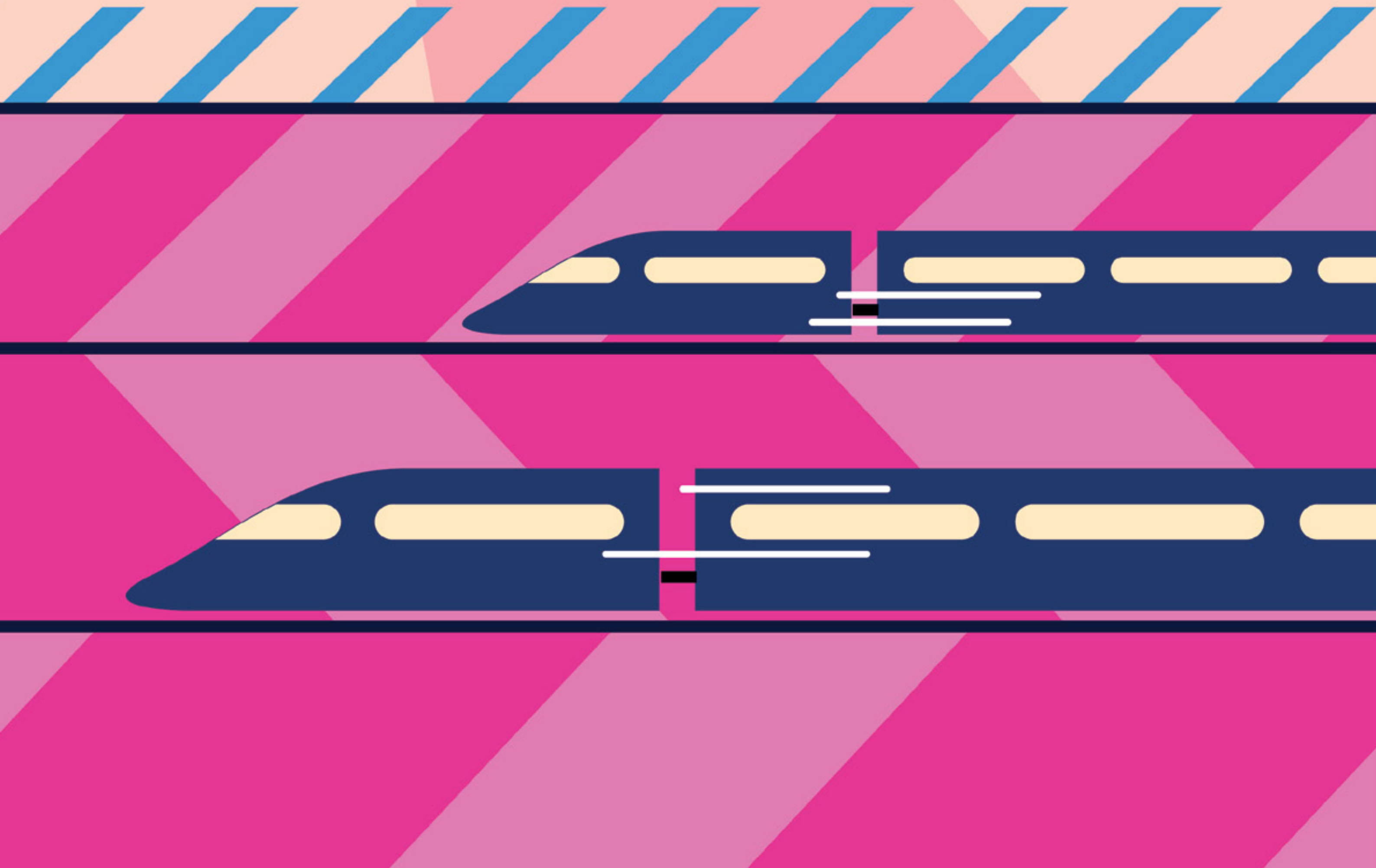
Riding Sunbeams

Powering our railways with solar PV



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10:10 Climate Action

10:10 is a registered charity that exists to help people take action on climate change. Whether we're installing solar panels on schools and community buildings, cooking up a vegan feast, celebrating the power of onshore wind, or lighting up our favourite places with LEDs, we're positive, inclusive and dedicated to cutting carbon. Charity no: 1157 363

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Community Energy South

Community Energy South was established in 2013 as an umbrella organisation and regional hub enabling its members (local community energy groups and community organisations) to grow as sustainable low carbon businesses in the South East of England.

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Turbo Power Systems

TPS specialise in the design and manufacture of auxiliary power converters and battery chargers for the rail industry and distributed generation systems.

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Designed by Matt Bonner and Duncan Geere.

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Foreword

Sometimes a straightforward question leads to much more than one could possibly guess. Repower Balcombe asked why, if the local grid didn't have the capacity to take more solar energy, couldn't they connect straight to the electrified railway that passes through the village instead? Quite quickly you realise that the answer might be more than the solution to one village's problem and possibly something to unlock untapped solar resource on a much wider scale.

When I first heard the question, I felt that the principle was fine but maybe there were just too many detailed barriers to overcome. But that's the sort of challenge an engineer likes and so I was keen to get stuck in. Clearly this is not just an engineering question, one has to know if there is the sort of widespread usefulness to make this worth pursuing. So 10:10 assembled a great team to address the many dimensions of the question and convinced InnovateUK to fund a short feasibility study.

This project has created enormous interest, across the UK and beyond, in solar power for railways. That is a great outcome in itself. Here in this report the case for solar powered railways is analysed in detail and the idea is now ready to take the next steps.

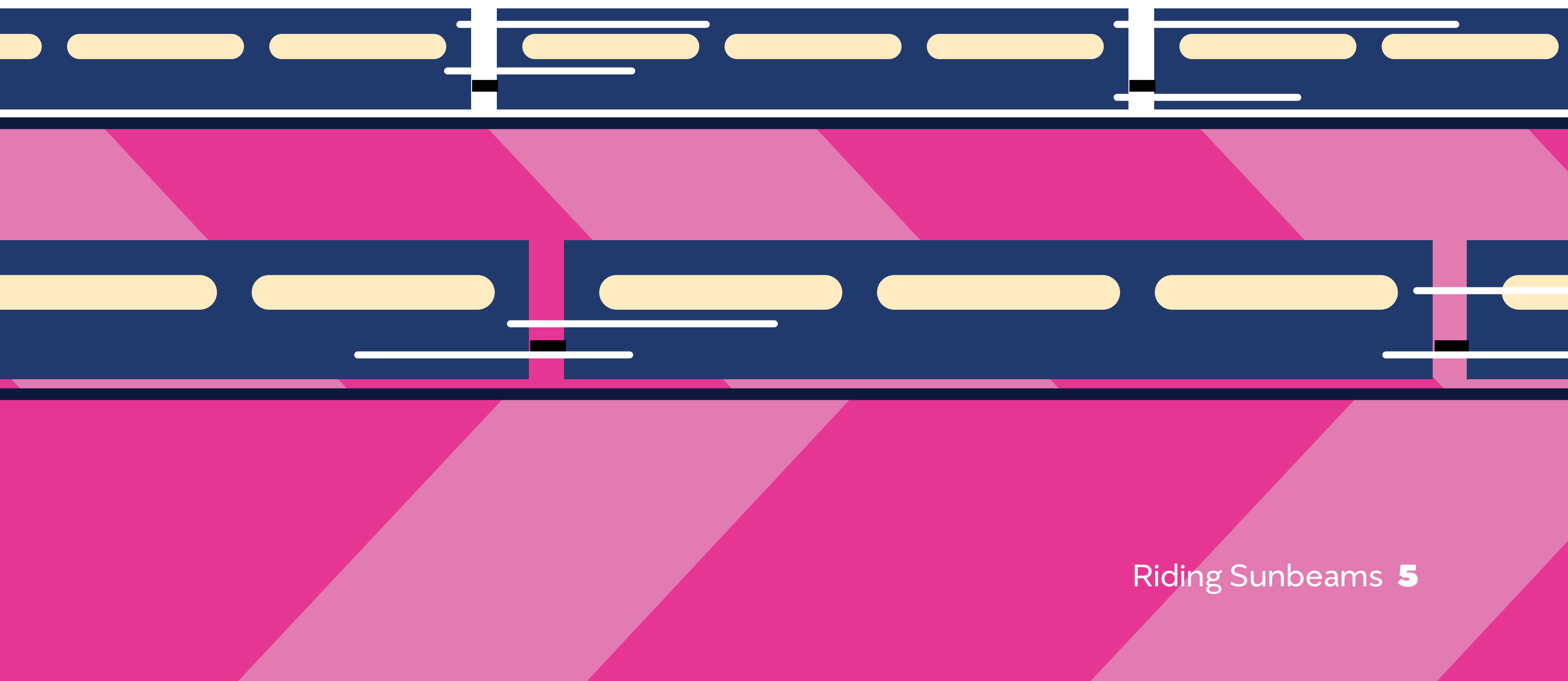
For me, as an electrical engineer, a Balcombe resident and a train aficionado, it is tremendously gratifying to see this idea marching towards becoming a reality.

Professor Tim Green
Director of the Energy Futures Lab, Imperial College London

December 2017

Executive summary

- Using specially designed power electronics, solar PV can be connected directly to electrified railways to power trains, with no need to connect to the grid. However, this has not yet been done anywhere in the world.
- Small solar farms installed alongside Britain's dc electrified tracks could provide around one tenth of the energy needed to power trains on these routes each year.
- Connection costs would be competitive today, meaning solar can already be developed for this market without the need for any public subsidy.
- Solar traction power would be cheaper for rail companies than grid supplied power, even at today's prices. Cost trends indicate this gap will continue to widen into the future.
- There are major opportunities to deploy direct solar traction power on the London Underground, Merseyrail in Liverpool and on the Kent, Sussex and Wessex commuter rail networks.
- Other light rail and tram networks in London, Manchester, Birmingham Sheffield, Blackpool, Nottingham, Edinburgh and Newcastle could also benefit.
- There is enormous scope for solar traction power on railways around the world, for instance in India and Spain. In tropical nations with year round sunshine, new electrified rail lines could even run exclusively on solar power and storage, with no need to rely on local grids.



Introduction

In 2014, 10:10 was helping people in the 'fracking village' of Balcombe in Sussex to develop a community owned solar farm big enough to meet the electricity needs of local people. But we couldn't find anywhere on the local grid to plug that much new solar power in. The distribution network had reached its thermal and voltage maximum, and we were told that connecting new generating capacity at this scale would require an expensive upgrade. Repower Balcombe's technical director, Tom Parker, wondered if we couldn't connect solar PV to the railway that runs through the village instead, to provide traction power directly to trains.

Repower Balcombe eventually found a field outside a neighbouring village with a decent grid connection, and got their 5MW solar farm built in early 2016. But we couldn't shake the feeling that we were onto something. On further investigation, 10:10 found that although electrical engineers agreed that it should in principle be possible to power trains directly with solar, this still hasn't been done anywhere in the world. Why not?

In 2017 we assembled a crack team of experts and won co-funding from Innovate UK's Energy Game Changers competition to answer this question. 10:10 have spent the past nine months working alongside researchers from Energy Futures Lab at Imperial College London, umbrella group Community Energy South, and electrical engineering specialists Turbo Power Systems on a technical feasibility study to assess if and how solar can be used to power trains on dc networks in a way that makes commercial sense for all parties. This report summarises our findings.

Most energy analysts now predict that decentralised renewables like onshore wind and solar will dominate the global energy landscape by the middle of the century. The withdrawal of subsidy support for these technologies in the UK means that Britain must now innovate to find creative ways to maintain our leadership in this transition. Fortunately, this is the sort of thing we are very good at.

If the opportunity outlined here can be realised, this innovation will be a world first which could transform the way electric trains are powered and make a major contribution to global efforts to tackle climate change. We hope you find reading this report as interesting and inspiring as we have found researching and writing it.

Leo Murray
Director of strategy, 10:10 Climate Action

Dr Nathaniel Bottrell
Research Associate, Imperial College London

Why solar railways?

Grid capacity constraints mean new renewable generating capacity can no longer connect affordably across whole regions of the UK.

Withdrawal of subsidies for solar PV means only developments with an on-site final customer are now commercially viable.

Traction power demand from railways is increasing, and railway operators could be supplied with track-connected solar that is both lower cost and much lower carbon than grid-supplied electricity.

Electrified rail lines offer important new market opportunities which could unlock new development of commercial scale solar in the UK and beyond. This is because they represent the ideal client for private wire supply: industrial level power consumption during daylight hours, AA credit rating[1] and a structural imperative to remain in-situ, using all of the electricity generated for the full operational lifetime of the equipment. Unlike most such clients however, their demand is not confined to a single large site, but distributed across thousands of kilometres of track. This constitutes a critical new route to market for solar energy – without the need for public subsidy.

As a climate change charity focused on public participation and cultural change, 10:10 also recognises the opportunity to engage huge new audiences in the low carbon transition through working to connect solar power to our railways. Solar is the nation's favourite energy source by a large margin.[2] Railways were invented by the British, and they still hold a central place in our national identity. Last year, British people made over 8 billion commuter journeys by rail.[3] The view from the train window on these trips is indelibly etched into the British cultural psyche – making such vistas ideal places to put solar panels.

Moreover, by initially pursuing a community-led development model, we hope to invite commuters and railway workers to cooperate with lineside communities to crowdfund investment in the first wave of renewable traction projects made possible through this work.

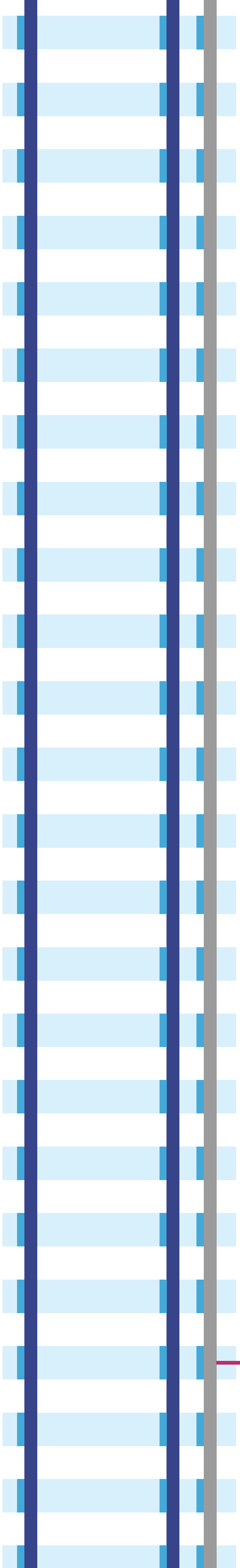
AC vs DC

Globally and within the UK, most electrified rail is powered by the alternating current (ac), overhead catenary cables system. Overhead, high voltage ac (typically 25kV) is safer, and better for high speeds and long distances. Third rail direct current (dc) tends to dominate in urban areas, largely because it is difficult and expensive to install overhead catenary cables on networks that frequently travel through tunnels below ground and under bridges and roads.

Our study focused on dc traction systems, partly due to the nature of decentralised renewable electricity generation. Solar PV arrays typically output direct current power at between 600 and 800 volts. Rail networks that use dc traction power typically operate at 750 volts.[4] This coincidence means that the costs of the power electronics needed to connect solar to dc traction networks should be competitive with typical grid connection costs. It also offers the prospect of reduced losses from avoiding dc to ac conversion to export power from PV to a conventional grid and ac to dc conversion to supply the rail network. Instead a single dc to dc voltage matching conversion can be used. We estimate that supplying dc power directly to dc traction substations should yield 4 – 5% more useful electricity from a given solar farm compared with a standard grid export model.

Direct current traction networks also have the advantage of closely spaced infrastructure to which solar PV could connect. Traction substations and track paralleling huts are located approximately every 3km or so along dc electrified routes. Because private wire supply from solar farms can be effective over distances of up to 2km, this means most lineside land will be within reach of a traction network connection. By contrast, on ac electrified routes substations can be up to 80 km apart – making them far more limited as an alternative route to market for distributed energy sources.

Connecting distributed renewable energy generators to alternating current railway traction systems remains a promising possibility, particularly where connections can be integrated during new electrification works. This opportunity should be factored into future UK rail electrification planning. Each ac traction substation covers a large length of the track and could connect a large solar PV array (or even wind or hydro generation) to the grid supply point. On ac electrified routes, there are also autotransformer sites, typically spaced every 10 km to boost the ac voltage.[5] The possibility of connecting solar to these should be explored.



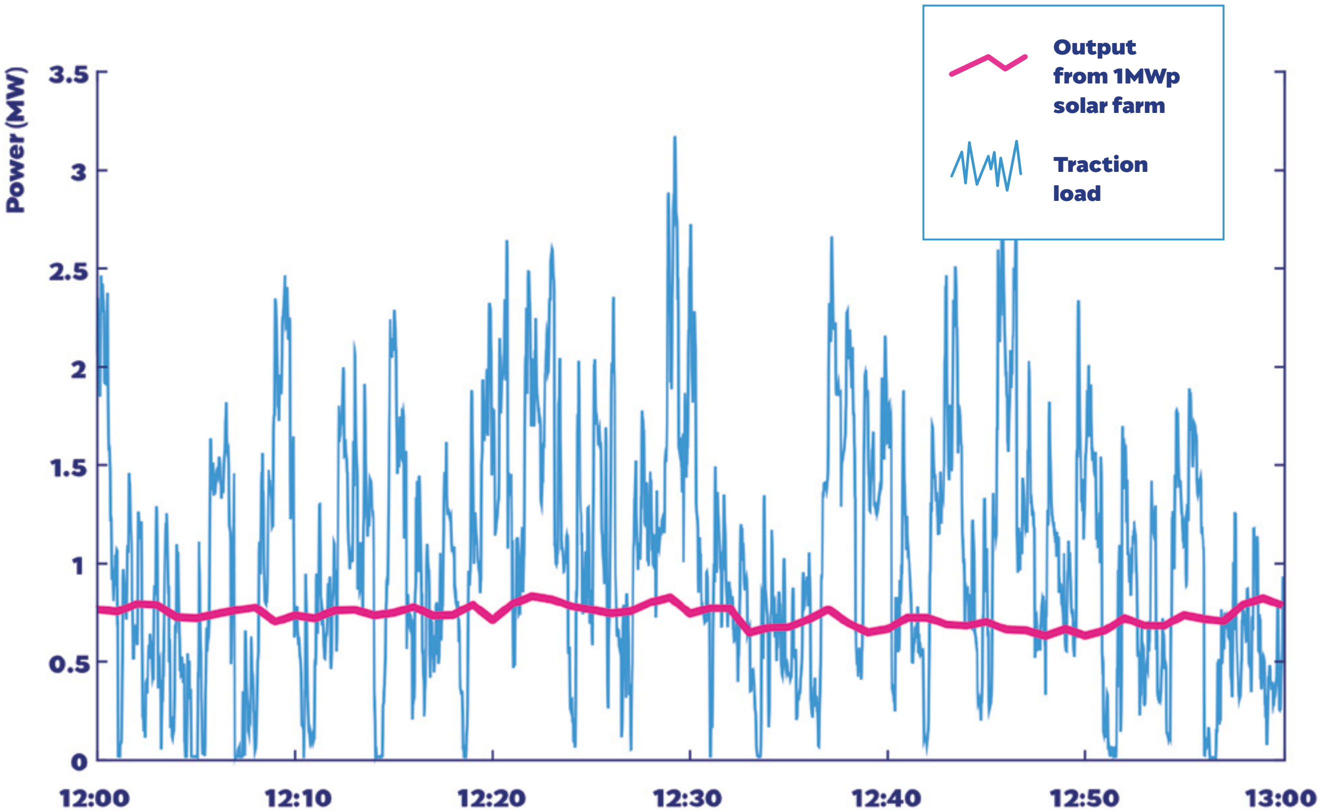
Engineering challenges

Intermittency

The traction load on the railway and solar generation are both intermittent, so they need to be matched as closely as possible for solar traction power to be effective: the intermittency of the dc load needs to be reconciled with the intermittency of the dc generation.

Direct current traction substations can be placed between 2km and 8km apart.[6] A train travelling at 100km/h will take just under five minutes to travel between each traction substation, and each train may consume up to 4MW of electricity. This causes large changes in the power supplied at the substation as the traction load is only supported for a short duration while the train is travelling past. If there are no other trains in the area, the demand will quickly fall to zero once the train has passed. In sections of track where there is a high frequency of trains, the substations can be said to have a base load. From the UK data analysed, this base load is approximately 1MW, with frequent peaks between 3MW and 5MW. The pattern of the trains and location of the traction substations will affect the base load and the load peak observed. Train frequencies vary widely across the dc network, for instance the stations at Seaford in Sussex and at Clapham Junction in London have, respectively, train frequencies of four trains per hour (two in each direction)[7] and 180 trains per hour during weekday services.[8]

Fig. 1
Hourly traction substation demand vs solar generation



To minimise losses in the traction system, the interface dc-dc converter should not export to the rail unless there is a train in close proximity. Exporting when there is no train close by will cause the power to be passed through the conductor rail to trains further down the line. This increases power losses and causes the local voltage to rise, perhaps exceeding the maximum permitted traction voltage. The interface converter will be required to rapidly change its power export to supply a train when it appears in section and either curtail generation or use storage technologies when there is no train close by.

Traction dc voltage

Changes in load as trains pass will cause a rapid change in voltage, with a voltage sag corresponding to each peak in load. The power that flows from each traction substation and the voltage present at the track depend on impedance of the dc network, the impedance of the rectifier (ac-dc converter) and the impedance of the ac network. The interface converter for the PV will need to be designed such that it is able to export power under different track voltage conditions. Although the nominal voltage of the third rail network is 750Vdc, it is permitted to range between 400Vdc and 1000Vdc. It is likely that the efficiency of the converter will reduce when the voltage falls below the nominal voltage of 750Vdc. If sufficient generation is available, it may be possible to maintain the rail voltage near the nominal voltage by controlling the power exported to the rail network.

Protection

Connecting distributed generation to a traction supply system could affect the protection system that is there to deal with faults in the electrical network and keep the system safe. One example of an electrical fault is a short circuit event where a large current, known as the fault current, will flow from the supply system to the location of the fault. Typically, protection will detect the fault and operate to isolate the section of track which is experiencing the short-circuit fault. Over-current devices are rated to interrupt a maximum fault current and if the current exceeds this maximum then the protection may not operate correctly. Adding generation increases the fault current and although power electronic converters are constrained in the amount of fault current they add, they may still add current up to their maximum rating. In a network which has already high fault currents, this increase could cause the current to be above the current rating of the protection equipment.

Distributed generation can also change the behaviour of a protection system, possibly blinding the protection by masking the location of the fault and not operating and isolating the track when there is a short circuit. We propose to avoide this by connecting the PV generation at the substation in parallel with the existing traction rectifier transformer. Any protection settings will need to be reviewed at substations which have distributed generation connected.

The proposed solar PV will be connected to the traction substation via a dc cable which may need to travel across public or private land not owned by Network Rail or the solar site. A protection system must also guard this cable and be sufficient such that if it were damaged, the supply to the cable would be immediately isolated to prevent large currents from causing significant damage to equipment or personnel. By placing a converter at either end of the cable, the fault current can be limited by the power electronics. Over-current protection will not be sufficient to detect a cable fault because of the low fault current from the converter. By measuring the impedance of the cable, it should be possible to detect a dc cable fault. A communication link installed alongside the cable will enable the two converters to quickly disconnect the supply after a cable fault has been detected.

Network Rail need to be able to isolate sections of the dc network for maintenance or to allow emergency access to the tracks. The solar inverters must be able to detect when the supply is switched off or receive a message to disconnect.

Train operation

Equipment connected to the traction supplies must not interfere with safety critical systems like signalling and the automatic train stop. It must allow the rail network to operate as normal. Train delays caused by solar equipment connected to the rail system could give rise to large compensation bills.

One railway feature of importance is that trains entering into stations or stopping at red signals may use regenerative brakes, a system by which their kinetic energy is converted back into electrical energy. The regenerative braking system allows energy to be recaptured and reused, but will cause the traction voltage to rise if there is not another train in the vicinity consuming electricity nearby. Any locally connected generation that also causes a voltage rise may prohibit or reduce the amount of regenerative braking which can be absorbed. Connecting solar to a location where trains often regeneratively brake could also curtail the amount of generation which can be supplied to the network.

Additional challenges

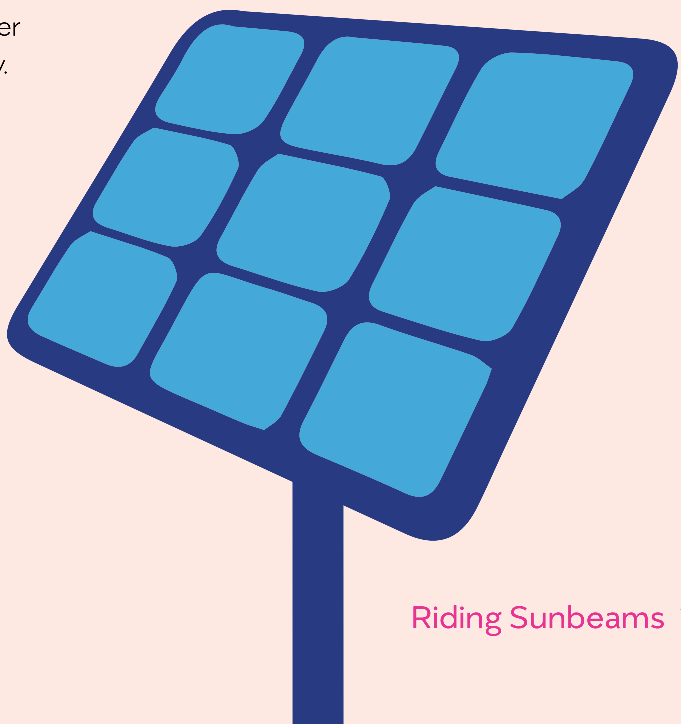
Metering

Solar generation connected to the distribution network is metered using a CoP 5 meter for installations between 100kW and 1MW and a CoP 3 meter for installations between 1MW and 10MW.[9] These meters measure ac power at half hour intervals. Our solution connects a dc source to a dc load and would require a dc meter accredited for half hourly billing.

Track connection

Any equipment requiring track access may only be accessed by specially trained personnel following strict safety guidelines. To minimise the cost of the solar installation, as little equipment as possible should be located inside the track boundary.

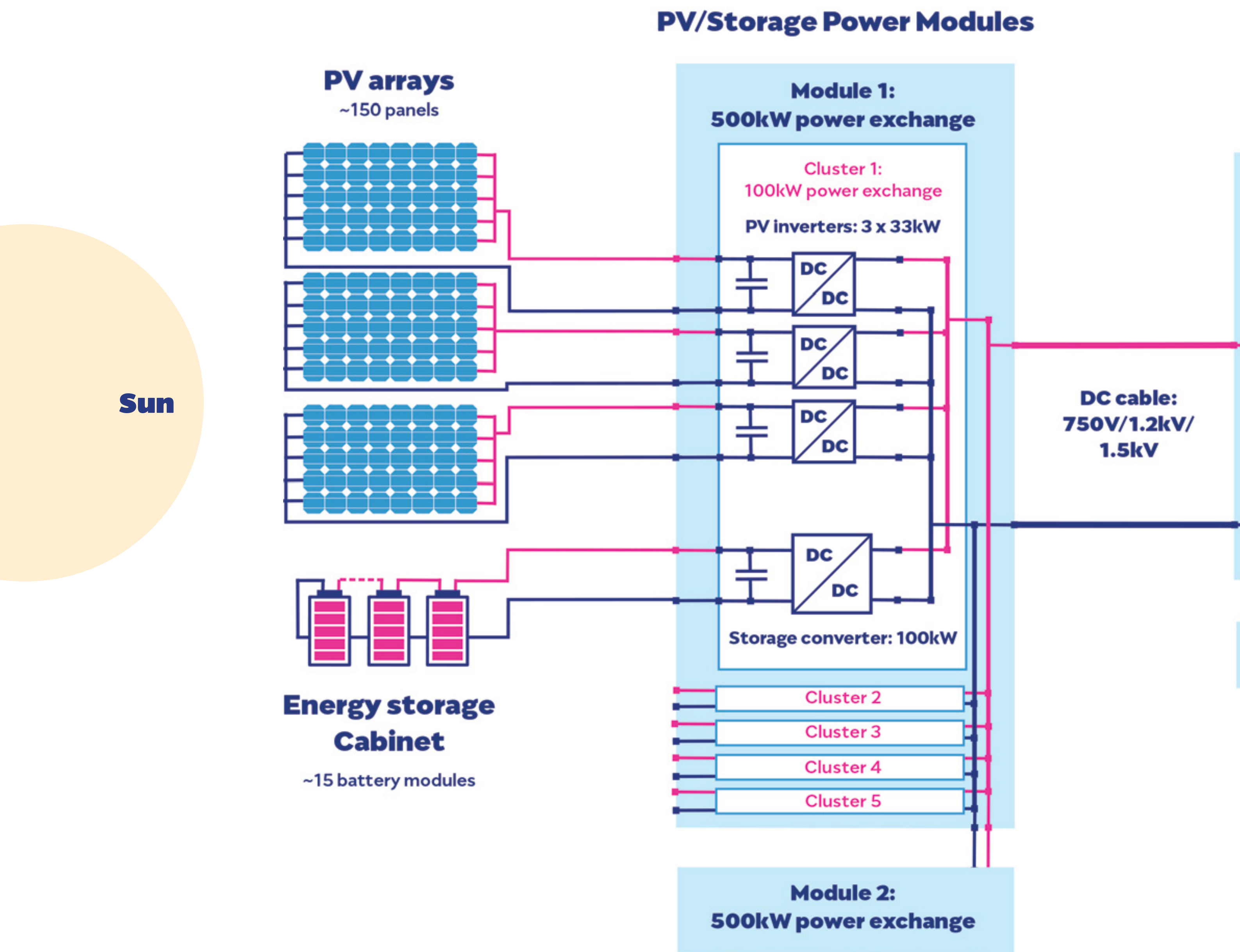
All equipment connected to the rail network must be approved by Network Rail, and new equipment developed could take three years to be accredited for connection to the rail network. This adds substantial cost to equipment development and could act to deter connection of solar PV to the traction supplies. The dc billing meter would also require certification to the appropriate standards.



Converter design

An assessment of a wide variety of possible dc-dc power converter circuits led to the selection of the dual active bridge as the interface converter between the rail and the solar generation. The dual active bridge is a bidirectional dc-dc converter which uses a high frequency transformer to provide galvanic isolation between the traction voltage and the voltage at the solar generation. Galvanic isolation physically and electrically isolates the track supply and allows the rail voltage to float with respect to the solar generation. Providing galvanic isolation should protect the solar generation from voltage transients that cause the local ground potential to change and attenuate any high frequency noise from propagating and damaging the storage system or PV panels. Voltage transients can be caused by arcing between the conductor rail and train, lightning strikes on the track and other electromagnetic disturbances.

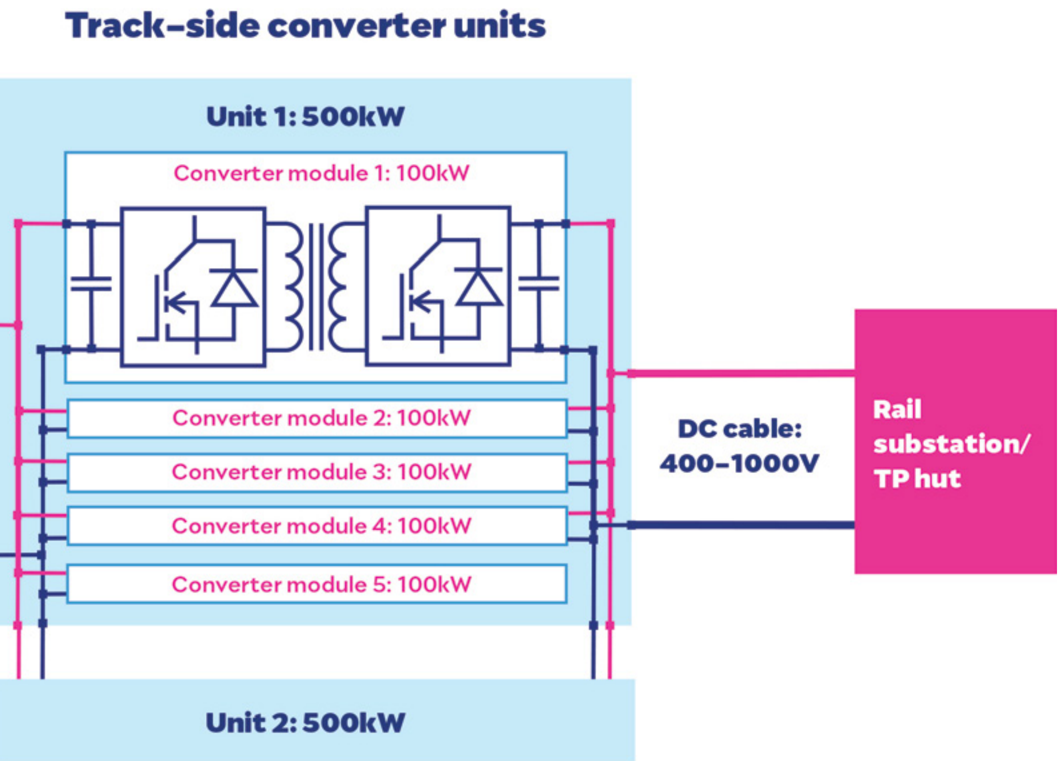
Galvanic isolation provided by the high frequency transformer in the dual active bridge converter also provides a high conversion efficiency when there is a large difference between the low voltage side and



the high voltage side. This would apply if interfacing to a non-UK train or tram network at 1,500 or 3,000 Vdc, or as one stage of conversion towards high voltage ac. The transformation ratio can be chosen to suit each application and maintain good efficiency. A high frequency transformer has a much higher power density than a low frequency transformer which helps reduce the volume of the device.

The dual active bridge allows for soft switching of the power electronics, a technique which reduces the power losses and improves the efficiency. Typically, this is only applicable for operation at the intended voltage conversion ratio and when the converter is operating near full load. Various control strategies are being proposed in the research literature to increase the efficiency and ability for soft switching at low load.

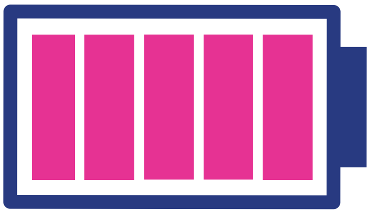
Fig. 2
Proposed solar traction converter schematic.



Storage technologies

Storage is the enabling technology which allows the intermittent generation to be interfaced with the intermittent load on the traction network. The obvious energy storage technology is a battery, which will be described first, but it is not the only option.

A key parameter in determining the characteristic of a battery is the discharge current, often defined as a "C-rate", as a way to normalise against battery capacity and allow comparisons to be made. A 1C rate means the battery discharges its entire capacity in one hour, a 2C rate is a discharge at twice the current and would discharge the battery in half an hour. The C rate is often limited by the rating of the interface converter. Storage with a low C rating would take a long time to charge and discharge the battery. Both the C-rate and the total capacity are features that need to be chosen to suit a particular application.



Each storage technology also has a limit to the number of charge-discharge cycles it can achieve before reaching its end of life. Each cycle is usually counted from a high state of charge to a low state of charge. Reaching the lifetime cycle limit generally means that significant reduction in capacity will have occurred or a high leakage (self-discharge) will occur, rather than a complete failure to operate.

The storage technology and converter may be sized to charge the storage technology when there is no train in the section and discharge when a train is near the connection of the solar generation. Alternatively, it may be sized to charge the battery throughout the day in between the trains and discharge the battery later when the solar output is low, such as during the evening peak train service and following morning. Discharging the storage when a train is near requires the interface converter to transfer the solar PV power and storage power simultaneously, and requires a storage technology which has a high C rating and a high cycle rating. Discharging the storage during the evening and morning peak requires a storage technology with a high energy density. The cycle rating or C rating is not critical since the storage technology may only be cycled once per day and the converter would not be sized to discharge the battery quickly.

Supercapacitors and flywheels have a high C rating and a high cycle rating. Although their storage capability is increasing as the technology advances, their energy density is lower than that of other technologies. Supercapacitors are suited to the case for discharging rapidly when a train passes and are capable of many discharge cycles before replacement is required. Lithium technologies, redox flow batteries and zinc hybrid batteries all have high energy densities. These would be suitable for charging when the solar generation is available but there is no traction load, and discharging gradually during the evening peak once the solar PV generation has decreased. A proportion of the storage energy could also be used to support the traction loads during the morning peak. By using storage with a large energy density, extra capacity could be added to the network without requiring more traction substations connected to the distribution network. A forecasting algorithm could be used to estimate the expected PV generation for the following day. Any shortfall of generation could be supplemented by charging the battery the previous night when there is less demand on the traction network.

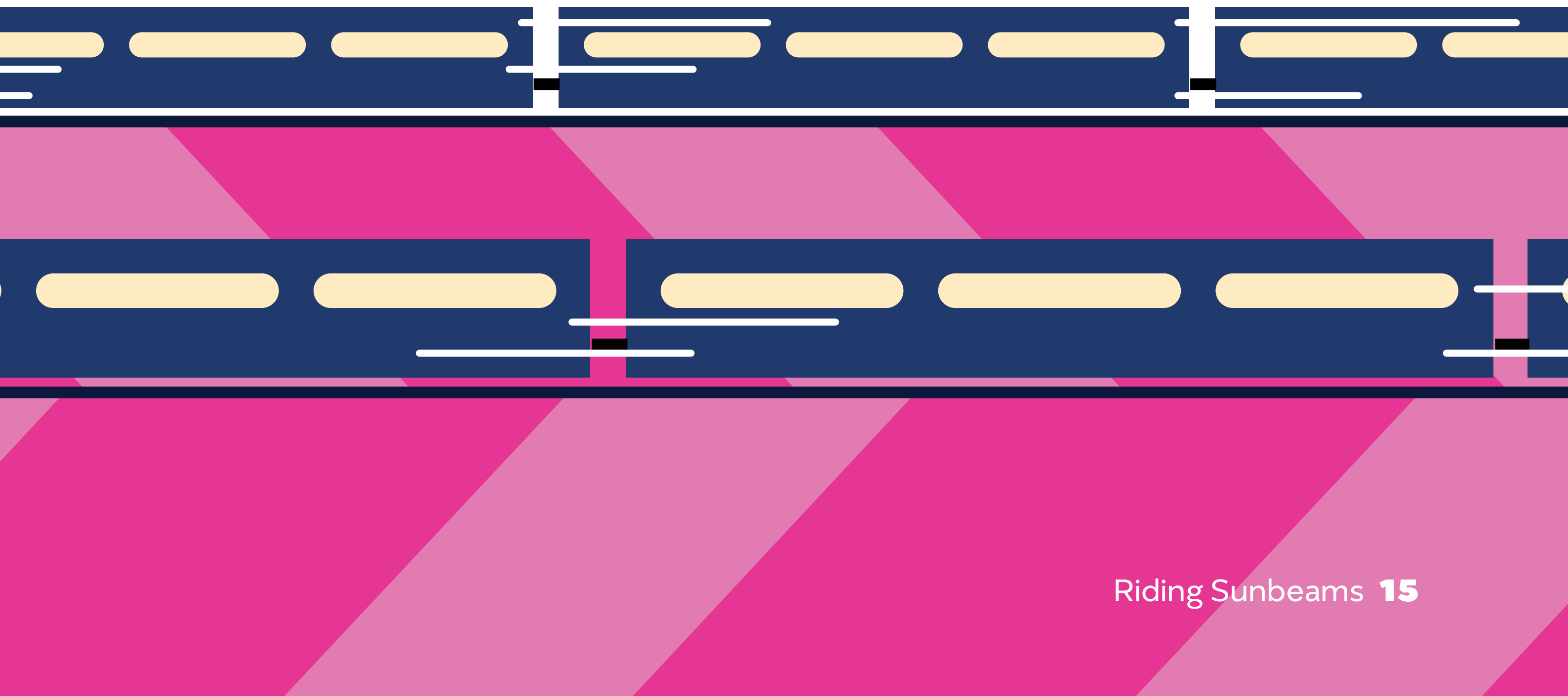
Storage technologies are evolving rapidly, with clear trends showing power and energy densities increasing and costs decreasing.

Sizing the energy storage

The amount of power generated by a solar PV installation in the UK has a large variation between the peak in the summer and the peak in the winter. Sizing any storage for the summer peak will mean the storage is underutilised during the winter peak, but reducing the size of the storage will mean that not all the energy from periods of maximum generation can be exported to the track. We need to balance the price of the electricity generated, the cost of the PV installation and the cost of the energy storage so that the returns from the solar installation can be maximised.

Connection locations

It is recommended that the solar generation is connected at the traction substations or track-paralleling huts. The connection can be placed between the output of the existing rectifier substation and dc circuit breakers. This ensures that the dc track can be isolated when necessary. Protection studies would need to be undertaken to ensure that the addition of the generation does not exceed the fault current rating in the event of a short circuit.



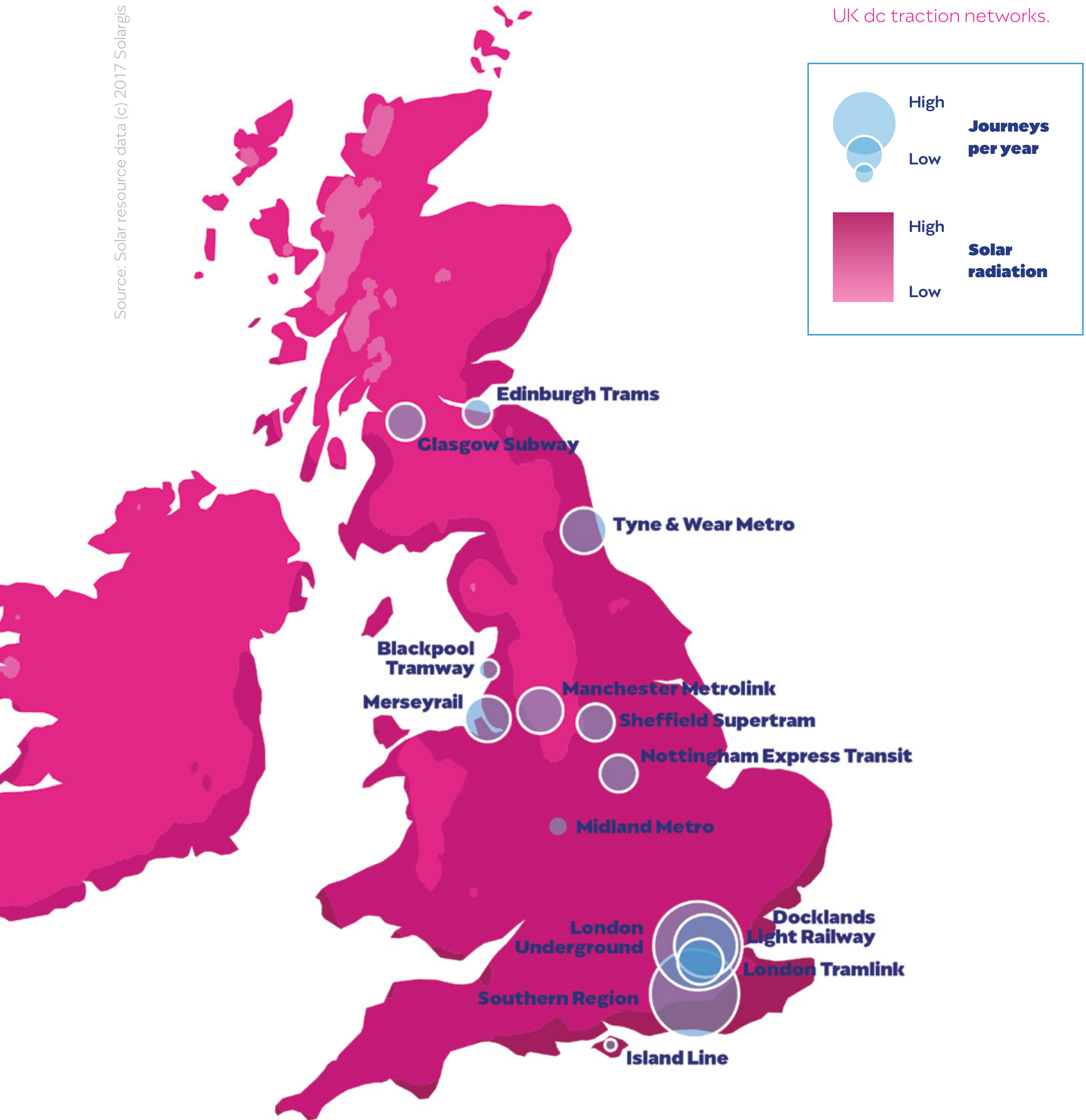
Opportunities in the UK

Approximately one third of the UK's existing ~5,300km of electrified rail network uses the third rail dc system to provide traction power to trains, with the rest using the 25kV ac overhead system.

Most of this dc traction network is spread across the South of England, spanning the Kent, Sussex and Wessex routes (the Southern Region). There is a second, smaller concentration around Liverpool's Merseyrail network, while the London Underground network comprises an additional 408km of dc electrified track. The following pages explore these three key markets in detail.

Source: Solar resource data (c) 2017 Solargis

Fig. 3
UK dc traction networks.



There are also a number of smaller city metros and tram systems which would be suitable for solar traction power. UK tram networks carry around 100m passengers each year,[10] with the largest, Manchester Metrolink, spending over £7m each year on traction electricity. It has routes running through former industrial areas with plenty of opportunities for solar PV on large roofs and brownfield sites.

It is important to note that in all of our UK opportunity mapping, we have not examined solar potential on trackside land in our analysis, focusing instead on lineside land and roof space, most often owned by third parties. Trackside working presents large additional costs, operational constraints and practical challenges, meaning it is not likely to be commercially viable under the present conditions.

Clearly though, Network Rail and Transport for London are large property owners in their own rights, and ultimately the vision here is to install solar PV along currently unproductive rail corridors and sidings. Previous analysis has suggested Network Rail could receive large potential financial benefits from adopting this approach at scale.[11]

Network Rail

Network Rail is the single biggest unregulated consumer of electricity in the UK,[12] procuring around 3.2TWh of electricity centrally for the entire rail industry each year.[13] This is equivalent to roughly 1% of the UK's total electricity demand.

Network Rail have explicitly targeted direct supply of renewable traction power as a priority for Control Period 6 (2019-2024) via a new formal Challenge Statement: "Using Large Scale Renewable Developments to Enable Decentralised Supply to the Rail Infrastructure."[14] This identifies "developing solutions to enable private-wire generation directly to the traction or non-traction infrastructure" as a specific research need, and recognises the important business opportunity for Network Rail in pursuing this agenda.

This report is the first major contribution to meeting this challenge.

Network Rail engineers have carried out a preliminary appraisal of options for using alternative energy sources on their traction systems. This identified solar PV plus storage, integrated at dc traction substations, as the option offering the greatest potential benefits to their networks.

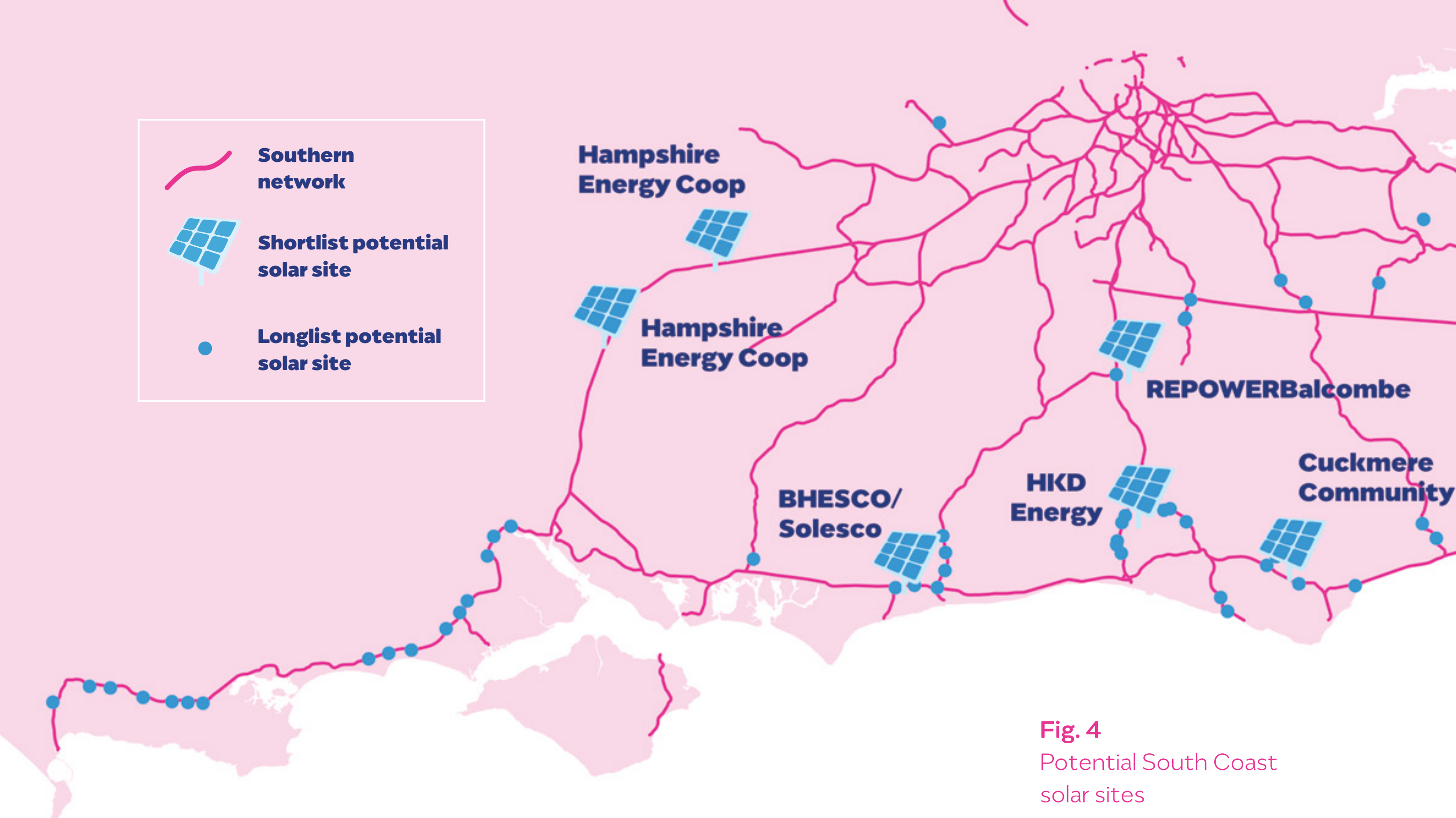


Fig. 4
Potential South Coast solar sites

Southern Region

The Kent, Sussex and Wessex routes together consumed 1.38TWh of traction electricity in 2015/16, at a total cost to train operators of £114m.[15] Our analysis indicates that each dc traction substation in the Southern Region should on average be able to comfortably accommodate intermittent supply from a connected ~1MWp solar array. This scale of solar capacity should be big enough to support the fixed development and connection costs for each array. In most cases this would mean the array would provide 100% or more of the substation's traction demand for four or five months of the year (roughly, May–August). At these times, any surplus would flow onto neighbouring track sections, implying that we should avoid connecting solar PV at this scale to contiguous substations.

The South of England enjoys some of the highest solar irradiance levels in the UK, but it is also home to some of the most congested electricity distribution networks.[16] Community Energy South's (CES) members have conducted a high level audit of land use constraints around the 540 traction substations on the Southern Region. Their findings suggest that around three quarters of these have suitable lineside opportunities for solar development.

Southern Region Solar Potential

15% of the Southern Region's total traction demand.

If 1MWp solar farms were developed and connected at half of the 400 or so suitable locations, this would generate the equivalent of 15% of the Southern Region's total traction electricity demand – currently a £17.1m a year market. This percentage assumes that storage is used where necessary; so the commercially optimal proportion may be somewhat lower, but will certainly exceed 10%. As storage costs continue to fall over the coming years, the commercially optimal proportion will rise as a consequence.

CES' work has also produced a long list of over 50 technically viable sites, and a shortlist of seven of the most promising sites. These are displayed on Figure 4 alongside their prospective community developers. This shortlist is likely to be the focus of any future pilot phase.

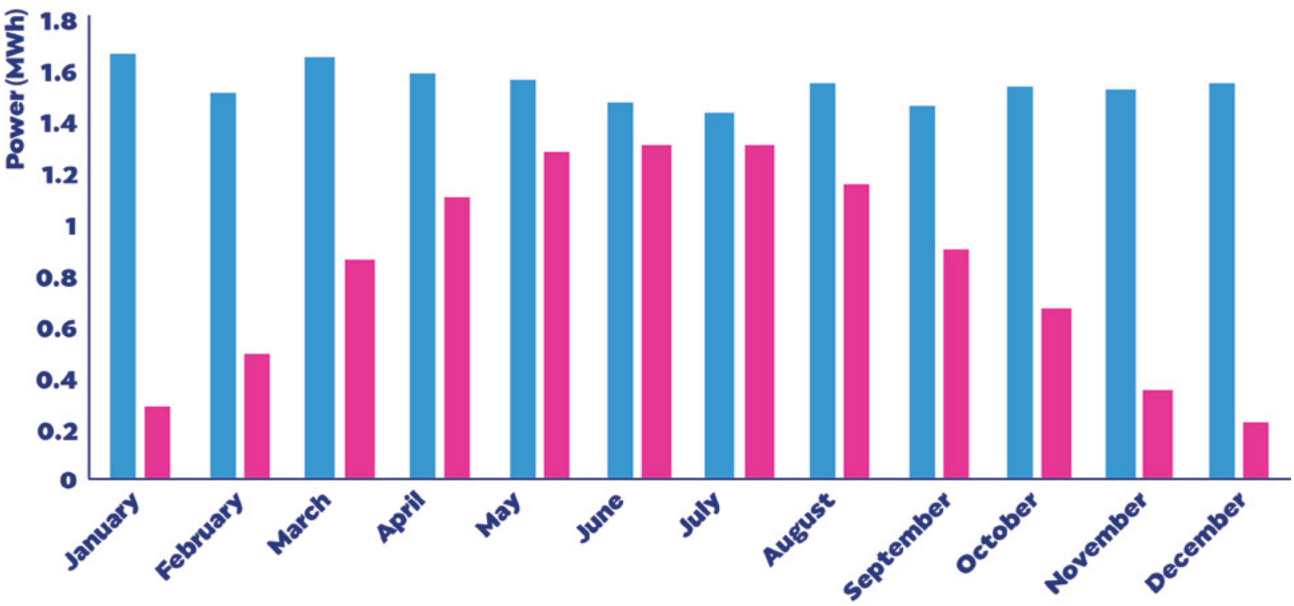


Fig. 5
Traction substation demand vs solar generation.

London Underground

The London Underground currently consumes around 1.3 Terawatt hours of electricity each year at a cost of roughly £100 million. Approximately 85% of this is used for traction purposes. Service frequency and demand for traction power at any typical point on the tube network are significantly higher than for the Southern Region; for instance, trains run every 100 seconds on the central Victoria line. This means substations on the tube could handle on average 1.5MW of solar input, but in the busiest sections of the network, this could be as much as 10MW.

Land use constraints around central London mean the scope for powering the tube with solar is limited, and potential sites are likely to be more complex and challenging to develop than more rural locations. Nevertheless, our high level desktop analysis identified a prospective 70MWp of practical solar resource at just over 50 separate sites in and around London which could in theory host large enough solar arrays to connect to the tube's traction system.

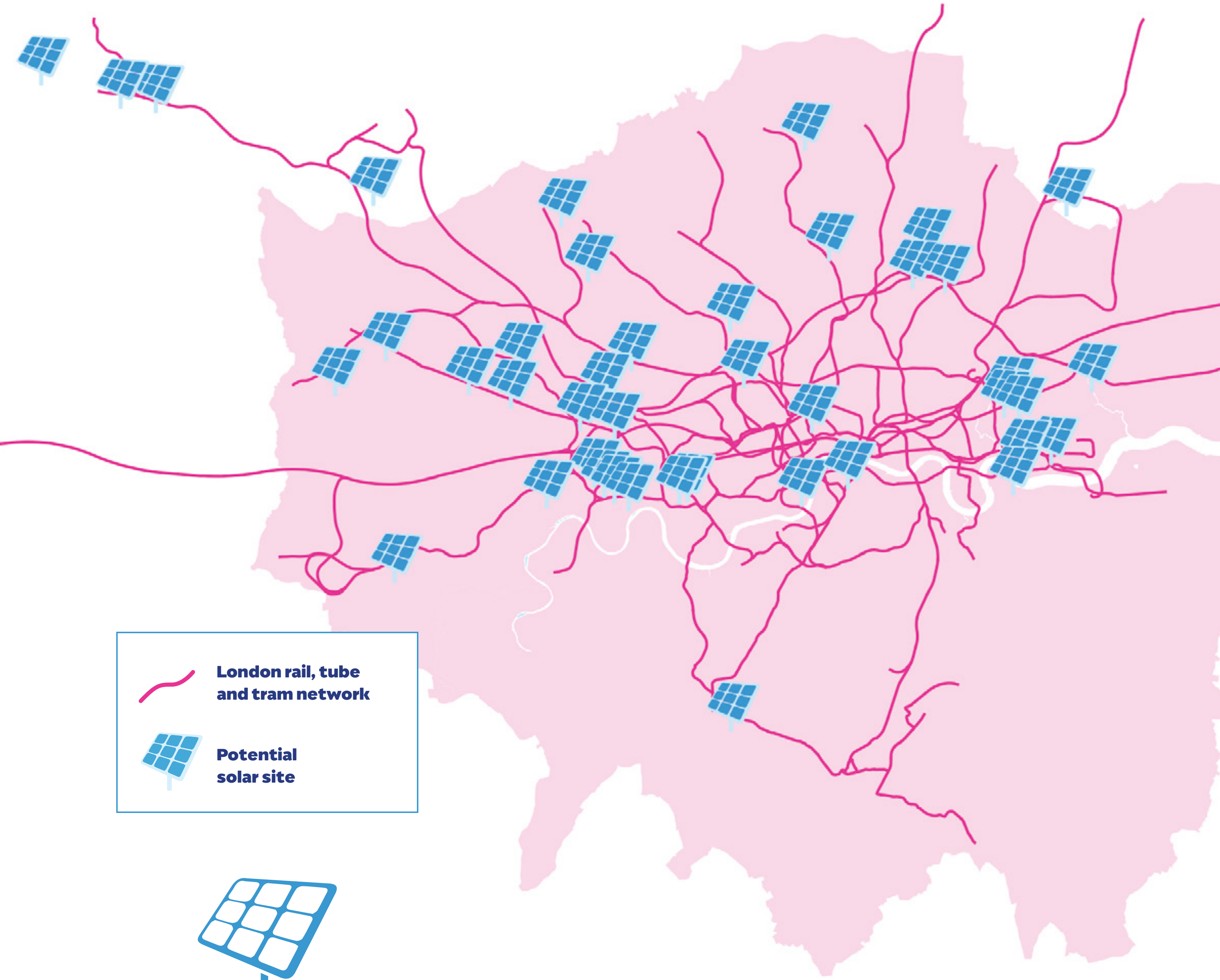


Fig. 6
Potential London Underground solar sites

London Underground Solar Potential

6%

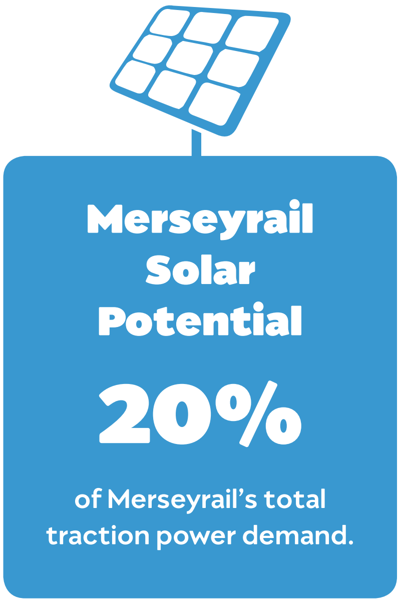
of the tube's total traction demand, equivalent to 50% of demand on the Piccadilly line.

The potential host sites are a diverse mix of TfL's own property such as large train depots and station car parks, and adjacent open land and industrial roof space, but they do not include potential on trackside land or operational station rooftops. If all 70MWp of potential solar PV were developed at these sites, they could supply electricity equivalent to 6% of the tube's total traction demand, or 50% of the power demand on the Piccadilly line. Because of the high costs of development and the competition for land, roof space and electricity supply in London, the commercially optimal figure is likely to be lower than this today – but the technical potential will be much higher if trackside land is included.

Merseyrail

Merseyrail consumes 67 to 70 GWh of traction electricity each year at a cost of around £6m. Demand is expected to rise substantially as a result of a network and rolling stock upgrade which is currently underway. Liverpool and Wirral Community Renewables have identified 22 sites that could host and connect up to17MWp of solar PV to the network. If all of this potential resource were to be developed, we would expect this to generate 14.1GWh annually – equivalent to 20% of Merseyrail's current annual traction power demand.

In practice this is likely to be close to the commercially viable limit for solar on the Merseyrail traction system, due to the rising costs of storage as a proportion of generation above these levels.



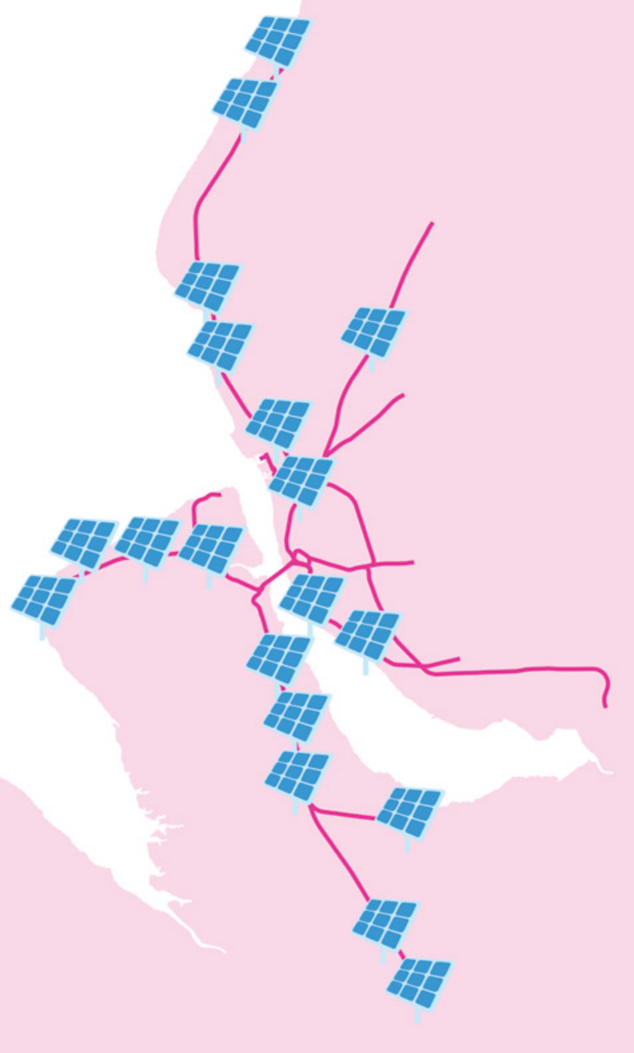


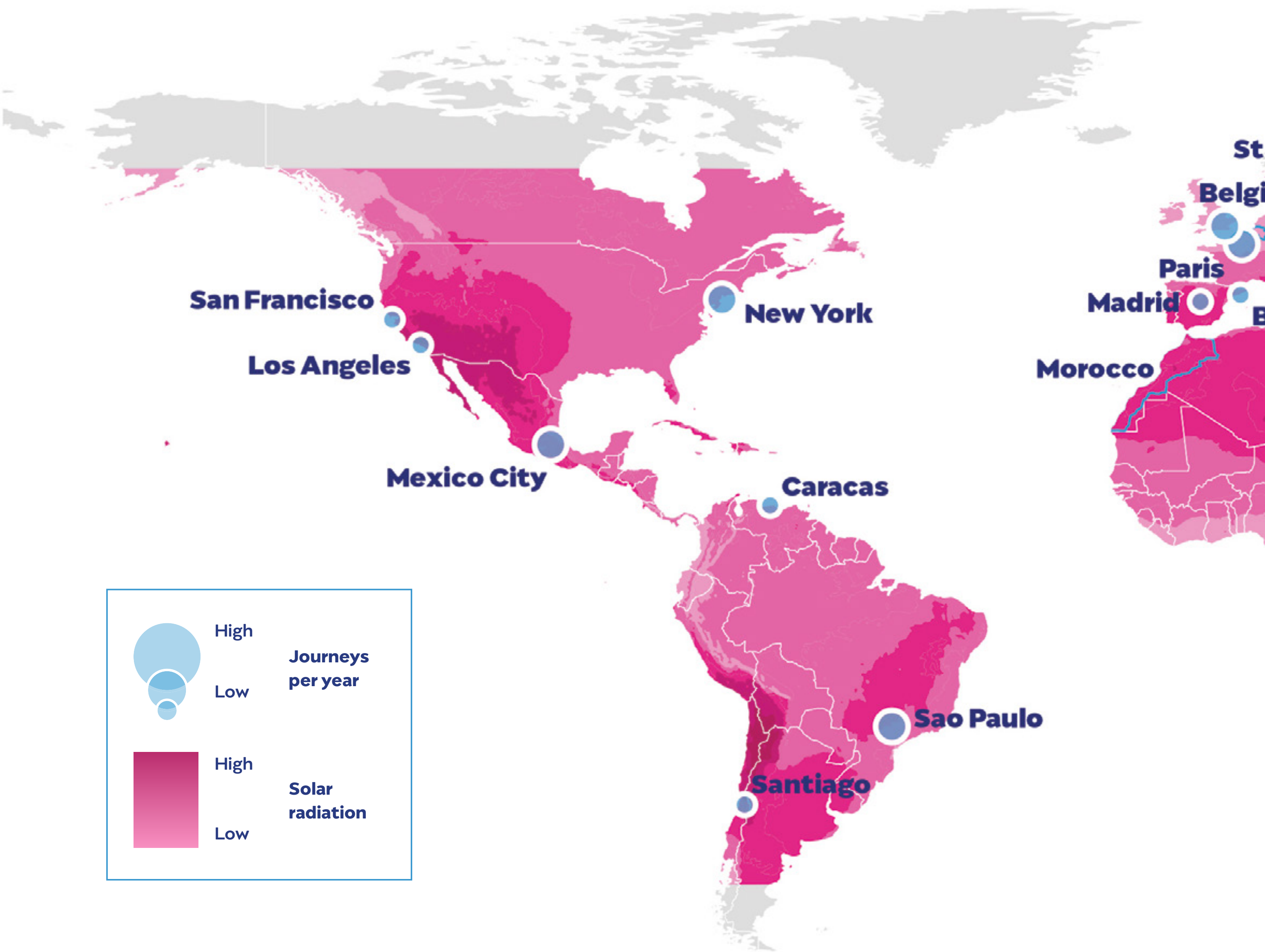
Fig. 7
Potential Merseyrail solar sites

Opportunities worldwide

Most city metros around the world run on third rail or overhead cable dc systems, usually at 750V. There are currently around 30 dc metro networks globally that carry more than one million passengers every day and would be suitable for solar traction power. We have featured these on the world map below which sets the potential locations against solar irradiance levels. We have also added the four countries that have dc traction power as their national rail standard (excluding North Korea).

High solar radiation levels and equally high access and use of system costs for grid supplied electricity in tropical developing nations mean the added value of solar traction power should be even greater in these contexts than it will be here in the UK. In particular, the greater constancy of solar irradiance across the year around tropical cities means that new electrified rail routes could in principle be powered exclusively by solar PV and storage, with huge implications for avoided grid infrastructure investment costs. There is particular potential in India and Spain.

Fig. 8
Global dc traction networks.



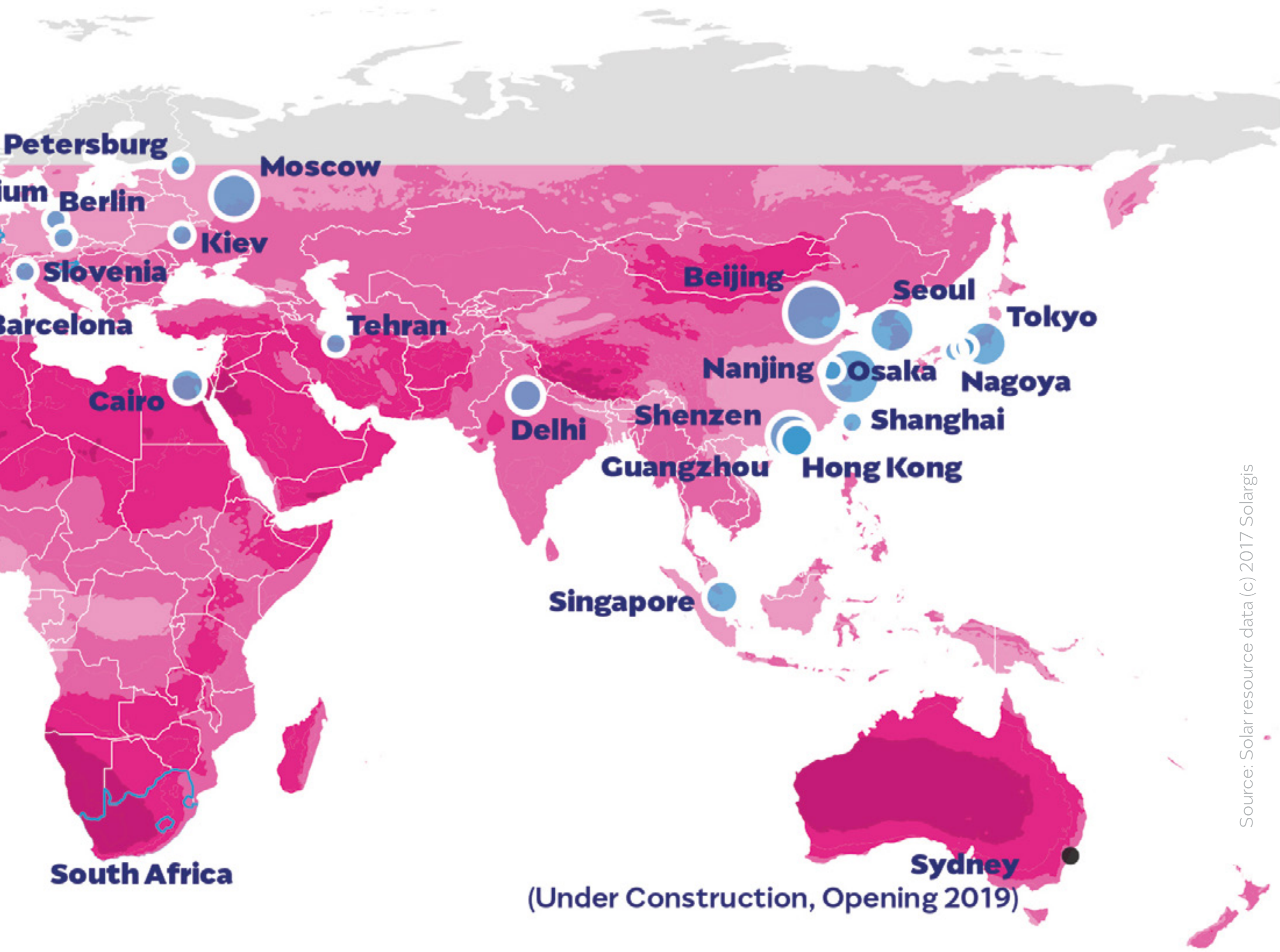
India

The Indian government has the most aggressive solar deployment target in the world, aiming for 100GW of installed solar PV generating capacity by 2022. But energy analysts have identified inadequate distribution and transmission infrastructure as a major obstacle to realising this ambition.

Meanwhile, India already has over 25,000km of electrified rail tracks. In spring 2017 the rail minister announced a 50% increase in investment in electrification, and an increased target of 2000km of new routes to be electrified annually. Indian Railways is already working with the UN Development Programme to deploy solar PV on 8,500 stations,[17] while the Delhi Metro has contracted developers to build the “world’s largest single-site solar project”, which will supply 90% of its daytime operating electricity needs – albeit via the standard distribution network.[18]

Spain

Spain currently has over 7000km of electrified tracks, and apart from the newest high speed routes, a national rail traction standard of 3000V dc. There are 11 dc commuter metros based around cities here, with the largest in Madrid and Barcelona. These both enjoy around 50% more hours of direct sunshine each year than London does, and host metro networks with nearly 3m daily passenger journeys. Barcelona already mandates solar for large buildings, and has a target of 100% renewable energy by 2050.



Source: Solar resource data (c) 2017 Solargis

Remaining Barriers

Product acceptance

New product acceptance on UK railways tends to be an exacting multi-year process. Integrating new technologies on the traction power network requires external funding before the technology readiness level is suitable for the mass market. Administrative inertia can act as a drag on innovative value propositions from new market entrants.

Contractual complexity

The transaction costs of Network Rail or TfL sourcing their energy from many small renewable operators instead of one large energy supplier could increase legal and administration costs, even if the unit price for power supplied is lower. Aggregation of pilot schemes under a single supply contract is likely to be necessary. Public sector procurement rules could also complicate things here.

Emerging technologies

Some integrated storage is likely to be essential in most practical applications of solar traction power. Network Rail have identified that storage could benefit their network, for instance by increasing the available capacity without the requirement for network reinforcement. But battery storage is too new to qualify as contributing to network resilience under Network Rail's resilience protocol.

Stacking unknown value

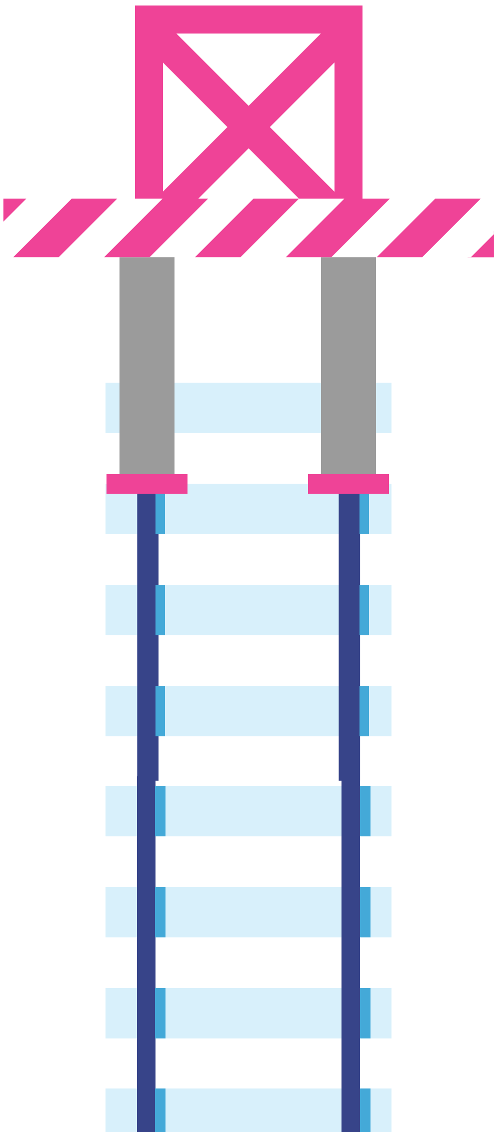
The business case for solar traction power is likely to depend on the storage function being available to the rail side – as well as the generation – so it can provide network services such as capturing surplus power from regenerative braking. But Network Rail have yet to quantify the financial value to the system of such a function.

Insurance

Network Rail and TfL require that third party equipment operators on their network must insure for effectively unlimited liability in case their equipment causes an incident on the rail network – potentially making the operational cost of adding generation to the network prohibitively expensive.

Trackside constraints

There is huge potential for installing solar PV on trackside land. However, the full potential of the business opportunity may not be realisable for Network Rail due to the short working windows and prescriptive safety rules governing the trackside work that would be needed to install and maintain the solar assets. These additional costs could limit solar traction assets to being hosted on neighbouring land.



Conclusion

Solar traction power is both technically feasible and commercially attractive under today's market conditions. It offers important cost, engineering and efficiency advantages over other models of renewable energy generation and supply. It represents a new route to market for unsubsidised solar energy in the UK, and a means to circumvent grid capacity constraints that are now a major barrier to new decentralised renewable energy. Hundreds of megawatts of new solar generation could be connected to Britain's dc traction networks, with vast potential on electrified railways around the world. Plans for new electrified rail routes in the tropics could be rolled out exclusively via solar and storage, with no need for local power grids to keep up.

Our analysis indicates that a first wave of six to ten solar traction farms could be community owned and built with backing from secure, long term (27 year) power purchase agreements to supply Network Rail with electricity at a price per kWh that matches the price they pay today under their current supply contract. Profit margins for this community-owned solar traction farm portfolio would be modest, but sufficient to underwrite crowdfunded investment, and to generate some surplus for community benefit funds. Economies of scale would mean the rollout of the next 100 solar traction farms would be even cheaper, unlocking tens of millions in new investment in renewable energy. The financial benefits of this approach will only continue to improve over time as the costs of solar, storage and associated technologies continue to fall.

Meanwhile, a 27 year price freeze will be an appealing prospect for train operating companies on solar powered routes; traction power makes up around 10% of these companies' operational costs. Deployment at scale under similar terms could plausibly shave around 4% off the Southern Region's traction electricity bill - and 13% off the associated carbon emissions. For Network Rail, solar traction power and integrated storage also offer solutions to voltage regulation, under-capacity and resilience challenges on their networks.

For passengers, rail industry workers and the communities that host these new assets, the first wave of solar traction farms will offer a chance to take a personal stake in driving forward the exciting transition to a zero carbon future that is taking place all around us. Picture the scene from the window of your daily commute: in winter, a sign appears in an empty field inviting you to invest in a solar traction farm there; in spring, construction begins; and by summer, your train is carrying you home on a sunbeam.

December 2017

Next Stops

Work with the UK's dc traction system operators to take the solar traction power project forward.

Secure innovation funding and social impact investment to pilot the approach.

Carry out site specific feasibility studies and develop full business cases for solar PV developments at the shortlisted pilot sites.

Explore similar opportunities around the London Underground, Merseyrail and the Manchester and London tram networks, and further afield if resources permit.

Determine if it is possible to connect some of these developments to the ac feeders that carry power from the grid to the dc traction substations using existing equipment which conforms to grid standards. This could serve as an interim solution while we take our new dc-dc power electronics through product acceptance.

Develop, assemble, test, accredit and install a prototype solar traction interface on the UK's railways.

Investigate partnerships for simultaneous trials in the Netherlands, Spain and India.

Connect a pilot wave of solar traction farms to the UK's railways.

Roll out solar railways everywhere.

Get in touch at
hello@1010uk.org

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