	MEXICO		KENYA		SPAIN		UK		AUSTRALIA	
Solar PV	62k	198%	57k	157%	29k	83%	23k	50%	6k	17%
PV + heat pump					29k	85%	23k	50%	7k	20%
PV + EV	60k	191%	52k	143%	33k	97%	29k	63%	9k	28%
PV + battery	60k	192%	54k	148%	27k	79%	22k	48%	4k	13%
PV + heat pump + EV					34k	99%	29k	63%	10k	31%
PV + heat pump + EV + battery	57k	182%	47k	129%	32k	92%	29k	61%	8k	25%

Source: Frontier Economics

Note: The savings expressed on the left are the TANS, where capex has been annualised over the lifetime of the asset. The TANS expressed on the right is as a % of CES costs. As Kenya and Mexico would not install heating equipment, for these countries the results that include a heat pump are replaced by the same combination without a heat pump. For example, the results for PV + heat pump are the same as the results for solar PV.

Summary of incremental analysis across all archetypes for the UK

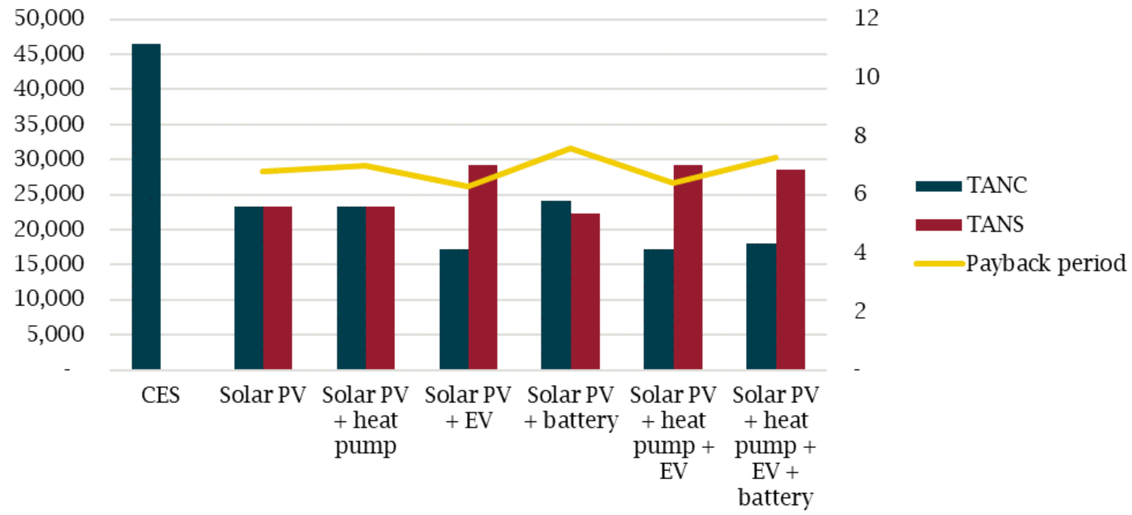
Figure 24 Incremental analysis for supermarkets in the UK



Source: Frontier Economics

Note: The minimum lifetime of an equipment in our model which is 14 years. For some equipment this can go up to 25 years. The coloured bars use the left-hand axis and the yellow line measures the payback period on the right-hand axis.

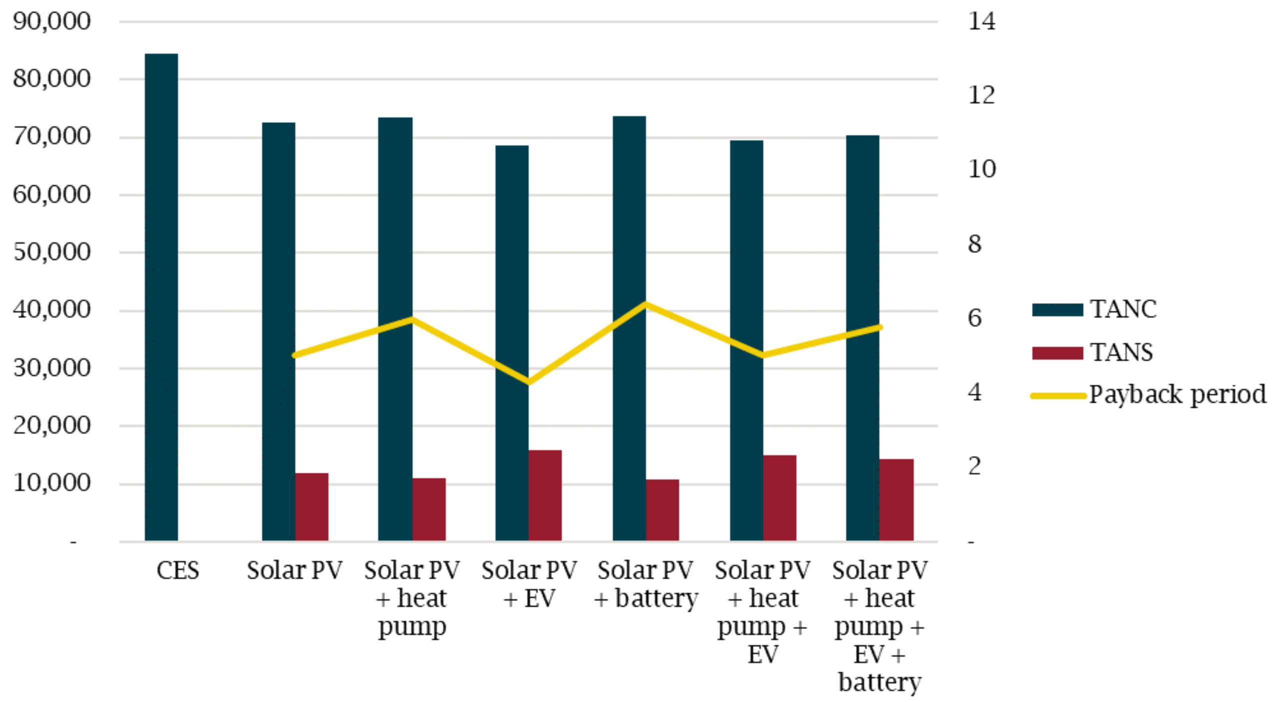
Figure 25 Incremental analysis for dairy farms in the UK



Source: Frontier Economics

Note: The minimum lifetime of an equipment in our model which is 14 years. For some equipment this can go up to 25 years. The coloured bars use the left-hand axis and the yellow line measures the payback period on the right-hand axis.

Figure 26 Incremental analysis for fast food restaurants in the UK

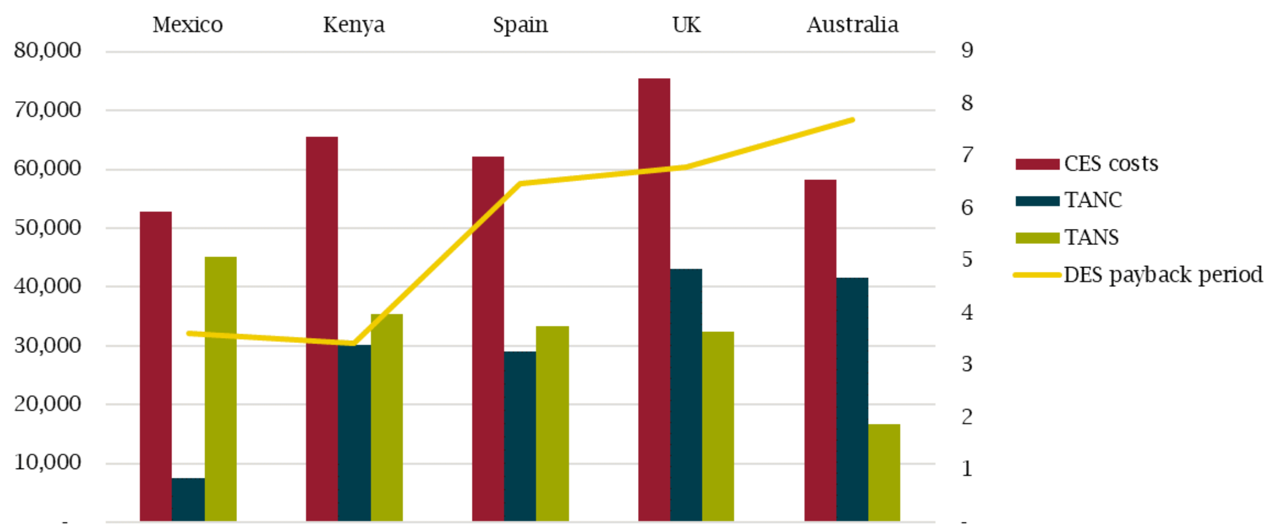


Source: Frontier Economics

Note: The minimum lifetime of an equipment in our model which is 14 years. For some equipment this can go up to 25 years. The coloured bars use the left-hand axis and the yellow line measures the payback period on the right-hand axis.

Summary of cross-country analysis for full DES conversion across all archetypes

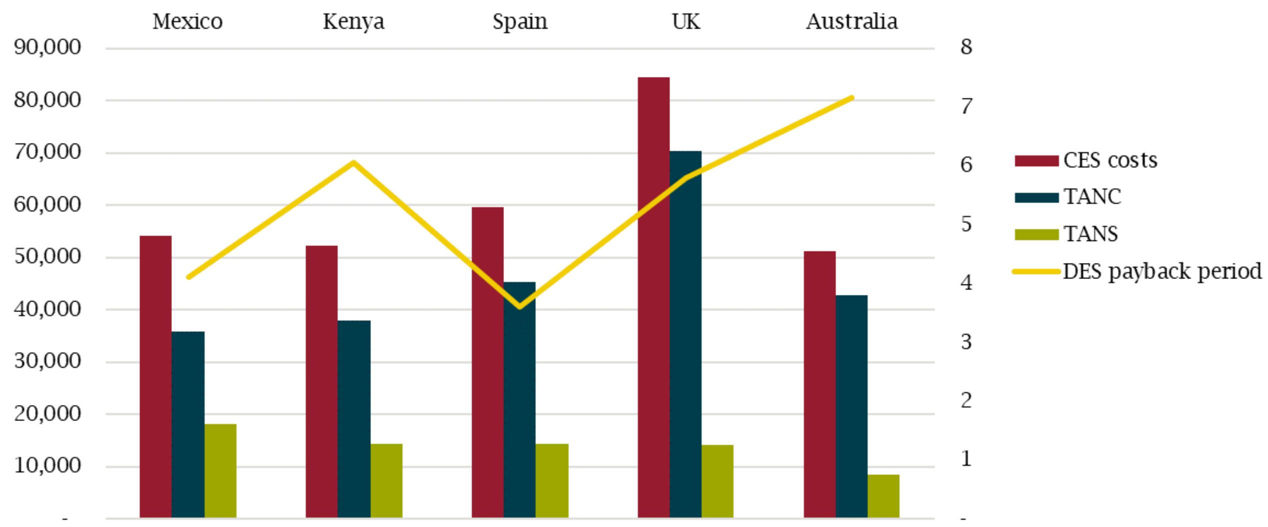
Figure 27 Comparison of DES TANC and TANS - Supermarkets



Source: Frontier Economics

Note: The yellow line representing the payback period uses the right-hand axis, all other measures use the left-hand axis.

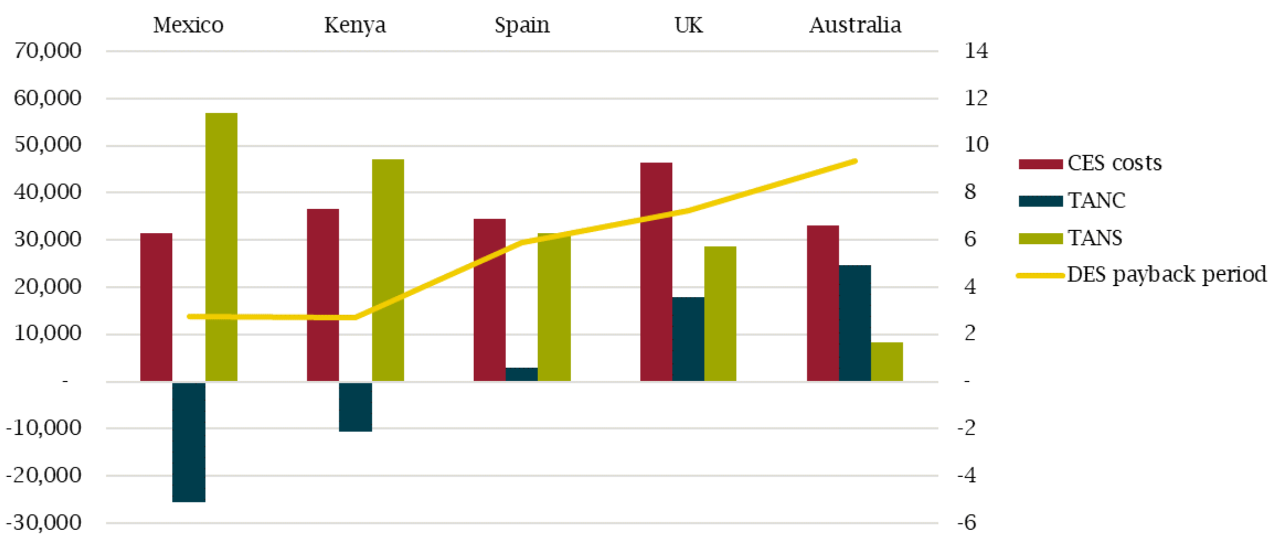
Figure 28 Comparison of DES TANC and TANS - Fast food restaurants



Source: Frontier Economics

Note: The yellow line representing the payback period uses the right-hand axis, all other measures use the left-hand axis.

Figure 29 Comparison of DES TANC and TANS - Dairy farms



Source: Frontier Economics

Note: The yellow line representing the payback period uses the right-hand axis, all other measures use the left-hand axis.

Annex G - Glossary of Terms and Abbreviations

Table 17 Definitions

Term / abbreviation	Definition
CDD	Cooling degree day – a measure of how cold or warm a location is, comparing the mean outdoor temperature recorded for a location to a standard temperature. Can be converted to a measure of cooling demand per metre squared (kWh/m^2).
CES	Centralised energy system - energy system that sources its energy predominantly from the central gas and electricity grid
DES	Distributed energy system - energy system that does not source its energy predominantly from the centralised gas or electricity grids
Electricity grid price	The price a customer pays to purchase electricity from the grid.
Electricity resale price	The price a customer is paid to sell electricity back to the grid.
EV	Electric vehicle – a vehicle that uses electricity to power its motors, instead of fossil fuels (usually petrol or diesel).
Full DES	Purchasing solar PV and a battery, as well as purchasing a heat pump instead of a gas boiler and an EV instead of an ICE vehicle.
Grid intensity	A measure of how much carbon dioxide (equivalent) is emitted per unit of electricity (gCO2e/kWh).
Heat pump	A device that can heat or cool a building. To heat a building it transfers thermal energy from outside of the building to inside. To cool it does the reverse, operating similarly to an air conditioning unit.
HDD	Heating degree day – a measure of how cold or warm a location is, comparing the mean outdoor temperature recorded for a location to a standard temperature. Can be converted to a measure of heating demand per metre squared (kWh/m^2).
ICE	Internal combustion engine – refers to vehicles that have a conventional engine powered by fossil fuels (usually petrol or diesel).
Irradiance	The amount of sunshine in a given place. When applied to solar panels this can be expressed as in kWh/kW/day, i.e. how much electricity can 1kW of solar PV cells produce in a day.
LCOE	Levelised cost of electricity – the £/kWh cost of consuming a unit of electricity. This can take into account either the fuel costs or the equipment required to produce the electricity (or both).

O&M	Operations and maintenance – the annual costs required to maintain a piece of equipment.
Payback period	An accounting concept that looks at the amount of time it takes to recover an investment. In this case, how many years a customer would need to own a piece of DES equipment before the annual savings (compared to CES) have 'paid back' the greater upfront costs compared to the equivalent piece of CES equipment.
Solar PV	Solar photovoltaics – solar electricity panels that capture the sun's energy and convert it into electricity.
TANC	Total annualised net costs – represent the average annual costs customers will be paying over the lifetime of the equipment, including: upfront capex and installation costs (which are evenly distributed over the lifetime of the asset using the nominal interest rate), maintenance costs, fuel costs, and any revenues customers may receive from selling electricity back to the grid (in the case of DES).
TANS	Total annualised net savings – represent the average annual savings customers will experience over the lifetime of the equipment by purchasing DES equipment instead of CES equipment. TANS = CES TANC – DES TANC
Total installation cost	This is the upfront capex plus the upfront installation cost.

Source: Frontier Economics

Note: Definition of cooling / heating degree day comes from here. Definition of payback period comes from here.

Annex H - Data assumptions

Table 18 Daily irradiance factor

Time	Irradiance factor
00:00-02:00	0%
02:00-04:00	0%
04:00-06:00	0%
06:00-08:00	8%
08:00-10:00	16%
10:00-12:00	24%
12:00-14:00	24%
14:00-16:00	16%
16:00-18:00	8%
18:00-20:00	3%
20:00-22:00	0%

Source: Frontier Economics

Table 19 Solar PV Capacity

Season	Unit	Spain	Mexico	Australia	UK	Kenya
Summer	kWh/kW/day	5.17	5.14	4.99	3.59	4.95
Winter	kWh/kW/day	3.66	4.71	4.42	1.64	4.05

Source: https://globalsolaratlas.info/global-pv-potential-study
Note: We use the 80th percentile of solar PV capacity as our default assumption

Table 20 Seasonal days

Country	Summer months	Summer days	Winter months	Winter days	Other months	Other days
Spain	June - Sept	122	Jan - Mar; Nov-Dec	151	Apr - May; Oct	92
Mexico	Apr- Sept	183	Jan; Nov - Dec	92	Feb - Mar; Oct	90
Australia	Jan - Mar; Dec	121	May - Sept	153	Apr; Oct - Nov	91
Kenya	Jan - Jun; Sept-Dec	303	Jul-Aug	62	-	-
UK	June - Sept	122	Jan - Apr; Nov-Dec	181	May; Oct	62

Source: *Frontier Economics analysis using data from https://www.degreedays.net/#generate*

Table 21 Customer archetype assumptions

Metric	Unit	Supermarket	Farm	Fast food restaurant
Roof size	m2	915	260	390
Additional roof space	m2	381*	1,360	163*
Usable roof	%	80%	80%	80%
Transport distance	km/year	144,840	30,303	72,420
Vehicle number	number	3	2	4
Vehicle type		Van	Tractor	Motorbike
Electricity use	kWh/m2	150	385	872

Source: *Frontier Economics desk research*

Note: **Assume 1 parking space per 30m2, and parking space is 12.5m^2 (following UK dimensions).*

Table 22 Heating and Cooling Demand

Country	Unit	Heating demand	Cooling demand
Spain	kWh/m2	63	161
UK	kWh/m2	94	47
Mexico	kWh/m2	17	141
Australia	kWh/m2	83	92
Kenya	kWh/m2	2	199

Source: Frontier Economics analysis using data from ESME 4.3

Table 23 Equipment characteristics

Metric	Unit	Solar PV	Heat pump	Gas boiler	Air conditioner
Energy Use	-	-	Heating/Cooling	Heating	Cooling
Fuel	-	-	Electricity	Gas	Electricity
Efficiency	%	-	270%	98%	270%
Capacity	kW/m2	0.23	0.10	0.25	0.10
Lifetime	Years	25	20	15	15

Source: Frontier Economics desk research

Table 24 Stationary battery characteristics

Metric	Unit	Value
Lifetime	years	20
Efficiency	%	92%
Depth of discharge	%	95%
Degradation	%/year	2%

Source: Lazard

Table 25 Demand Profiles

Supermarket				
Time	**Electricity use**	**Heating**	**Cooling**	**Transport**
00:00-02:00	5%	0%	0%	5%
02:00-04:00	5%	0%	0%	5%
04:00-06:00	5%	0%	0%	5%
06:00-08:00	5%	10%	0%	0%
08:00-10:00	15%	20%	10%	0%
10:00-12:00	10%	10%	15%	0%
12:00-14:00	10%	10%	20%	15%
14:00-16:00	10%	10%	20%	15%
16:00-18:00	10%	10%	20%	15%
18:00-20:00	15%	20%	15%	15%
20:00-22:00	5%	10%	0%	15%
22:00-24:00	5%	0%	0%	10%

Dairy Farm				
Time	**Electricity use**	**Heating**	**Cooling**	**Transport**
00:00-02:00	2%	0%	0%	0%
02:00-04:00	2%	0%	0%	0%
04:00-06:00	2%	0%	0%	13%
06:00-08:00	8%	0%	0%	13%
08:00-10:00	10%	10%	10%	13%
10:00-12:00	12%	20%	20%	13%
12:00-14:00	16%	20%	20%	13%
14:00-16:00	16%	20%	20%	13%
16:00-18:00	16%	20%	20%	13%
18:00-20:00	12%	10%	10%	13%
20:00-22:00	2%	0%	0%	0%
22:00-24:00	2%	0%	0%	0%

Fast food restaurant				
Time	**Electricity use**	**Heating**	**Cooling**	**Transport**
00:00-02:00	3%	0%	0%	0%
02:00-04:00	3%	0%	0%	0%
04:00-06:00	3%	0%	0%	0%
06:00-08:00	3%	0%	0%	0%
08:00-10:00	6%	5%	5%	0%
10:00-12:00	6%	10%	10%	5%
12:00-14:00	21%	20%	25%	25%
14:00-16:00	8%	10%	20%	10%
16:00-18:00	8%	10%	10%	10%
18:00-20:00	15%	20%	10%	20%
20:00-22:00	21%	25%	20%	25%
22:00-24:00	3%	0%	0%	5%

Source: Frontier Economics

Note: The tables below describe the percentage of total daily demand in 2 hour slots for each component of energy use. This is not comparable to actual values of energy demand as it divides the total demand for a specific demand throughout the day. E.g, In the supermarket archetype, cooling demand during 08:00-20:00 is greater than electricity use in terms of % but the kWh demand for cooling is less than that of electricity use.

Table 26 Fuel Prices

Fuel	Unit	Spain	Mexico	Australia	UK	Kenya
Electricity	£/kWh	£0.12	£0.14	£0.12	£0.22	£0.15
Electricity resale	£/kWh	£0.09	£0.14	£0.04	£0.12	£0.15
Petrol	£/kWh	£0.14	£0.09	£0.10	£0.16	£0.09
Diesel	£/kWh	£0.12	£0.08	£0.09	£0.15	£0.07
Gas	£/kWh	£0.07	£0.03	£0.06	£0.05	
Network costs	£/kW	£6.88		£49.75	£17.40	

Source: Frontier Economics desk research

Table 27 Lending rates in 2021

Country	Value
Spain	2.0%
UK	1.1%
Mexico	4.9%
Australia	4.3%
Kenya	12.1%

Source: Frontier Economics desk research

Table 28 Total Installation Costs (CAPEX + Installation Costs)

Appliance	Unit	Spain	UK	Mexico	Australia	Kenya
Solar PV	£/kW	660	790	435	525	430
Battery storage	£/kWh	207	207	207	207	207
Battery power	£/kW	289	289	289	289	289
Battery fixed	£/kW	880	880	880	880	880
Heat pump	£/kW	646	646	-	646	-
EV Van	£/vehicle	50,002	50,002	50,002	50,002	50,002
EV motorbike	£/vehicle	3,500	3,500	3,500	3,500	3,500
EV tractor	£/vehicle	54,533	54,533	54,533	54,533	54,533
Gas boiler	£/kW	65	65	-	65	-
Air conditioning	£/kW	180	180	180	180	180
ICE Van	£/vehicle	43,915	43,915	43,915	43,915	43,915
ICE motorbike	£/vehicle	1,350	1,350	1,350	1,350	1,350

Source: Frontier Economics desk research

Note: Total installation costs remain constant across countries for all equipment barring Solar PVs. There is no heating demand in Mexico and Kenya, hence, no costs on gas boilers and heat pumps

Table 29 O&M Costs

Appliance	Unit	Spain	UK	Mexico	Australia	Kenya
Solar PV*	£/kW/year	12	14	8	9	8
Battery	£/kW/year	22	28	6	31	2
Heat pump	£/kW	8	10	-	11	-
EV Van	£/vehicle/year	244	305	62	347	23
EV motorbike	£/vehicle/year	17	21	4	24	2
EV tractor	£/vehicle/year	266	333	67	379	26
Gas boiler	£/kW/year	5	6	-	7	-
Air conditioning	£/kW/year	4	6	1	6	0
ICE motorbike	£/vehicle/year	16	20	4	23	2
ICE Van	£/vehicle/year	516	646	131	735	50

Source: *Frontier Economics desk research*

Note: *Solar PV O&M is assumed to be 1.75% of capital costs. There is no heating demand in Mexico and Kenya, hence, no costs on gas boilers and heat pumps.*

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