LOCAL PLAN for Buckinghamshire

Climate Change Study

Renewable Energy Assessment

January 2024

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List of Acronyms

Acronym	Meaning
AD	Anaerobic digestion
AONB	Area of outstanding natural beauty
BEIS	Department for Business, Energy and Industrial Strategy
BUS	Boiler Upgrade Scheme
CHP	Combined heat and power
CO_2	Carbon dioxide
COP	Coefficient of performance
CSE	the Centre for Sustainable Energy
DEC	Display energy certificate
DESNZ	Department for Energy Security and Net Zero
DNO	Distribution network operator
EfW	Energy from waste
EPC	Energy performance certificate
GIS	Geographic information system
GWh	Gigawatt-hour
ha	Hectare
HNPD	Heat networks planning database
kg	Kilogram
km^2	Kilometre squared
$ktCO_2e$	Kilotonne (thousand tonne) of carbon dioxide equivalent
kW	Kilowatt
kWh	Kilowatt-hour
LiDAR	Light detection and ranging
m^3	Meter-cubed
MOD	Ministry of Defence
MW	Megawatt
MWh	Megawatt-hour
NATS	National Air Traffic Services
NFI	National Forest Inventory

Acronym	Meaning
NG ESO	National Grid Electricity System Operator
NGED	National Grid Electricity Distribution
NNR	National nature reserve
NPPF	National planning policy framework
odt	Oven-dried tonnes
PV	Photovoltaics
REPD	Renewable energy planning database
RHI	Renewable Heat Incentive
SAC	Special areas of conservation
SHW	Solar hot water
SRC	Short-rotation coppice
SSEN	Scottish and Southern Electricity Networks
SSSI	Site of special scientific interest

Executive Summary

This report presents the outputs of the renewable energy assessment undertaken by the Centre for Sustainable Energy on behalf of Buckinghamshire Council. The findings are intended to become part of the evidence base supporting the development of a Local Plan for Buckinghamshire. The renewable energy resources considered were:

- Ground-mounted solar photovoltaics (PV)
- Roof-mounted solar PV
- Roof-mounted solar hot water
- Wind power
- Hydropower
- Woody biomass
- Energy crops – miscanthus and short rotation coppice (SRC)
- Batteries
- Hydrogen
- Geothermal
- Energy from waste
- Renewable heat

The assessment has shown that there is significant technical potential within Buckinghamshire, which can offset significant amounts of carbon compared to current practices. The technical potential is sufficient to exceed Buckinghamshire's current total energy demand of 7,108.5 GWh per year. Figure 1 shows the potential energy of each renewable energy source compared to Buckinghamshire's current energy demand. Figure 2 shows how much carbon could be offset by developing this maximum technical potential.

Figure 1: Summary of the technical energy potential of each renewable energy source compared to Buckinghamshire's current energy demand

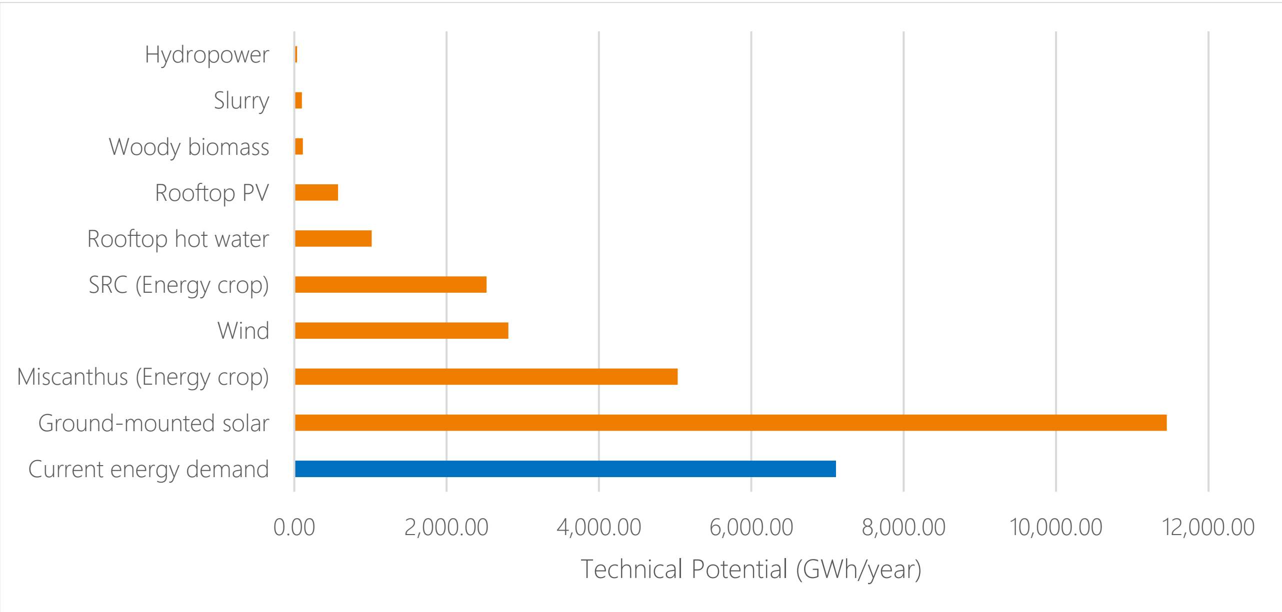
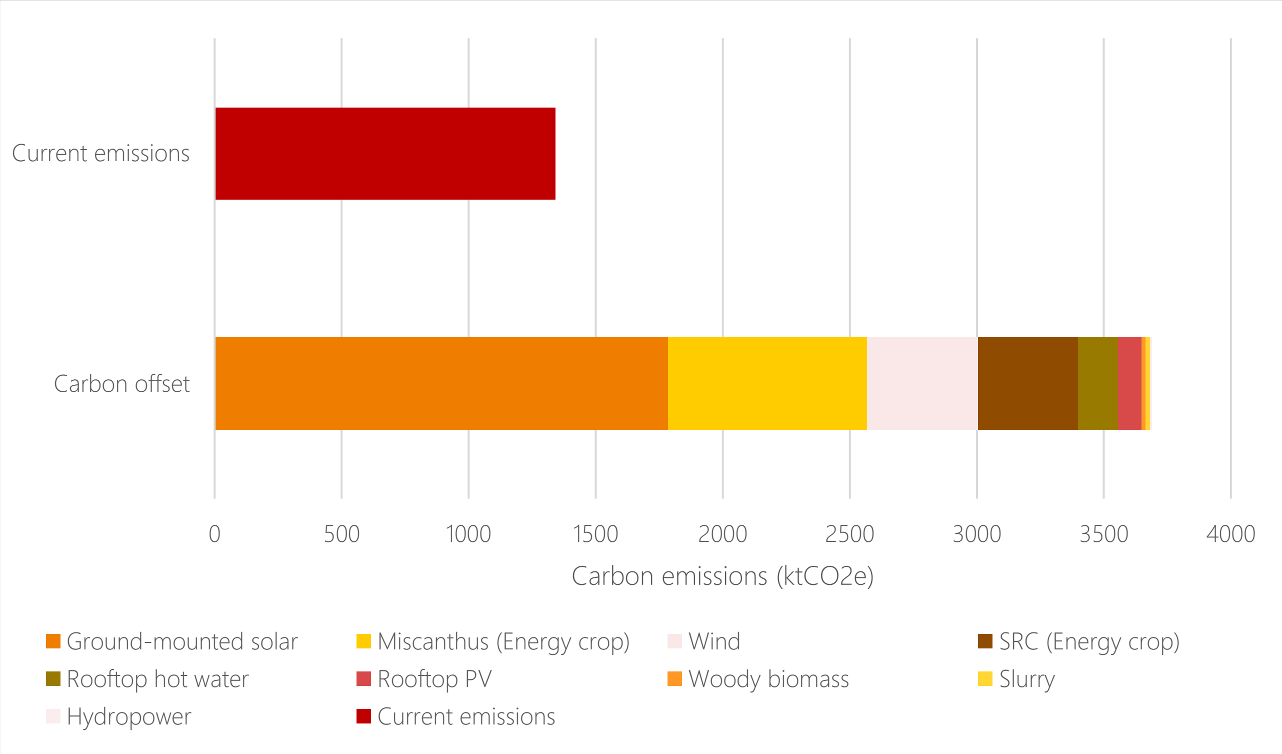


Figure 2: Summary of the potential carbon offset from developing Buckinghamshire's renewable energy resources



The renewable resource with the greatest potential in Buckinghamshire is ground-mounted solar photovoltaics, this is largely due to the flexibility of this renewable energy source, and the large open area available in Buckinghamshire due to its rural nature. The resource with the least potential is hydropower. This is because hydropower requires specific characteristics for effective functioning that largely do not exist in Buckinghamshire.

Whilst there is very good technical potential, the actual deployable potential is likely to be less once non-technical factors are taken into consideration and analysis is undertaken at site specific level. Additionally, some renewable energy resources may not be compatible with one another and compete for the same land. The following recommendations seek to aid plan-makers in their decision making on local renewable energy generation:

- Buckinghamshire Council should use their powers as a local authority to engage with the local community and key stakeholders to determine the desirable renewable technology mix and deployment rate.
- The council should facilitate discussions and maximise its influence to promote renewable energy development and deployment in the local area.
- The Local Plan should designate and allocate suitable areas and sites for renewable energy development.
- Full consideration should be given to other land uses that may compete with renewable energy development when allocating areas and sites.
- Stakeholder and public engagement are key elements of the plan-making process and should inform policy proposals and help prioritise certain resources.
- The council should build relationships and work closely with the three distribution network operators who operate within Buckinghamshire.

- The council should develop an energy strategy that is in line with and supports the emerging policies of the Local Plan, helping to contextualise this work within the wider decarbonisation of the energy system within the UK.

This report contains a review of the renewable energy technology potential within Buckinghamshire, considering technical, geographic and other constraints. Further impact assessments (including landscape visual impact) would likely be needed to inform planning decisions and considerations of deliverability. The conclusions of this assessment are intended to form an evidence base for consideration in the development of the Local Plan for Buckinghamshire. Additional considerations and evidence will be required to determine the suitability of any policy approach, suitable areas or sites for development in the future Local Plan for Buckinghamshire and planning decisions to be made.

1. Introduction

This report presents the outputs of the renewable energy assessment undertaken by the Centre for Sustainable Energy (CSE) on behalf of Buckinghamshire Council. The findings are intended to become part of the evidence base supporting the development of a new Local Plan for Buckinghamshire. Buckinghamshire Council is a single unitary authority formed in April 2020 that covers the former district council areas of Aylesbury Vale, Chiltern, South Bucks and Wycombe, and Buckinghamshire County Council.

This study provides technical evidence in support of the development of Local Plan policies that encourage the use and generation of renewable energy across Buckinghamshire. The study can also help the Council consider site specific infrastructure requirements. The outputs of this work provide an indication of what renewable energy resources exist in the study area, and the opportunities and constraints that impact their use.

The need for such a study broadly stems from an increased interest in renewable energy across the UK. This is part of efforts to reach carbon neutrality, in line with the national 2050 target. In June 2019, the Government committed the UK to a 100% reduction of greenhouse gas emissions by 2050, compared to 2019 levels (Department for Business, Energy and Industrial Strategy, 2019a). In this context net zero means that any remaining emissions in 2050 would be balanced by schemes to offset an equivalent amount of greenhouse gases from the atmosphere (Department for Business, Energy and Industrial Strategy, 2019b).

In 2021 Buckinghamshire Council adopted a Climate Change and Air Quality Strategy (Buckinghamshire Council, 2021). In line with this national ambition, the aims of this strategy are to:

- Achieve net zero carbon emissions for Buckinghamshire as a whole by 2050
- Achieve net zero carbon emissions for the council no later than 2050, potentially as early as 2030
- Improve air quality across Buckinghamshire

There is also a requirement for local planning authorities to align their key policy documents and strategies with the National Planning Policy Framework (NPPF), as revised in 2021. This framework places climate mitigation and adaptation at the heart of plan-making and encourages the transition to a low carbon future and the use of renewable resources. It requires that local authorities take a proactive approach to mitigating and adapting to climate change and adopt a positive strategy to promote energy from renewable and low-carbon resources. It also requires the identification of suitable areas for specific low carbon energy sources and supporting infrastructure. The proposed reforms to the NPPF that were published in early 2023 for consultation also required that local plan making promotes climate mitigation and adaptation.

This Renewable Energy Study is one of a number of evidence studies informing the early stages of producing a new Local Plan for Buckinghamshire. On adoption, that plan will replace the existing adopted local plans for the former Aylesbury Vale, Wycombe, Chiltern and South Bucks Council areas. For the purposes of evidence studies for the new local plan, the period to cover is 1 April

2023 to 31 March 2045, but we anticipate the actual local plan period to be 2027-2042 (i.e. 15 years from the date of adoption). To date there has been an initial questionnaire and invitation to promote sites to be considered for the plan (Buckinghamshire Council, 2023a). Then in April 2023 a consultation on Vision and Objectives took place (Buckinghamshire Council, 2023b), including the cross-cutting area of climate change. Objective 2 was 'Mitigating/Adapting to Climate Change' and part (d) of Objective 2 was to increase the supply of renewable/low carbon energy including providing supporting infrastructure. The Council is currently considering the consultation responses received by June 2023 and an amended vision and objectives will form part of a draft local plan in 2024.

2. Scope and methodology

The study focuses on assessing the potential for renewable energy generation across the area covered by Buckinghamshire Council. The study considers each energy resource in relation to the relevant energy generation technologies associated with it.

The methodology employed has been developed and used by CSE in a number of studies for local areas and includes:

- Establishing a baseline energy demand for Buckinghamshire, and a carbon baseline for this energy demand
- Using a range of desk-based research methods, including Geographic Information System (GIS) mapping, data analysis and the industry-standard assumptions detailed in Appendix 2: Buffers used in modelling and Appendix 3: Factors used in modelling, to investigate the energy potential of renewable resources in the study area
- Considering further sets of constraints (mainly technical in nature) that may have an impact on the practical or deployable potential of each energy resource

The renewable energy potential for each technology is expressed as generating capacity in kilowatts (kW) or megawatts (MW), typical annual energy yields in kilowatt hours (kWh) megawatt hours (MWh) or gigawatt hours (GWh), and carbon savings resulting from offsetting fossil fuels normally in thousand tonnes of CO_2 equivalent ($ktCO_2e$). Further information about these units:

- kW and MW refer to the generation capacity of a technology (maximum instantaneous output or nameplate rating)
- kWh, MWh and GWh refer to the generation yield of an energy source, i.e. the amount of energy it is likely to produce over a specified period (normally a year)
- Carbon savings are calculated directly from generation yields rather than generation capacities

Potential CO_2 savings are based on 2023 Government conversion factors (Department for Business, Energy and Industrial Strategy, 2023a). The 2022 Future Energy Scenarios figures (the most recent released at time of writing – National Grid ESO, 2022) were used for grid electricity emissions.

3. Baseline energy demand in Buckinghamshire

This chapter provides an overview of the current demand for energy and associated carbon emissions within the Local Plan for Buckinghamshire area, which will be referred to as 'Buckinghamshire' in this report. This can be used to contextualise renewable energy potential within the local area's needs.

According to the most recent statistics from the former Department for Business, Energy and Industrial Strategy (BEIS), now the Department for Energy Security and Net Zero (DESNZ), the total stationary energy usage in Buckinghamshire was 7,108.5 GWh in 2020 (the most recent data available at time of writing). The stationary energy usage is made up of 4,657.6 GWh of demand from domestic sources, and 2,450.9 GWh from industrial, commercial and other sources. The breakdown across fuels is shown in Table 1.

Table 1: Energy consumption statistics for Buckinghamshire (non-transport)

Sector	Electricity (GWh/year)	Gas (GWh/year)	Other fuels excl. bioenergy and waste (GWh/year)	Bioenergy and waste (GWh/year)	Total (GWh/year)
Domestic	1,053.0	3,155.0	375.4	74.3	4,657.6
Industrial, commercial, and other	893.2	885.1	475.2	197.5	2,450.9
Total	1,946.2	4,040.0	850.5	271.8	7,108.5

Source: Department for Energy Security and Net Zero, 2022a

Table 2 gives the estimated carbon emissions from Buckinghamshire's current energy use.

Table 2: Carbon emissions estimates for Buckinghamshire energy use (non-transport)

Sector	Electricity ($ktCO_2$/year)	Gas ($ktCO_2$/year)	Other fuels excl. bioenergy and waste ($ktCO_2$/year)	Bioenergy and waste (tCO_2/year)	Total ($ktCO_2$/year)
Domestic	164.1	577.4	105.3	16.3	846.7
Industrial, commercial, and other	139.2	162.0	133.3	43.5	434.5
Total	303.2	739.3	238.6	59.8	11,281.2

Source: Department for Energy Security and Net Zero (2023a)

Note that these figures are used for comparison throughout this study alongside the current heat demand of Buckinghamshire (estimated in the Renewable heat section). When these comparisons are made, conversion efficiencies are not considered. For example, a conventional gas boiler may achieve an efficiency of 85%, whereas if gas is used in electrical generation the conversion could be 60% efficient. Use in a combined heat and power (CHP) plant would have different efficiencies for each of heat and electricity. The reason for not considering conversion efficiencies is that the purpose of this study is to quantify renewable resources and provide input into the upcoming Local Plan with regards to deploying these resources. Because there is great variability in the conversion efficiencies of different thermal generators (e.g. gas boilers, CHP plants, wood boilers, etc.), conversion efficiency has not been considered for this type of resource. This is because selecting one technology with a high conversion efficiency could overrepresent the available resource. Similarly, a generator with a low conversion efficiency could underrepresent the available resource.

4. Overview of existing and planned renewable energy generation installations in Buckinghamshire

4.1. Overview of existing generation and planned installations

The Renewable Energy Planning Database (REPD) (Department for Energy Security and Net Zero, 2023b) is published quarterly and monitors renewable power projects over 150 kW (the threshold was 1MW prior to 2021). The most recent publication (May 2023) contains applications up to the end of April 2023. The REPD is a starting point to examine the potential for renewable energy generation in the study area, explored in the next chapter. Spatial analysis of the REPD shows that 62 installations have been logged in the REPD for Buckinghamshire. Of the 64 installations, 17 projects are considered inactive – with status of “application withdrawn”, “abandoned”, “application refused” or “planning permission expired” (Table 3). Note that not all applications have an electricity capacity recorded, especially when they are in the early planning stages.

Table 3: Status of renewable energy installations in Buckinghamshire as recorded in the REPD as of the end of April 2023

Status	Installations	Electric Capacity (MW)
Operational	16	110.7
Application withdrawn	4	70.9
Abandoned	2	20
Application refused	8	101.7
Planning permission expired	3	11.2
Revised	3	92.4
Awaiting construction	17	252.4
Under construction	1	79.9
Application submitted	10	212.2
Total	64	951.4

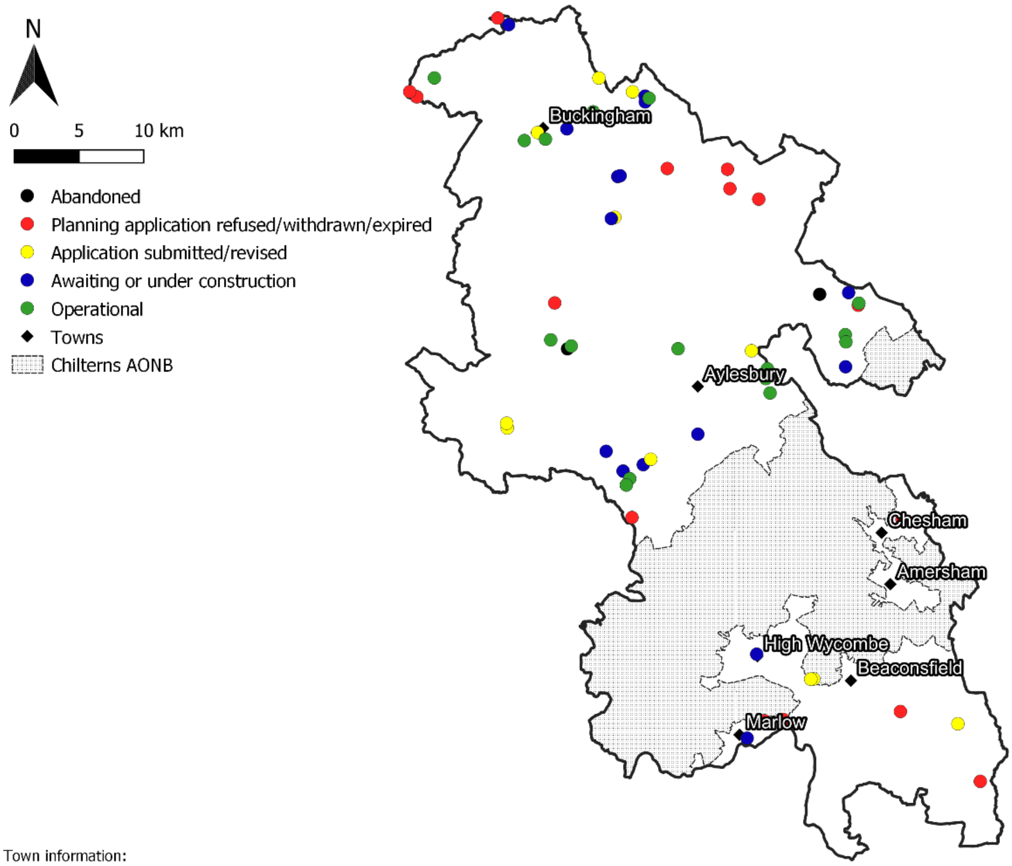
Source: Department for Energy Security and Net Zero, 2023b

Note that this analysis discounts energy from waste and landfill gas despite these being recorded in the REPD. This is because both are generated from residual waste, which is not itself renewable.

However, these can still be valid as transition energy sources because they make use of waste resources that may otherwise not be utilised.

The total operational capacity is 110.7 MW. The total capacity of installations active in the planning system (status of "application submitted" or "revised") is 304.6 MW. Projects at the construction stage (status of "under construction" or "awaiting construction") have a capacity of 332.3 MW. The locations of the projects are given in Figure 3.

Figure 3: The locations of REPD-registered renewable energy installations as of the end of April 2023



Town information:
Source: Office for National Statistics licensed under the Open Government Licence v.3.0
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As can be seen, the majority of REPD-registered renewable energy is in the north of Buckinghamshire. This is likely due to the increased difficulty of developing renewable energy within the designated area of the Chilterns Area of Outstanding Natural Beauty (AONB) and the presence of the green belt.

The details of different renewable generation installation types in the REPD are discussed over the following sections.

4.2. Solar energy

Solar renewable energy is generally split into photovoltaics (PV) and thermal. Solar thermal installations provide renewable heat energy, normally in the form of hot water. Solar PV installations generate electricity.

There are no solar thermal installations recorded in the REPD because the REPD examines only electricity generation. Larger scale solar thermal is relatively rare in the UK, with installations generally limited to rooftop installations at a domestic scale. However, some solar thermal installations do exist in the study area, recorded outside of the REPD, and are summarised in the section Renewable heat.

Solar PV has many of the same issues as solar thermal in terms of many installations being small domestic or commercial scale rooftop installations, which do not appear on the REPD. However, larger solar PV installations are more common in the UK than solar thermal. Ignoring small scale systems below 150kW, solar PV currently is the largest renewable energy source in Buckinghamshire, with 88.9 MW capacity from 12 operational installations. A further 154.4 MW of capacity (6 installations) are active in the planning system. Fifteen installations with a total capacity of 252.4 MW are at the construction stage. The status of solar PV installations in Buckinghamshire is shown in Table 4.

Table 4: Status of solar PV installations above 150kW in Buckinghamshire as recorded in the REPD as of the end of April 2023

Status	Installations	Electric capacity (MW)
Operational	12	88.9
Application withdrawn	3	13.9
Abandoned	2	20
Application refused	3	48.5
Planning permission expired	1	1.2
Revised	2	52.4
Awaiting construction	15	252.37
Under construction	0	0
Application submitted	4	102
Total	42	579.3

Source: Department for Energy Security and Net Zero, 2023b

The majority of solar PV installations in the REPD are ground mounted, and ground-mounted installations are much larger than rooftop installations. An overview of the status of roof and ground mounted solar is shown in Table 5. Note that some solar installations are not recorded as either in the REPD, and these are not shown below.

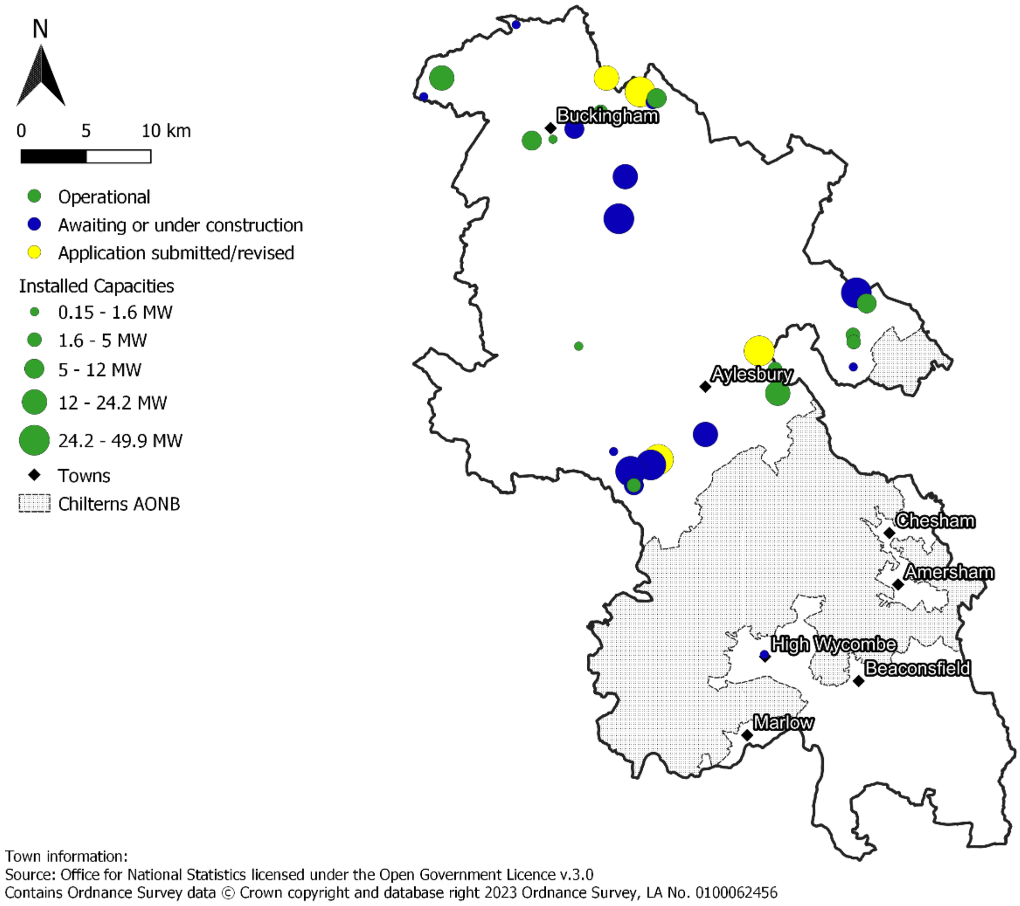
Table 5: Status of roof and ground mounted solar installations in Buckinghamshire as recorded in the REPD as of the end of April 2023

Status	Roof installations	Roof capacity (MW)	Ground installations	Ground capacity (MW)
Operational	1	0.2	11	88.7
Application withdrawn	0	0	2	10.5
Abandoned	0	0	2	20
Application refused	0	0	3	48.5
Planning permission expired	0	0	1	1.2
Revised	0	0	2	52.4
Awaiting construction	5	2.37	10	250
Under construction	0	0	0	0
Application submitted	0	0	4	102
Total	6	2.57	35	573.3

Source: Department for Energy Security and Net Zero, 2023b

An overview of the locations of existing and planned solar installations within Buckinghamshire, as recorded in the REPD is shown in Figure 4.

Figure 4: Overview of existing and planned solar installations in Buckinghamshire recorded in the REPD as of the end of April 2023



The operational solar PV installations within Buckinghamshire are shown in Table 6.

Table 6: Operational solar PV installations in Buckinghamshire as of the end of April 2023

Site	Postal Town	Capacity (MW)
Gib Lane (Aston Clinton solar park)	Bierton	24.2
Turweston Solar Farm	Biddlesden	16.7
Gawcott Fields Farm	Buckingham	9.2
Land At Potash Farm	Beachampton	7
Church Farm	Slapton	6.2
Church Farm	Slapton	6.2
Great Seabrook Farm	Cheddington	5
Bumpers Farm Phase 1	Ilmer	5
Land at Thornborough Grounds	Thornborough	5
Gib Lane Solar farm (Extension)	Bierton	5
Long Meadow Farm	Leighton Buzzard	4.1
Westcott Venture Park Phase 2 & 3	Westcott	1.3
Buckingham Tesco Superstore	Buckingham	0.2

Source: Department for Energy Security and Net Zero, 2023b

4.3. Wind power

Wind power involves converting the energy of the wind to electricity. Generally, this is accomplished by wind turbines, either solitary turbines, or many turbines in proximity, known as wind farms. There is very little existing or planned wind power in Buckinghamshire. There is a single operational installation in Buckinghamshire recorded in the REPD, with an capacity of 1.5 MW. There are also two refused applications, with a combined capacity of 20 MW. Current national planning policy makes it very difficult to get approval for onshore wind power in England, which has likely influenced the limited number of planning applications registered for this kind of renewable energy. Table 7 shows the status of applications for wind installations as recorded in the REPD.

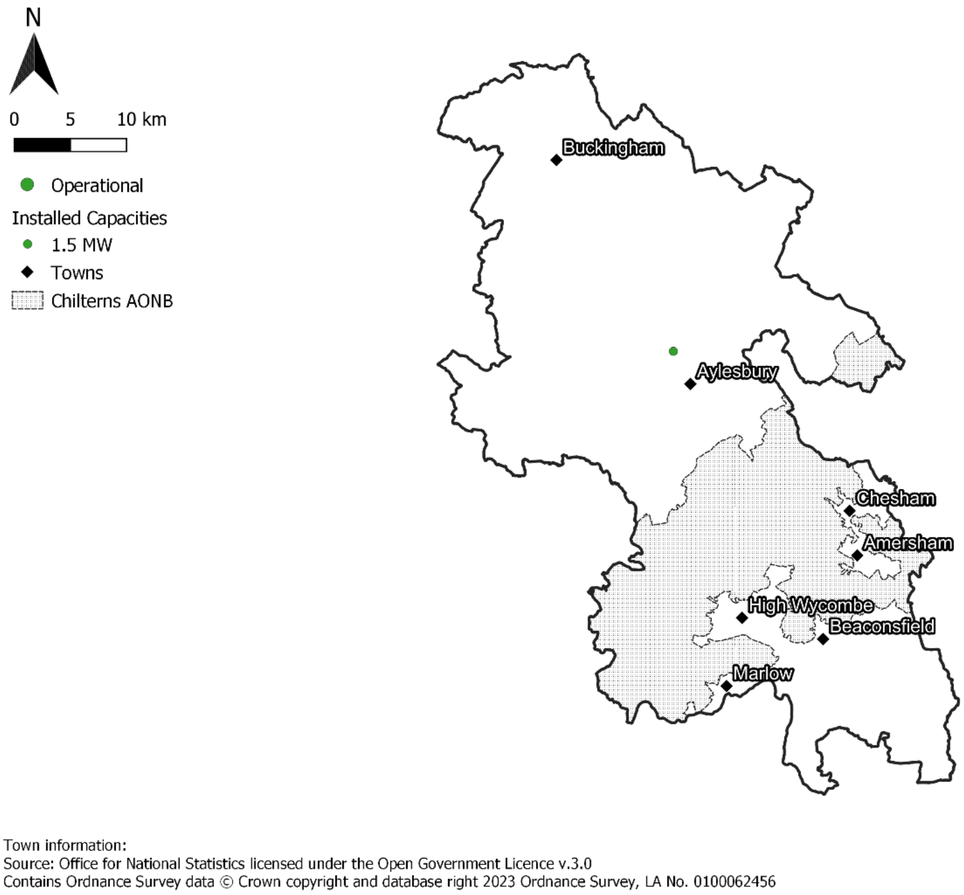
Table 7: Status of wind installations in Buckinghamshire as recorded in the REPD as of the end of April 2023

Status	Installations	Electric capacity (MW)
Operational	1	1.5
Application refused	2	20
Total	3	21.5

Source: Department for Energy Security and Net Zero, 2023b

The location of the existing wind installation as recorded in the REPD is shown in Figure 5.

Figure 5: Overview of existing and planned wind installations in Buckinghamshire recorded in the REPD as of the end of April 2023



The operational wind installation in Buckinghamshire is Quarrendon Fields, near Aylesbury. It has a capacity of 1.5MW.

4.4. Anaerobic digestion

Anaerobic digestion involves the breaking down of organic matter into simpler compounds to use as a fuel. Normally, this is biogas, which can then be used to generate heat or electricity. There are currently two operational anaerobic digestion installations in Buckinghamshire providing an electrical capacity of 7 MW. One of these installations is a CHP plant, which means it will produce heat and electrical energy. A further two installations are active in the planning system, though neither currently has a recorded electrical capacity (shown as "unknown capacity" in Figure 6). It is likely that these capacities have not yet been determined and will later be recorded in the REPD.

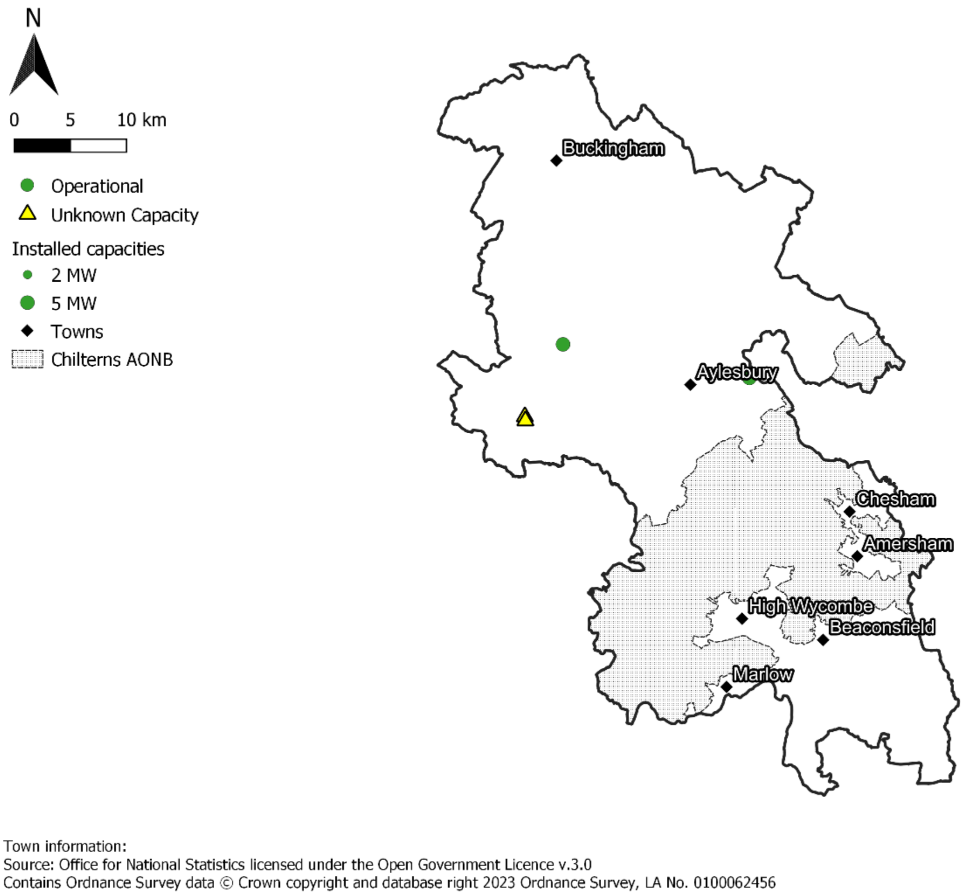
The status of anaerobic digestion installations in Buckinghamshire is shown in Table 8.

Table 8: Status of anaerobic installations in Buckinghamshire as recorded in the REPD as of the end of April 2023

Status	Installations	Electric capacity (MW)
Operational	2	7
Application refused	1	1
Application submitted	2	0
Total	5	8

Source: Department for Energy Security and Net Zero, 2023bAn overview of existing and planned anaerobic digestion installations within Buckinghamshire, as recorded in the REPD, is shown in Figure 6.

Figure 6: Overview of existing and planned anaerobic digestion installations in Buckinghamshire recorded in the REPD as of the end of April 2023



The operational anaerobic digestion installations in Buckinghamshire are shown in Table 9.

Table 9: Operational anaerobic digestion installations in Buckinghamshire as of the end of April 2023

Site	Postal Town	Capacity (MW)
Arla Dairy Site	Aston Clinton	5
Westcott Venture Park	Westcott	2

Source: Department for Energy Security and Net Zero, 2023b

4.5. Batteries

Batteries are the only storage technology currently recorded in the REPD for Buckinghamshire. Storage technologies do not generate electricity but do allow the storage of renewable energy to help grid balancing, among other services. This is particularly true where batteries are built in conjunction with renewable energy generation, known as co-location. In this analysis it is assumed that storage technologies are renewable because they will play a key role in decarbonising energy. This is because storage technologies make it easier to balance a decarbonised energy grid by smoothing the variability in renewable energy generation. They can store excess generation when there are favourable conditions for generating renewable energy (e.g. high winds and sunny days) and release this energy when these conditions are lacking. This helps to reduce the number of generators needed at any one time.

There is only one operational battery recorded in the REPD for Buckinghamshire, with a capacity of 13.3 MW. However, there is a large amount of pipeline activity in developing batteries, with five installations (150.2 MW) active in the planning system and three (79.9MW) ready for or awaiting construction. An overview of batteries as recorded in the REPD is shown in Table 10.

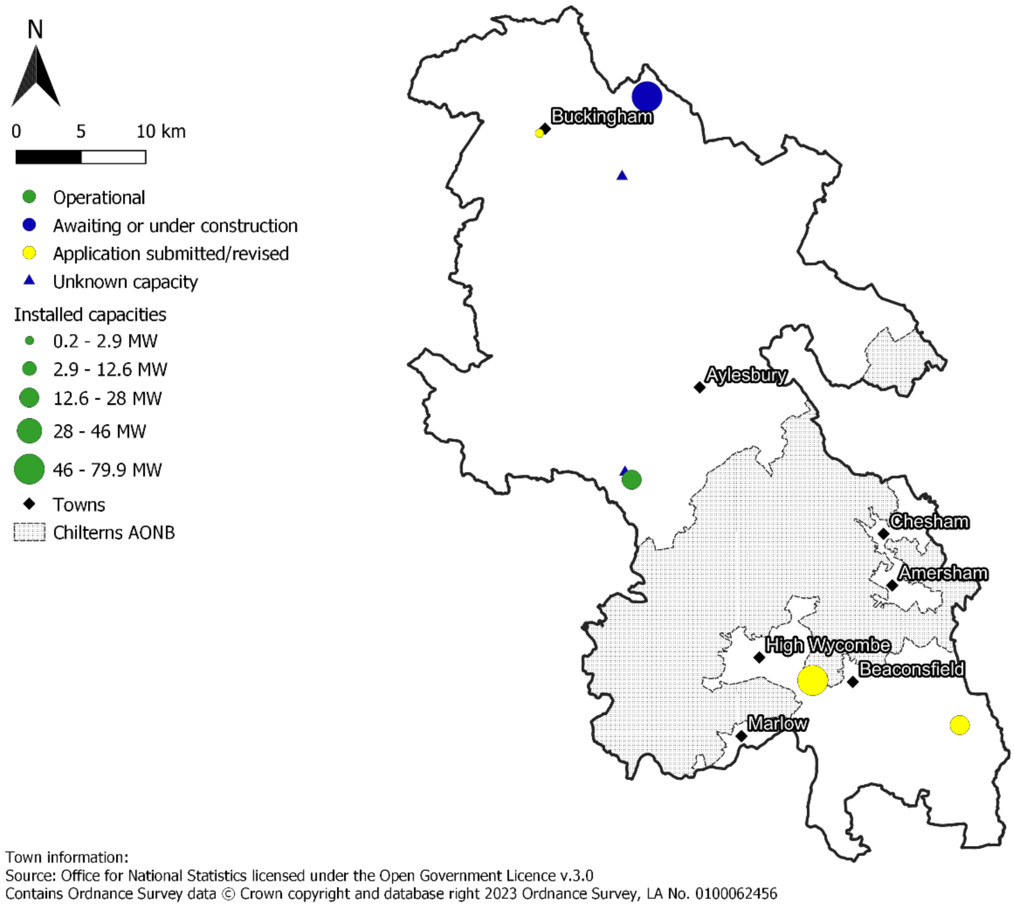
Table 10: Status of batteries in Buckinghamshire as recorded in the REPD as of the end of April 2023

Status	Installations	Electric capacity (MW)
Operational	1	13.3
Application withdrawn	1	57
Abandoned	0	0
Application refused	2	32.2
Planning permission expired	2	10
Revised	1	40
Awaiting construction	2	0
Under construction	1	79.9
Application submitted	4	110.2
Total	14	342.6

Source: Department for Energy Security and Net Zero, 2023b

An overview of existing and planned battery installations within Buckinghamshire as recorded in the REPD is shown in Figure 7.

Figure 7: Overview of existing and planned battery installations in Buckinghamshire recorded in the REPD as of the end of April 2023



The operational battery installation in Buckinghamshire is located alongside Bumpers Lane Solar Farm, near Ilmer. The capacity of the battery is 13.3 MW.

Several of the operational and planned battery installations are (or are intended to be) co-located with other renewable energy installations. The following list comprises the co-located batteries, all of which are co-located with solar PV:

- Bumpers Lane Solar Farm (near Ilmer)
- Church Farm (near Slapton)
- Fox Covert Solar Farm (near Milton Keynes)
- Whirlbush Farm (near Kingsey)

4.6. Renewable heat

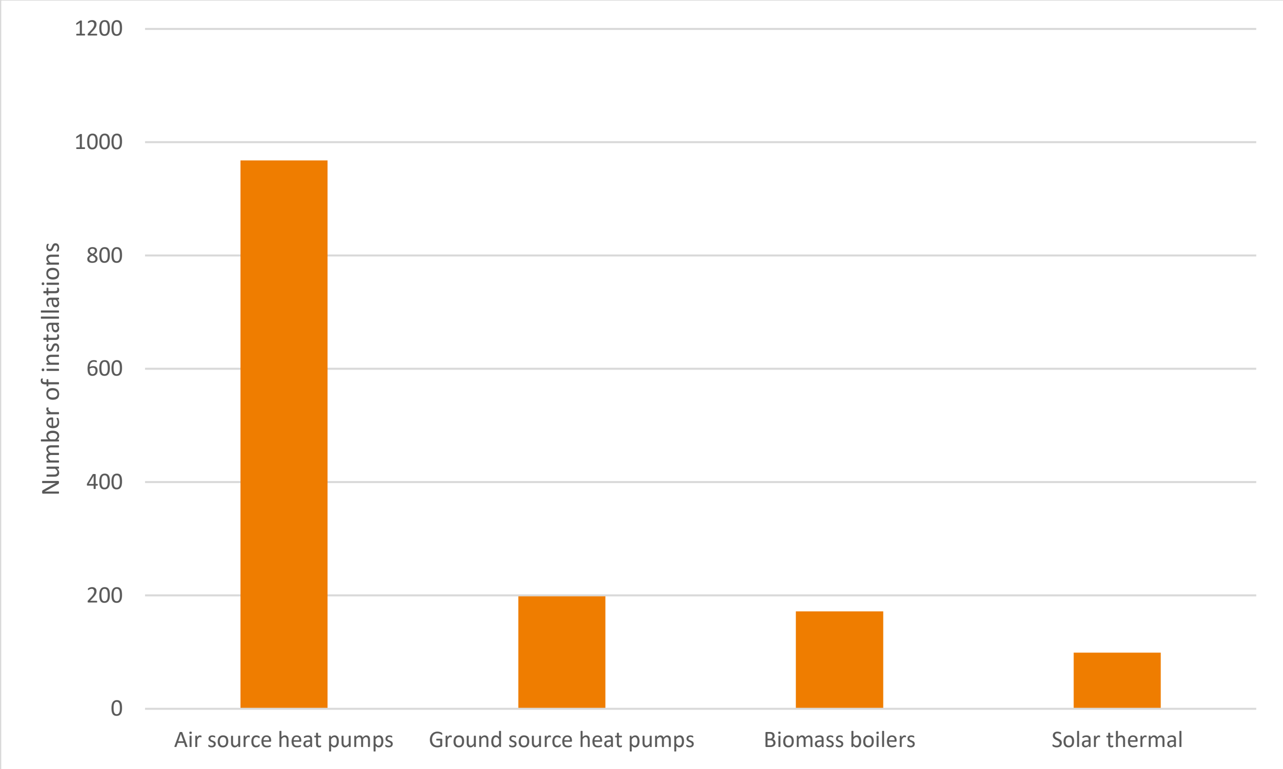
It is difficult to gather information on renewable heat. The most reliable sources of information are the statistics gathered through Government schemes: renewable heat incentive (RHI – Department for Energy Security and Net Zero, 2023c) and boiler upgrade scheme (BUS – Department for Energy Security and Net Zero, 2023d). Both cover domestic and non-domestic installations. However, some renewable heat installations will exist that did not receive funding through either of these schemes. Therefore, they will not be captured in this analysis. However, the schemes are still useful to gauge the scale of renewable heat in the region.

The RHI separates domestic and non-domestic installations. Domestic installations are given as number of installations per local authority on a technology basis. The number and capacity of non-domestic installations are given at local authority level but are not available on a per-technology basis. The total capacity across all RHI categories in Buckinghamshire is 35 MW. The percentage of applications per technology type is only available at Great Britain resolution. To estimate the installations per technology type in Buckinghamshire, the Great Britain proportions have been apportioned to the number of installations in Buckinghamshire.

The BUS can be applied for in relation to both domestic and non-domestic installations. Statistics are not currently published on a per local authority basis but are available on a per 10,000 household basis at regional level. The South-East regional statistics have been apportioned to Buckinghamshire.

The combined statistics are shown in Figure 8, note that the BUS funded installations are shown as "unknown" because it is not known if these are domestic or non-domestic.

Figure 8: Total existing renewable heat installations in Buckinghamshire by technology



Air source heat pumps currently dominate the renewable heat landscape in Buckinghamshire. Note that the total number of renewable heat installations are still only a small fraction of the number of buildings in Buckinghamshire. From Ordnance Survey data we estimate there to be approximately 418,000 buildings in Buckinghamshire – though not all of these will be heated.

In addition to individual heating systems as discussed above, the heat networks planning database (HNPD) shows four renewable heat networks under construction or in planning in Buckinghamshire. These are shown in Table 11.

Table 11: Renewable heat networks in Buckinghamshire according to the HNPD as of August 2022

Site name	Number of customers	Domestic or non-domestic	Heat source	Status
The Wycliffe Centre Redevelopment	167	Domestic	Biomass	Under Construction
Woodrow High House - Biomass Boiler	1	Non-domestic	Biomass	Application Submitted
Westwood, High Wycombe	42	Domestic	Air Source Heat Pump	Application Submitted
Plot 3000, Avenue A, Westcott Venture Park - 2 Industrial Units	2	Non-domestic	Air Source Heat Pump	Application Submitted
45-47 Oxford Road, High Wycombe - 27 Flats	27	Domestic	Air Source Heat Pump	Application Submitted

Source: Department for Business, Energy and Industrial Strategy (2023)

5. Renewable energy potential assessment

The following sections examine the technical potential of different renewable energy sources. The approach taken is generally to examine the maximum technical potential of the resource. This means that the constraints imposed are designed to show the maximum amount of energy that could be generated from each source. Additional constraints are likely to exist, for example public acceptance of renewable technologies, but have not been quantified in this study. The objective of the study has been to provide Buckinghamshire Council with the necessary supporting evidence to inform the development of the Local Plan for Buckinghamshire. The objectives of the local plan and policies therein will likely influence how much of the technical potential could be deployed.

5.1. Ground-mounted solar PV

5.1.1. Assumptions

The assessment of technical potential for solar developments was undertaken using GIS, by mapping spatially key constraints. The full list of constraints is given in Table 12. In the mapping, constraints were separated into two levels. Level 1 constraints are technical constraints, which are relatively “hard” limits (making level 1 the group of ‘toughest constraints’ of those in Table 12). These constraints are unavoidable (though they may vary in site-specific analysis). Level 2 constraints are where land is designated (protected) in some way. Generally, this does not necessarily preclude development of renewables on the land but can make projects more difficult to implement. There is some local control of the treatment of renewable energy in these areas, and therefore they are included here to aid decision making by Buckinghamshire Council. Full reasoning and any buffers applied to these constraints are given in Appendix 2: Buffers used in modelling.

Table 12: Constraints applied to ground-mounted solar PV mapping

Constraint	Level of constraint
Roads	Level 1
Rail	Level 1
MOD (Ministry of Defence) land	Level 1
Residential properties	Level 1
Employment sites	Level 1
Water	Level 1
Woodland	Level 1
Scheduled monuments	Level 1

Constraint	Level of constraint
Historic parks and gardens	Level 1
Flood zones 2 and 3	Level 1
Existing settlements	Level 1
Agricultural land grades 1 – 3a	Level 1
Minerals commitments and safeguarding areas (Buckinghamshire Council, 2019)	Level 1
Special areas of conservation (SAC)	Level 1
Adopted Local plan and neighbourhood plan sites	Level 2
Area of outstanding natural beauty (AONB)	Level 2
Sites of special scientific interest (SSSIs)	Level 2
National nature reserves (NNRs)	Level 2
Green belt	Level 2

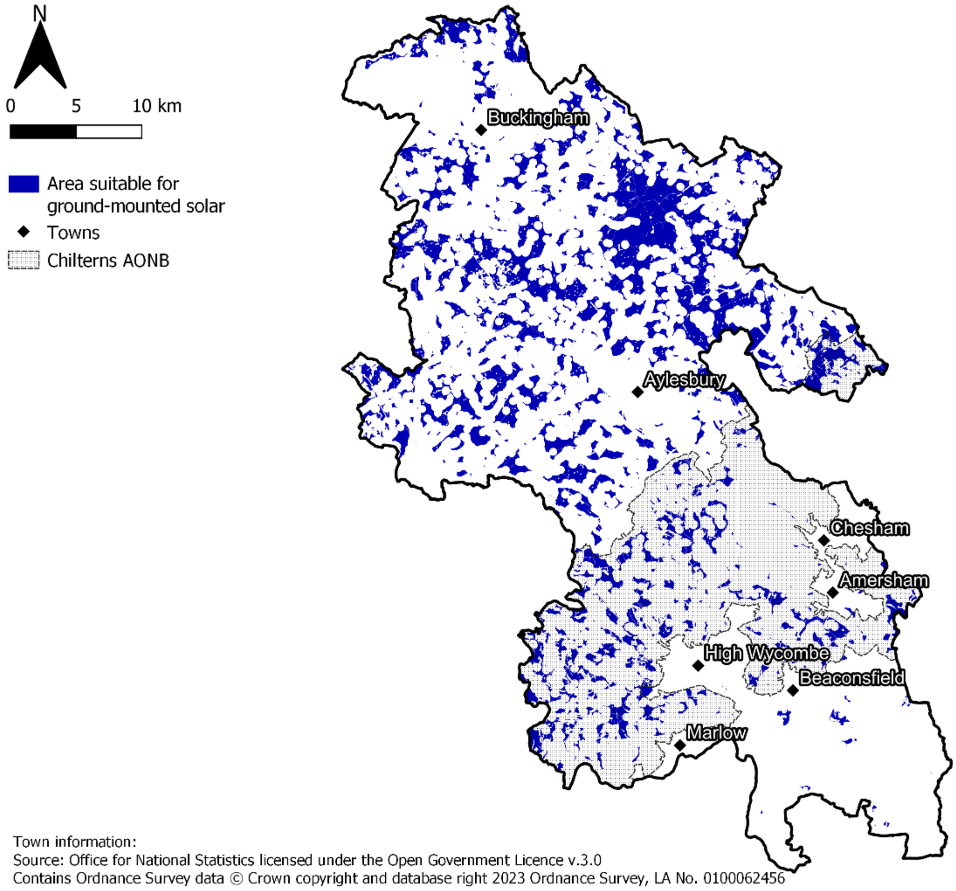
It should also be noted that this assessment does not include a full landscape sensitivity assessment. While some thought has been put into the impact of renewables on the landscape in terms of the constraints applied, the landscape impact has not been examined.

5.1.2. Results

Solar is generally the least constrained of renewable energy sources. This is because the lower profile of solar panels and their near-noiseless operation (silent but with minor noise from components such as inverters) require less separation from roads, residents, etc. They also are suitable anywhere the sun shines – though there is variation in the strength of the sun (and therefore the energy generated). This variance is known as solar irradiance. It refers to the energy per unit area received from sunlight in a specific place. Irradiance varies due to the curved surface of the Earth, with regions towards the poles receiving less energy from the sun than those at the equator. Generally, there is little variance within the UK, therefore in this assessment solar irradiance has not been examined. However, when examining generation, a local capacity factor of 10.1% (see Appendix 3: Factors used in modelling) has been used to reflect typical solar irradiance levels in the South East region. A capacity factor is a measure of how much electricity is generated compared to the capacity of an electricity generator. For example, if a 1MW solar panel could generate at full output all day every day, it would generate 8,760 MWh per year and would have a capacity factor of 1 (100%). However, it would only be able to generate while the sun was up and would produce less with cloud. If, because of this, it had a capacity factor of 0.12 (12%), it would generate 1,051 MWh per year.

The areas of Buckinghamshire that are considered viable when only level 1 constraints are applied is shown in Figure 9. This can be considered the area available for the maximum technical potential.

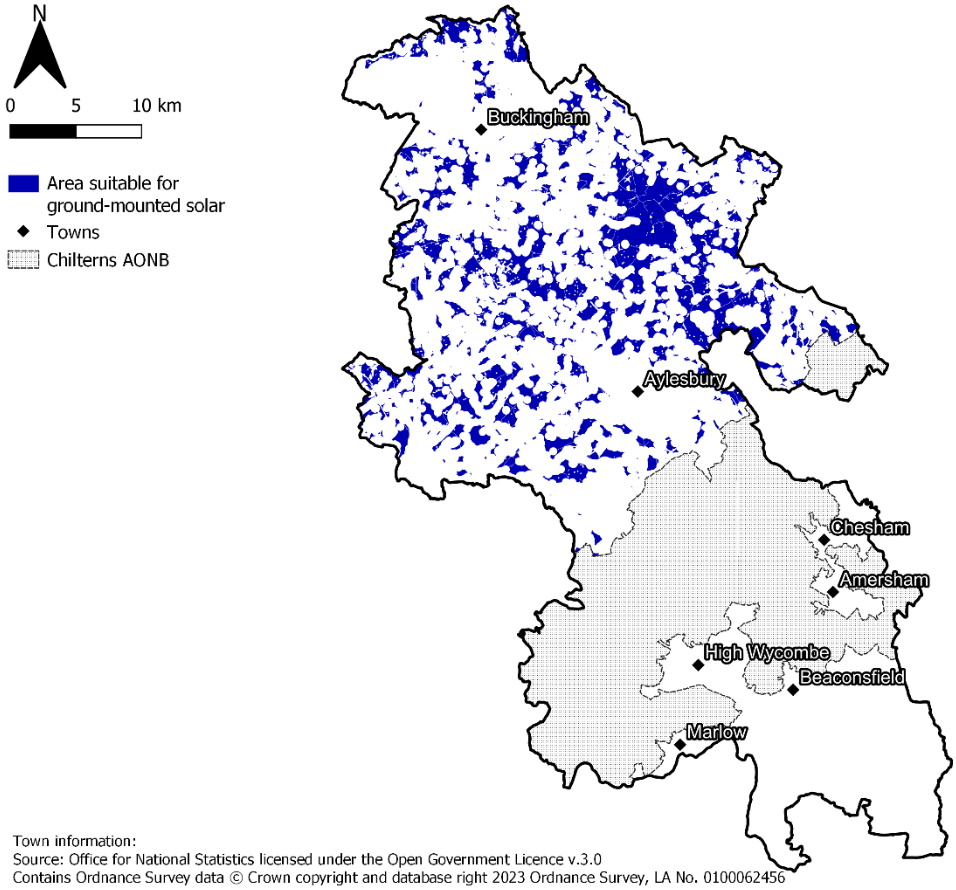
Figure 9: Areas suitable for ground-mounted solar when applying level 1 constraints



Under level 1 constraints, solar suitability is well distributed across Buckinghamshire. Larger concentrations are seen in the north of the study area. This is roughly in line with the deployment profile of existing solar, suggesting that the constraints applied reflect those encountered in practice.

Level 2 constraints are applied after level 1 constraints. In other words, level 2 constraints further reduce the viable area left over after level 1 constraints are applied. Level 2 constraints have been grouped into 2 rough categories. The reason for these groupings is the Council may wish to consider these constraints differently in the local plan, due to differing justification for the designations. Local Plan allocations have been included in both groups. The Chilterns AONB and the green belt have been combined as both restrict development based on landscape character. The viable areas excluding this group are shown in Figure 10.

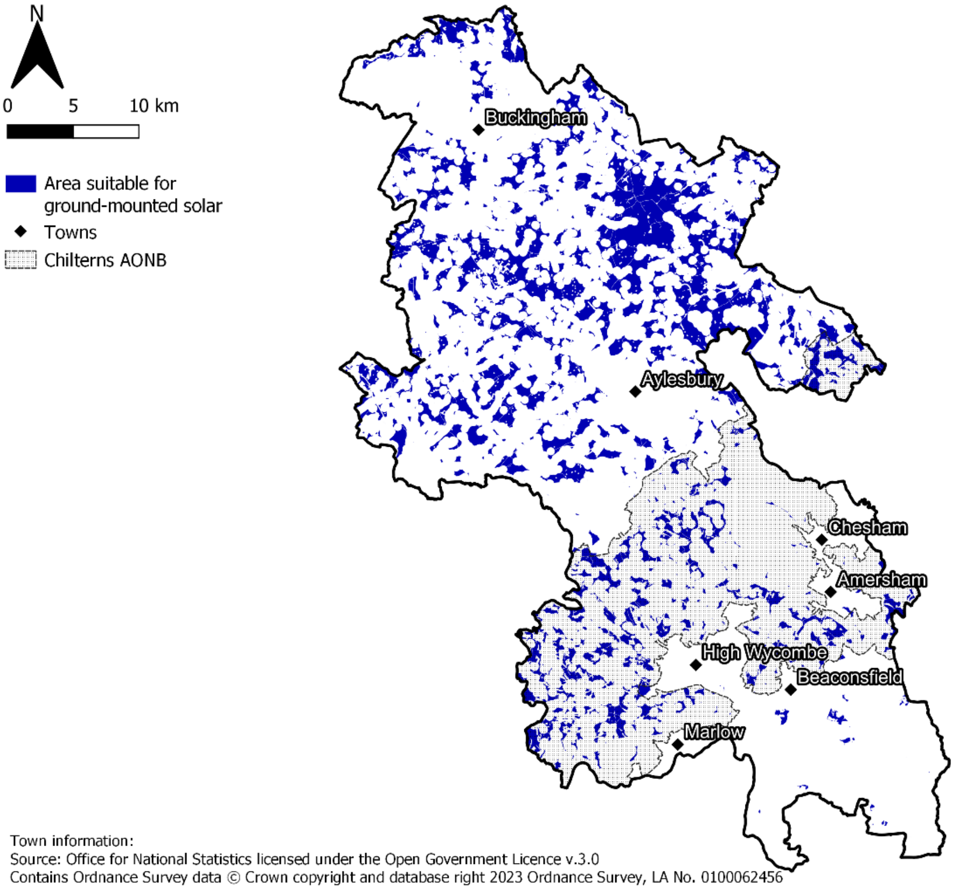
Figure 10: Areas suitable for ground-mounted solar when applying level 1 constraints and excluding the AONB and green belt and Local Plan allocations



After excluding the AONB and green belt, solar no longer remains viable in the south of the study area. This shows the impact that the ability to establish renewable energy in designated areas may have on the available resource.

SSSIs and NNRs have been grouped as these are concerned with the protection of flora, fauna, or other natural processes. The viable areas excluding these groups is shown in Figure 11.

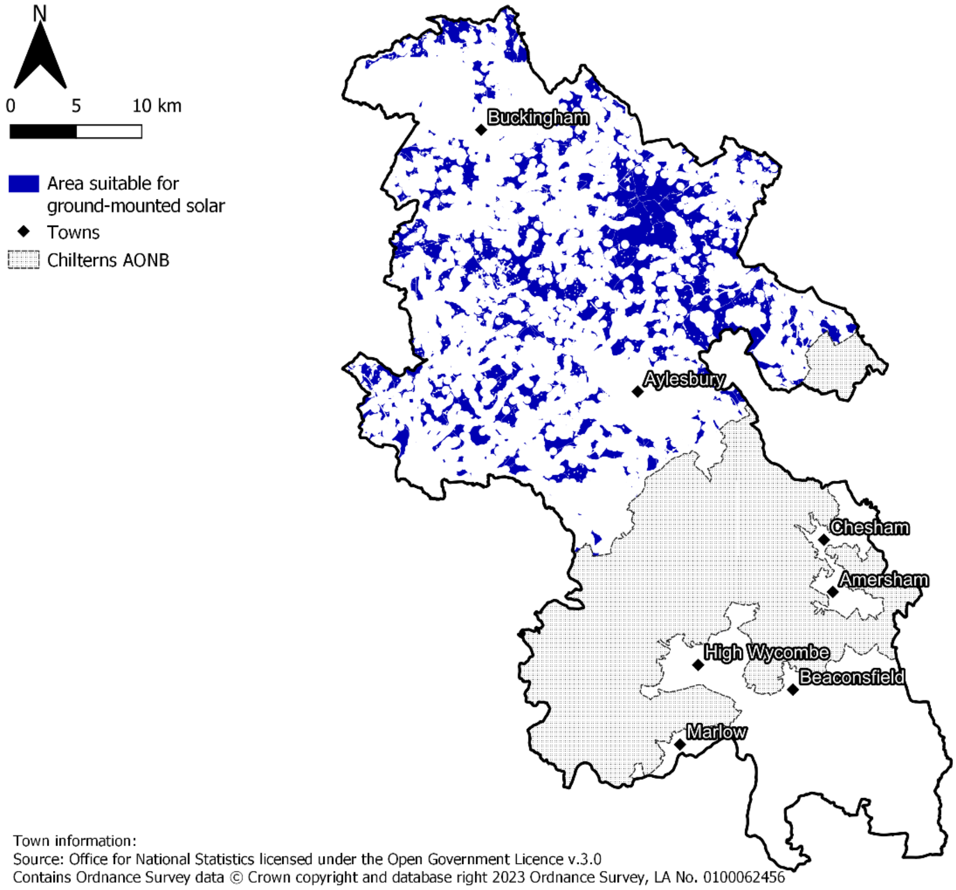
Figure 11: Areas suitable for ground-mounted solar when applying level 1 constraints and excluding SSSIs, NNRs, and Local Plan allocations



The exclusion of SSSIs and NNRs has a much lesser impact than the exclusion of the AONB and the green belt. This is largely because the constraints applied here are much smaller than the area covered by the AONB and the green belt.

The effect of a combination of the two groups – in other words, all level 2 constraints – is shown in Figure 12.

Figure 12: Areas suitable for ground-mounted solar when applying both level 1 and level 2 constraints



As above, the impact of excluding the AONB and green belt from land suitable for ground-mounted solar is far more apparent than excluding the other land designations under level 2 constraints.

Table 13 quantifies the above suitable areas, as well as summarising the technical potential of ground-mounted solar within Buckinghamshire. The maximum technical potential is 11,200 GWh of generation per year, with 8,278 GWh remaining even after applying all level 2 constraints. Table 14 shows the carbon offset potential. Note that this assumes that solar energy offsets carbon from electricity use, both within and outside Buckinghamshire.

Table 13: Summary of potential of ground-mounted solar in Buckinghamshire

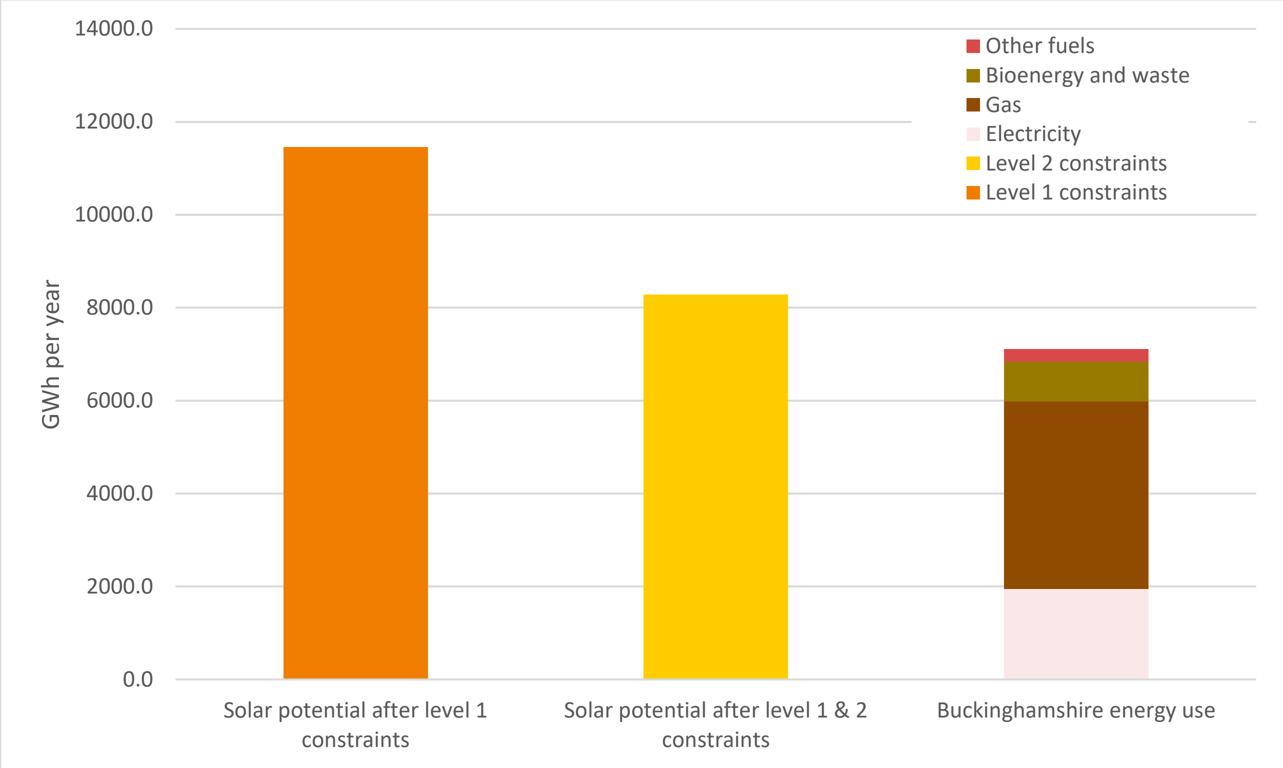
Solar viability	Area (km^2)	Capacity (MW)	Estimated generation (GWh/year)
After applying level 1 constraints	258.7	12,935	11,452.2
After applying level 1 constraints and excluding the AONB, green belt, and Local Plan Allocations	187.0	9,350	8,278.2
After applying level 1 constraints and excluding the SSSIs, NNRs, and Local Plan Allocations	250.2	12,510	11,075.9
After applying all level 2 constraints	187.0	9,350	8,278.2

Table 14: Carbon offset potential of ground-mounted solar PV in Buckinghamshire

Solar viability	Estimated generation (GWh/year)	Carbon offset ($ktCO_2e$/year)
After applying level 1 constraints	11,178	1784.3
After applying level 1 constraints and excluding the AONB, green belt, and Local Plan allocations	8,278	1289.7
After applying level 1 constraints and excluding the SSSIs, NNRs, and Local Plan Allocations	11,076	1725.6
After applying all level 2 constraints	8,278	1289.7

To better contextualise Buckinghamshire's solar potential, Figure 13 compares potential to current energy use in Buckinghamshire. Even after applying both level 1 and level 2 constraints, Buckinghamshire's solar potential outweighs the entirety of its current energy use.

Figure 13: Solar potential in Buckinghamshire compared to current energy use



Even with all level 2 constraints applied, there is enough solar potential to completely meet Buckinghamshire's current energy demand. It should be noted that the electricity produced by PV won't be able to offset all energy usage. For example, some high temperature industrial processes will not be able to be electrified.

5.2. Roof-mounted solar PV and hot water

5.2.1. Solar PV

CSE has developed a rooftop solar potential model that forms the core of the analysis in this section. This model uses LiDAR data (where available) to calculate the footprint of a rooftop. This data is supplemented by Ordnance Survey building footprint polygons. This process detects and models rooftops for solar panels. It follows the below process:

1. Model horizons: using LiDAR data, the model builds a horizon profile for each building. This profile is the horizon height in degrees from horizontal in a ring around the building. This mimics the process of an observer being stood on the roof, and reporting how much sky could be seen in each direction. This helps to calculate shadowing on the roof which may impair solar performance.
2. Detect roof planes: for each building, the model detects the "planes" that make up the roof. For example, a flat-roofed building would have one plane, as would a roof with a single slope. A gabled roof would have two, and so on. This gives the size and orientation of each part of the roof, with each part acting as a potential panel site.
3. Exclude unsuitable sections: the model excludes roof sections which would not suit good solar production. These exclusions are:
    a. Too north-facing
    b. Angled too steeply

   c. Overshadowed to the south, south-east or south-west (using the data calculated in step one)
   d. The roof section is too small for a useful installation
4. Fit panels: a series of panels are fitted to each viable roof section. The model selects a number and positioning and varies these until it finds the best arrangement of panels for that roof section. Best here means the most panels that can fit within that roof plane subject to a series of constraints.
5. Calculate PV output: the model then calculates the PV potential of the panels, considering factors such as shadowing, orientation, and location.

This model has some limitations. It cannot detect where roofs may be unsuitable due to roof weakness or type of building. It is also unable to calculate solar potential when LiDAR data is unavailable. Within Buckinghamshire, LiDAR data covers approximately 80% of buildings within Buckinghamshire. Note that this does not mean that the below figures are 80% of the potential – there is no guarantee that unmodelled buildings would be suitable for rooftop solar.

As shown in Table 15, Buckinghamshire has significant potential in rooftop PV. The maximum technical potential capacity is 756.2 MW. This would give a yearly yield of 576.2 GWh per year. This generation would be able to supply 29.6% of Buckinghamshire's current electricity consumption (assuming generation would coincide with use).

As there may be different decisions to be taken as to where solar PV is deployed, Table 15 categorises the PV potential within building types. The total potential includes both residential and non-residential buildings, and both listed and non-listed buildings. Table 16 shows the potential carbon offset of this technical potential of rooftop PV, assuming that it offsets emissions from electricity usage.

Table 15: Technical potential of rooftop solar in Buckinghamshire

Scenario	Number of buildings	Estimated technical capacity (MW)	Estimated generation (GWh/year)	Total panel area (km^2)
Total potential	149,044	756.2	576.2	3.78
Non-listed buildings	146,337	742.5	566.8	3.71
Listed buildings	2,707	13.7	9.4	0.07
Residential buildings excluding listed buildings	117,554	317.6	443.9	2.22
Non-residential buildings	28,783	298.6	249.3	1.49

Table 16: Potential carbon offset of roof-mounted solar PV in Buckinghamshire

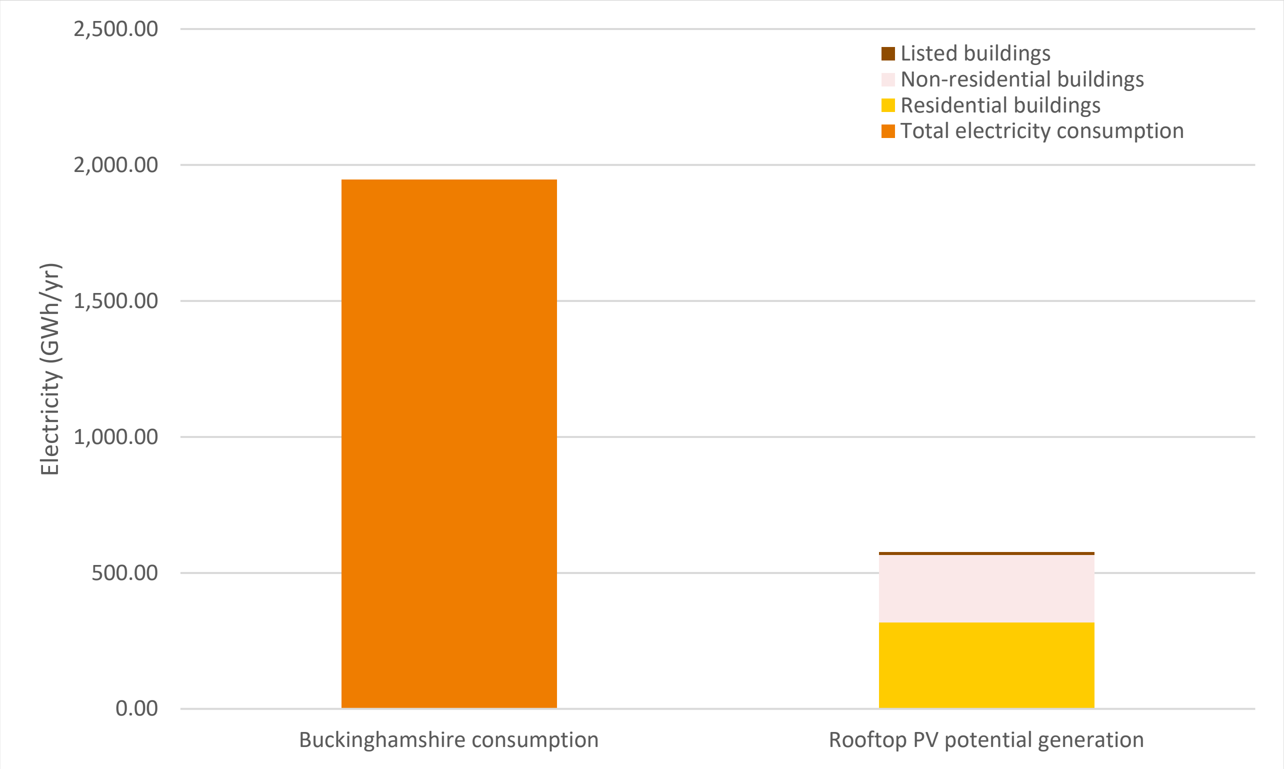
Scenario	Estimated generation (GWh/year)	Potential carbon offset ($ktCO_2e$/year)
Total potential	576.2	89.8
Non-listed buildings	566.8	88.3
Listed buildings	9.4	1.5
Residential buildings excluding listed buildings	443.9	69.2
Non-residential buildings excluding listed buildings	249.3	38.8

Generally, it is more difficult to install rooftop solar on listed buildings. As the decision on modification of listed buildings sit with local planning authorities, it is useful to examine the impact of enabling solar installations on listed buildings. In Buckinghamshire, listed buildings are only 1.6% of the total technical potential generation in the study area (and 1.8% of potential capacity). Therefore, the barriers posed by listed buildings has a relatively low impact on the total solar PV potential of the area.

Non-residential buildings generally have larger rooftops (and therefore greater solar potential) than residential buildings. However, the process for installing PV on these buildings is more complex, and expensive, than for residential. Therefore, it is useful to consider these separately. In Buckinghamshire, commercial buildings are 19.3% of the potentially suitable buildings, but 43.3% of the potential yearly generation (and 39.5% of potential capacity).

To contextualise the above, Figure 14 compares the current yearly electrical consumption of Buckinghamshire to the potential yearly generation from rooftop PV, broken down by the above categories.

Figure 14: Rooftop PV potential generation compared to Buckinghamshire's electricity consumption



Rooftop PV cannot meet the entirety of Buckinghamshire's electricity consumption. However, it does provide a significant level of contribution towards that figure. One should note that rooftop PV can provide wider benefits to the buildings on which it is installed. One of the biggest benefits is decreased fuel bills, which can go a significant way towards alleviating fuel poverty.

It is also useful to know which areas of Buckinghamshire have the most solar potential. To demonstrate this, Buckinghamshire has been broken down into its wards. Figure 15 shows the distribution of potentially suitable buildings in each ward.

Figure 15: Distribution of total rooftop solar PV potential by buildings across Buckinghamshire's wards, including existing rooftop solar PV

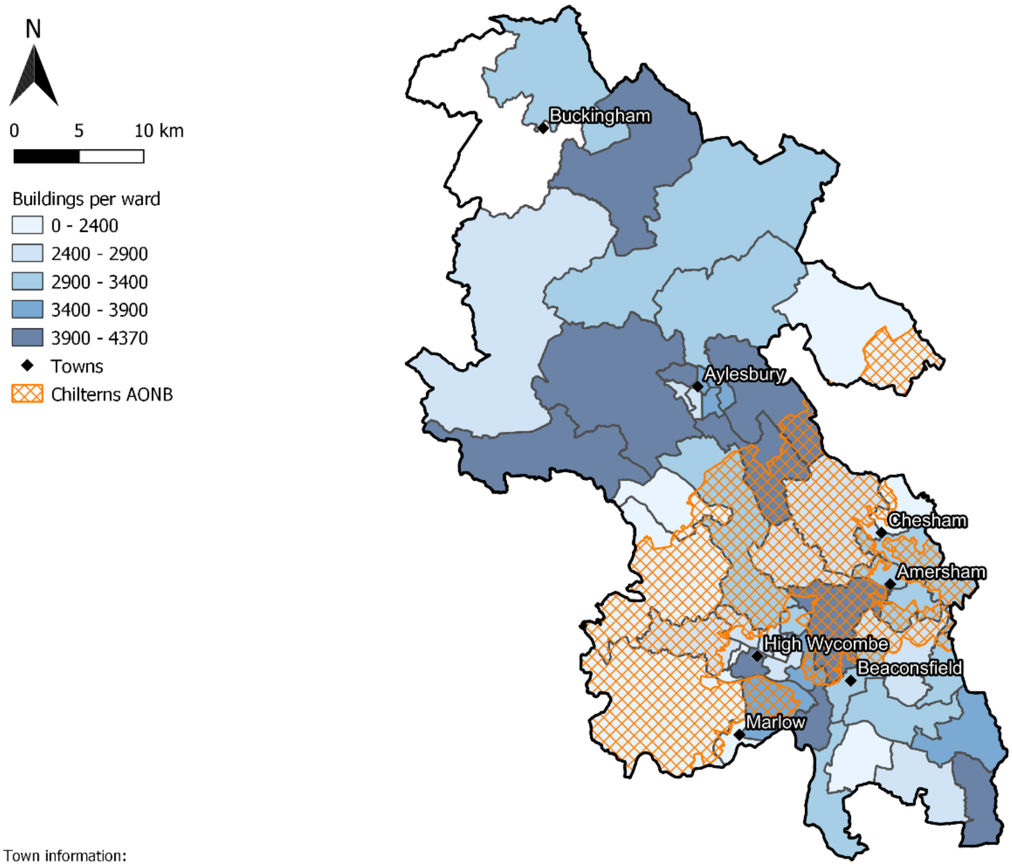


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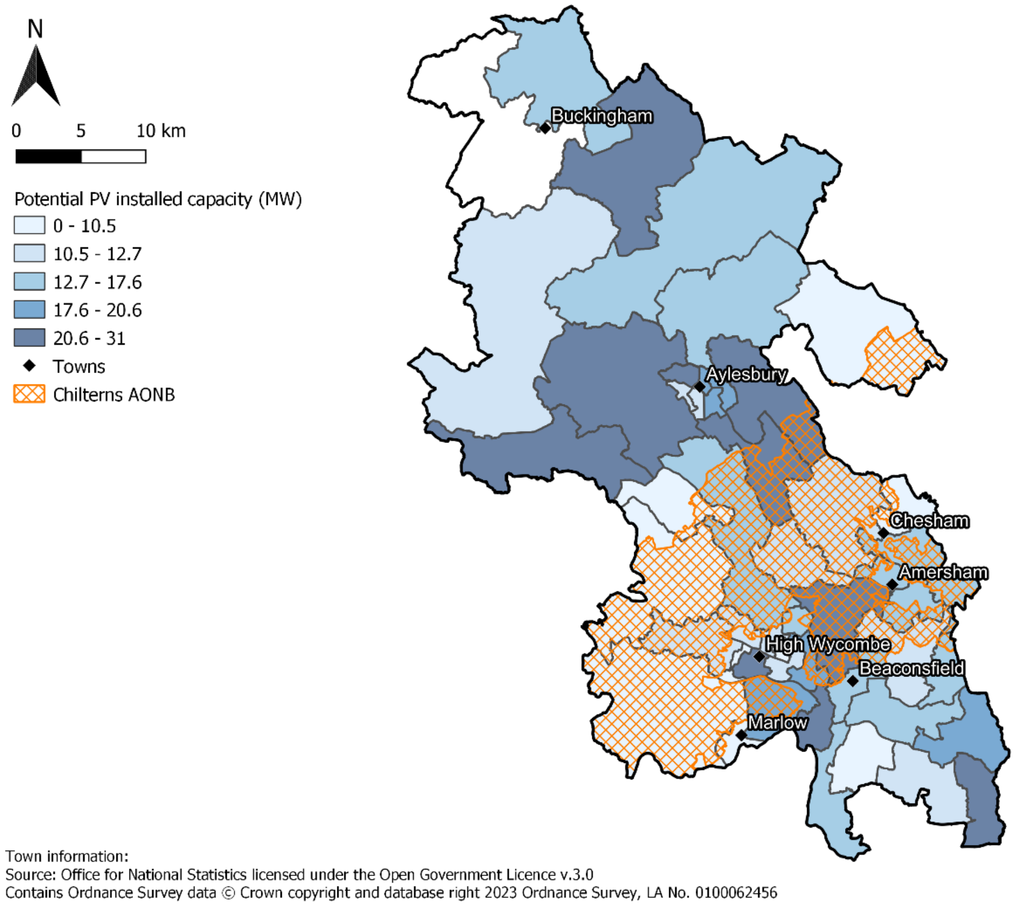
Figure 16: Distribution of total solar PV potential capacity across Buckinghamshire's wards, including existing solar PV installations



Solar PV, both when considering the capacity and the number of suitable buildings, is relatively well distributed throughout Buckinghamshire. The greatest concentrations are near the largest built-up areas – which is common due to a higher number of rooftops. More rural areas have lesser potential due to a lack of rooftops to install solar upon.

5.2.2. Solar hot water

In this study, we have assumed that solar hot water can make use of the same amount of roof space, under the same conditions as solar PV. Therefore, the panel areas derived for solar PV hold true for solar thermal. A yearly generation figure per m^2 of solar hot water panel is applied to the area predicted for the solar PV. This figure is based on the use of evacuated tube solar hot water systems. These are more expensive but offer better capture of solar energy than glazed panels.

It is further assumed that only residential buildings are suitable for rooftop solar hot water (SHW) in this study. This is because residential SHW can be assumed to be used within the building where the panels are located. Non-residential buildings may not use enough hot water to take advantage of some or all of the generated hot water. This is particularly true of large non-residential buildings. These types of installation are more suited to being a potential heat source for heat networks – this is discussed in the section Heat networks.

There are estimated to be 119,514 buildings suitable for SHW installations. This would provide 1,017.3 GWh of hot water per year. As for PV, there can be difficulties with installing SHW systems on listed buildings. Table 17 shows the difference in potential when considering listed buildings. Table 18 shows how much carbon would be offset by this production of hot water, both against gas and electricity-generated hot water.

Table 17: Technical potential of rooftop solar hot water in Buckinghamshire

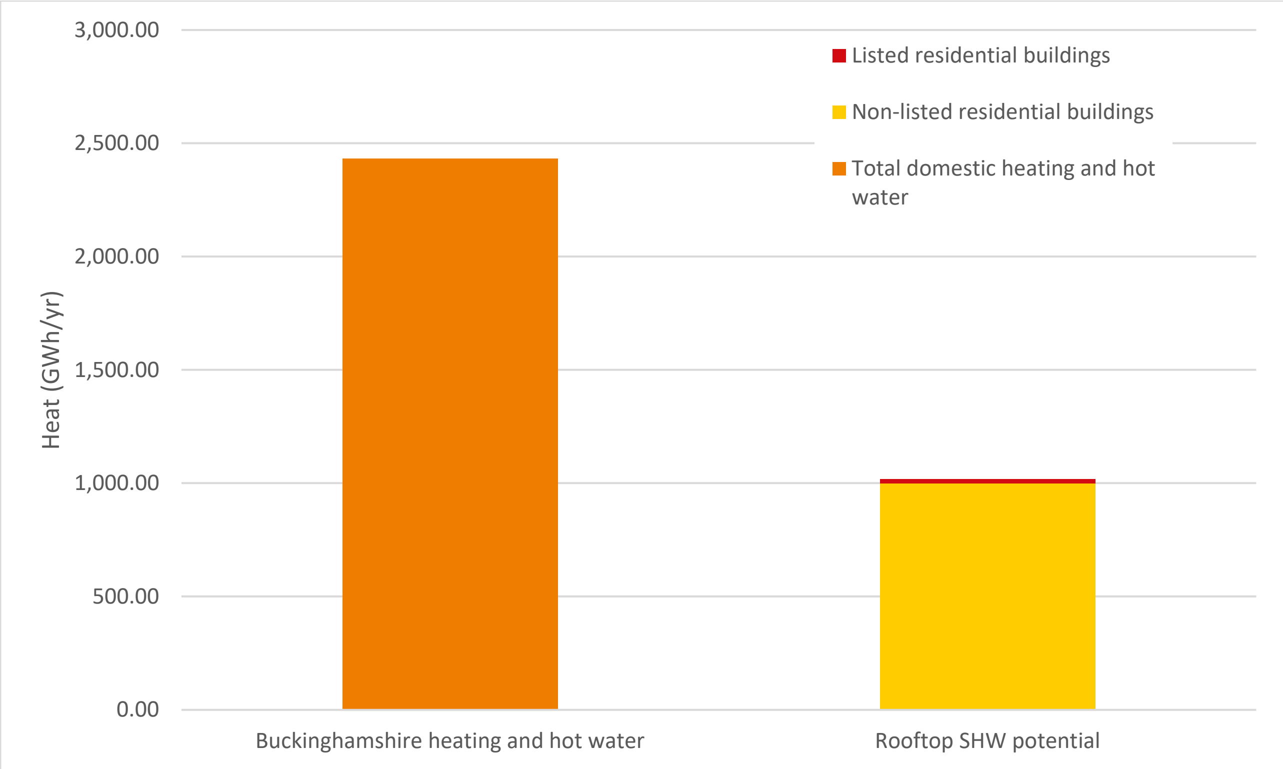
Scenario	Number of buildings	Estimated generation (GWh/year)	Volume of hot water at 60°C (million litres)	Total panel area (km^2)
Residential buildings (including listed buildings)	119,514	1017.3	17,509	2.26
Non-listed residential buildings	117,554	998.8	17,191	2.22

Table 18: Potential carbon offsets of solar hot water in Buckinghamshire

Scenario	Estimated generation (GWh/year)	Carbon offset compared to gas ($ktCO_2e$/year)	Carbon offset compared to electricity ($ktCO_2e$/year)
Listed and non-listed residential buildings	1,017.3	186.2	158.5
Non-listed residential buildings	998.8	182.8	155.6

It is worth considering how the solar potential in Buckinghamshire compares to the demand for heating and hot water. Figure 17 compares the estimated potential to an estimate of Buckinghamshire's current heat and hot water demand (see Section 4.6 for estimation of Buckinghamshire's heat demand).

Figure 17: Rooftop solar hot water potential compared to Buckinghamshire's estimated heating and hot water use



Solar hot water has greater potential in terms of energy generation than solar PV on a comparable basis. One m^2 of SHW generates more energy than one m^2 of PV. However, its use is much more limited – it can only meet some of the heating and hot water requirements of a building. This is because solar hot water does not normally produce water that is hot enough for use in domestic hot water and central heating systems. The water heated by SHW must be "topped up" (for example with an immersion heater) to the correct temperature. Additionally, SHW has the best performance during summer – when the sun is up for longer periods and is more intense. The greatest requirement for heating and hot water is in the winter. Generally, solar hot water can only meet a small portion of hot water demand in the winter, and the top up system must be relied upon much more heavily. It should also be noted that heating requirements are generally far greater than current electricity requirements.

As with PV, it is useful to know which areas of Buckinghamshire have the greatest rooftop SHW potential. Figure 18 shows the distribution of the number of buildings suitable for SHW by ward. Figure 19 shows the potential yearly hot water generation by ward.

Figure 18: Distribution of solar hot water potential by buildings across Buckinghamshire's wards

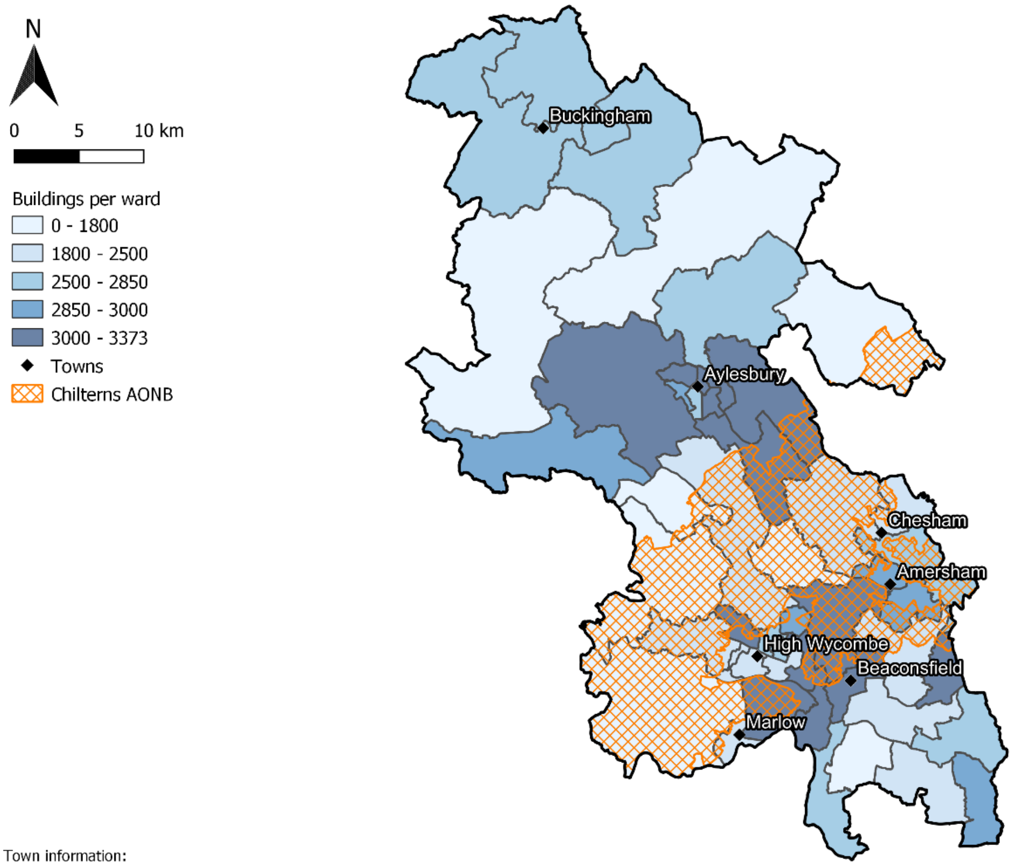


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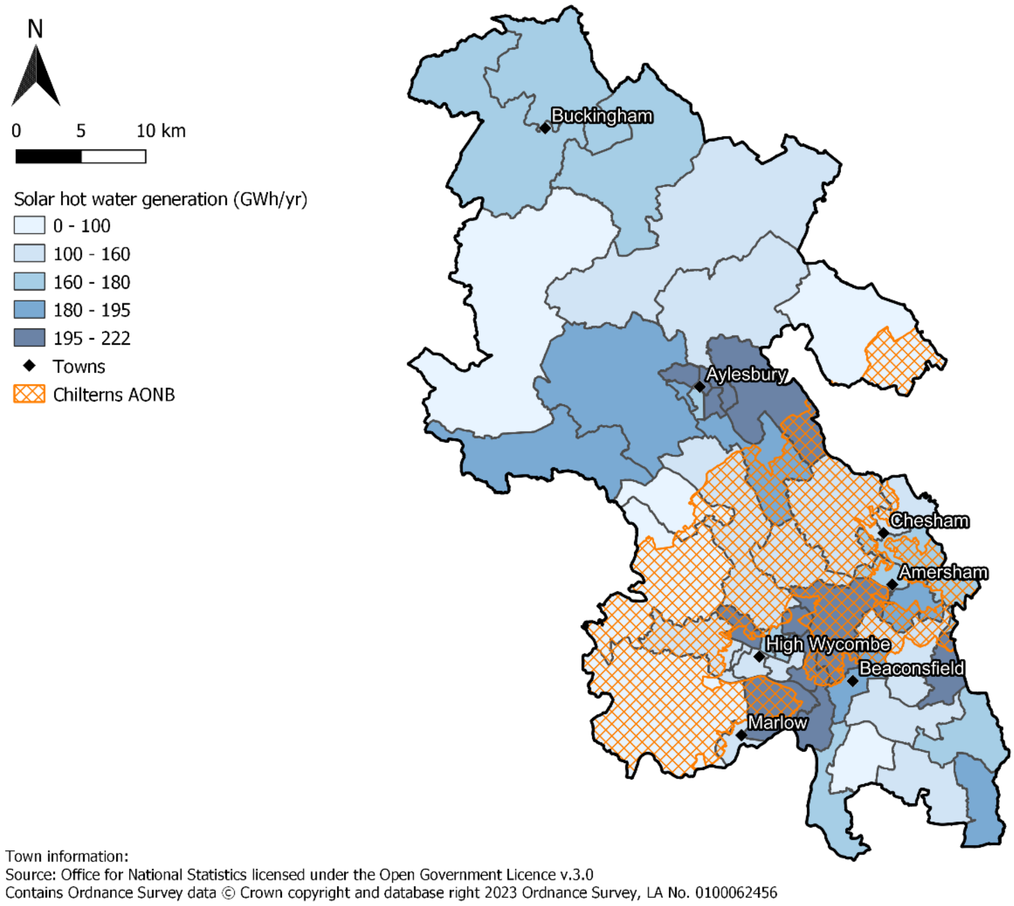
Figure 19: Distribution of total solar hot water potential yearly generation across Buckinghamshire's wards



As with solar PV, solar thermal is concentrated in more densely populated areas, due to the availability of rooftops on which to install the technology.

It should be noted that there is overlap between PV and SHW in this study, but the same rooftop can't be used twice. It is therefore necessary to understand which technology is more beneficial in the study area – as well as which is likely to have greater utility. In the domestic sector, heating and hot water is responsible for the largest portion of the average home's usage. As SHW has greater energy potential than solar PV (in terms of energy per m^2), it may seem obvious to use this wherever practical. However, SHW does not line up well in terms of generation (when hot water is produced) and demand (when heat and hot water are required). SHW also rarely produces water hot enough for heating the home. Therefore, the greater production is limited in what it can achieve.

As the UK continues to decarbonise, heating is likely to be increasingly electrified – either through heat pumps or more traditional immersion heaters. A combination of solar hot water and an immersion heater can reliably supply heat and hot water to a home, but the running costs could end up being higher than with a heat pump (which can offer greater efficiencies). Because of this, a heat pump combined with solar PV could prove to be cheaper to run in the long term. These trade-offs must be considered when deciding which of rooftop PV or SHW to pursue. This is particularly important when considering any proposals, to ensure that inequalities are not exacerbated, and that any proposals enable equity.

5.3. Wind power

5.3.1. Assumptions

This assessment was undertaken using GIS to map key constraints and opportunities. It examined areas with potentially viable windspeeds and the number of turbines that could be deployed in these areas. The areas were constrained using physical features and environmental and heritage designations. The remaining areas are considered to offer the maximum technical potential for wind in Buckinghamshire. With wind there are a great deal of site-specific considerations that need to be examined on an individual site basis, which is outside the scope of this study. Therefore, constraints were based on typically used values and guidance from a variety of sources. At the site-specific level, areas identified as suitable may not be, and areas not identified as suitable may prove to be suitable. As a result, the outcomes of this assessment highlight potential areas for wind power, but it is likely in reality that these areas may be slightly larger or smaller than indicated here. One example of the variance is the distance from residential properties. A value of 350m (for more information see Appendix 2: Buffers used in modelling) is used in this study, but site-specific characteristics may allow this to be reduced or may need it to be expanded.

Table 19 shows the constraints applied during wind potential mapping. Level 1 and 2 constraints apply as with ground-mounted solar. A level 1 constraint is one which is a relatively hard limit and is likely unavoidable, though there may be variation in site-specific analysis. Level 2 constraints are less hard limits, where renewable development may be possible, but likely with greater effort. Level 3 constraints are those where there are statutory or mandatory consultees. A description of the buffers applied to each constraint and the reasoning for its inclusion are given in Appendix 2: Buffers used in modelling.

Table 19: Constraints applied to wind potential mapping

Constraint	Level of constraint
Roads	Level 1
Rail	Level 1
Transmission lines (and pylons)	Level 1
MOD land	Level 1
Residential properties	Level 1
Employment sites	Level 1
Existing wind	Level 1
Water	Level 1
Woodland	Level 1
Scheduled monuments	Level 1

Constraint	Level of constraint
Historic parks and gardens	Level 1
Flood zones 2 and 3	Level 1
Existing settlements	Level 1
Special areas of conservation (SACs)	Level 1
Agricultural land grades 1 - 3a	Level 1
Areas of non-viable windspeed	Level 1
Minerals commitments and safeguarding areas (Buckinghamshire Council, 2019)	Level 1
Local plan and neighbourhood plan sites	Level 2
Area of outstanding natural beauty (AONB)	Level 2
Sites of special scientific interest (SSSIs)	Level 2
National nature reserves (NNRs)	Level 2
Green belt	Level 2
Airports	Level 3
NATS (formerly the National Air Traffic Services) safeguarding areas	Level 3
MOD safeguarding area	Level 3

To carry out a widespread assessment such as this, it is necessary to create typical archetypes for wind turbines, as there is a great variation of size, design and capacity across the market. Based on a review of turbines available, the characteristics of different turbines are given in Table 20. For comparison, the turbine outside Aylesbury is considered a large turbine, with a hub height of up to 100m and rotor diameter of 87m.

Table 20: Archetypes for different turbine sizes used in this study

Characteristic	Very Large Turbines	Large Turbines	Medium Turbines	Small Turbines
Typical capacity (MW)	4	2.5	0.5	0.05
Hub height (m)	125	100	50	25
Rotor diameter (m)	150	125	50	25

The analysis first presents the total viable area for each turbine type under the various constraints given above. It then examines the turbines in a hierarchy with level 1 constraints. The hierarchy is:

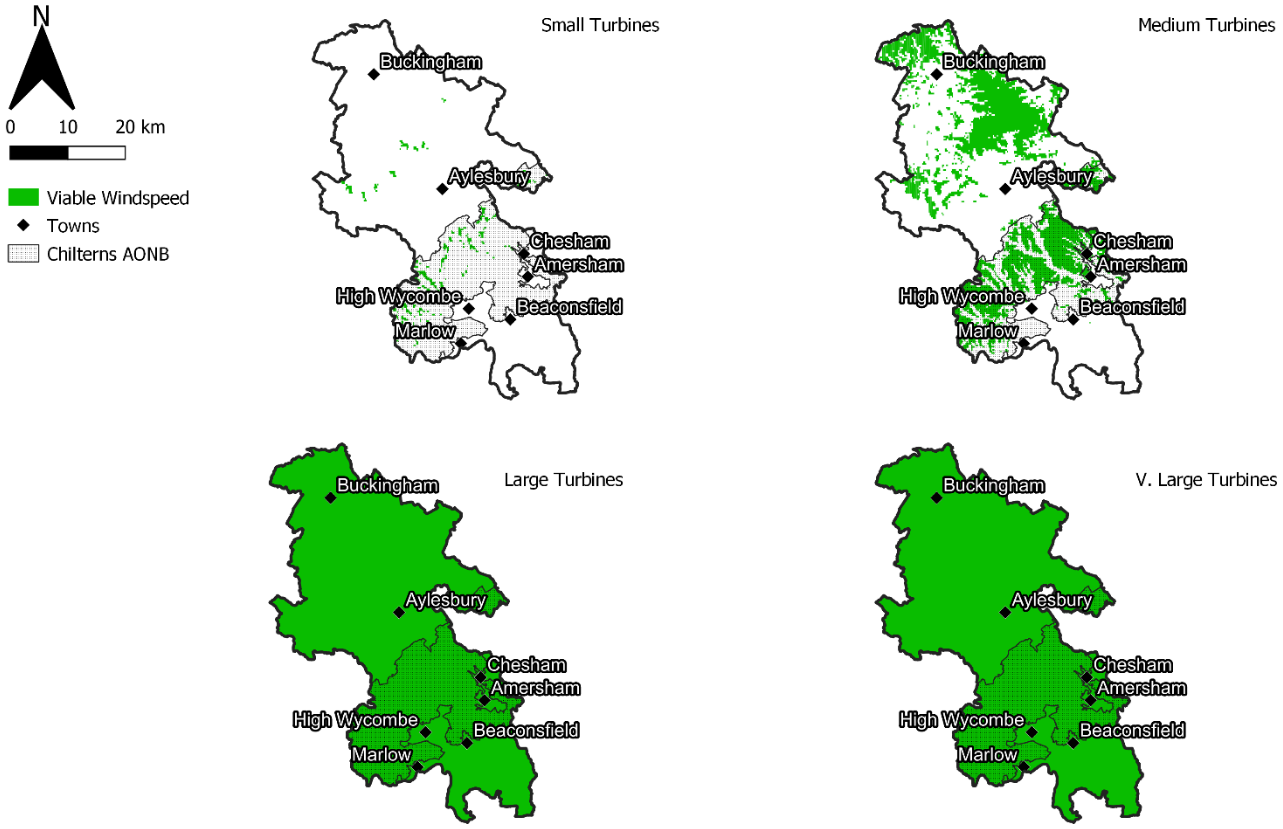
Very large turbines > large turbines > medium turbines > small turbines

This is because very large and large turbines are those most likely to be deployed on larger scales, as they better capture the wind energy available at a site. Medium and small turbines are more likely to be applied as single units rather than in farms. They can be used to capture wind that is not captured by larger turbines due to constraints which are lesser on smaller turbines, or from smaller sites.

5.3.2. Results

The area viable based on windspeed alone is shown in Figure 20. This highlights that larger turbines are viable across far larger ranges than smaller turbines due to better capturing the wind's energy. For smaller turbines, it can be seen that the best areas in terms of viable windspeed for wind development are in the Chilterns AONB and in the northern part of Buckinghamshire.

Figure 20: Areas of Buckinghamshire with suitable windspeeds at the hub height of turbines of different scale



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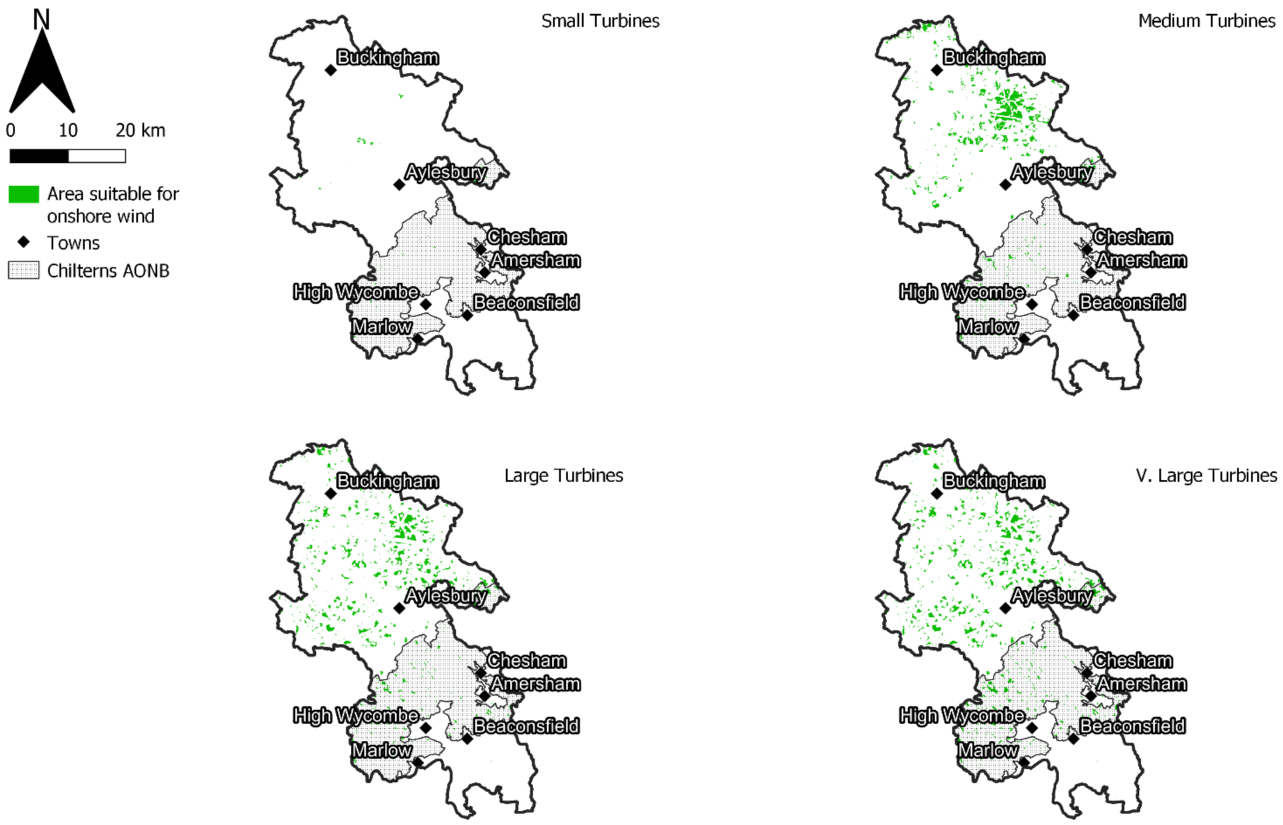
The higher hub height of large and very large turbines means that they can capture the higher windspeeds at greater altitudes. This means that they are both viable across a wider spread of Buckinghamshire than the smaller turbines. The areas highlighted under small and medium turbines would show the areas of Buckinghamshire with the greatest windspeeds at any altitude. Greater windspeeds produce more energy. Because of this, large and very large turbines would still perform better in the regions highlighted by the small and medium turbines, so should be prioritised in these areas if possible.

Figure 21 shows the areas viable for wind turbines of different sizes when level 1 constraints are applied. This can be seen as the maximum technical potential with Buckinghamshire.

Figure 21: Areas suitable for wind turbines when applying level 1 constraints



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Level 1 constraints severely limit the viable area for all sizes of wind turbines. This is because, due to their size, wind turbines are far more limited in where they can be deployed compared to ground-mounted solar energy. It should also be considered whether sites should be prioritised for wind or solar power.

The area viable for wind turbines is further reduced when applying level 2 constraints. As with ground-mounted solar, level 2 constraints have been grouped. The reason for these groupings is the Council may wish to consider these constraints differently in the Local Plan, due to differing justification for the designations. Whilst the designations for the Chilterns AONB and the green belt have different purposes and geographical significance, and whilst they cover different areas of Buckinghamshire, particularly in the south, in this study these have been grouped as Level 2 constraints, as they both restrict the potential for development in the countryside. The viable areas excluding this group are shown in Figure 22. SSSIs, and NNRs have been excluded in Figure 23. In both cases, allocations from the 2021 Vale of Aylesbury Local Plan, 2019 Wycombe District Local Plan and 2011 Chiltern and South Bucks Core Strategies are excluded. All level 2 constraints are shown in Figure 24.

Figure 22: Areas suitable for wind turbines after applying level 1 constraints and excluding the AONB, green belt and Local Plan allocations

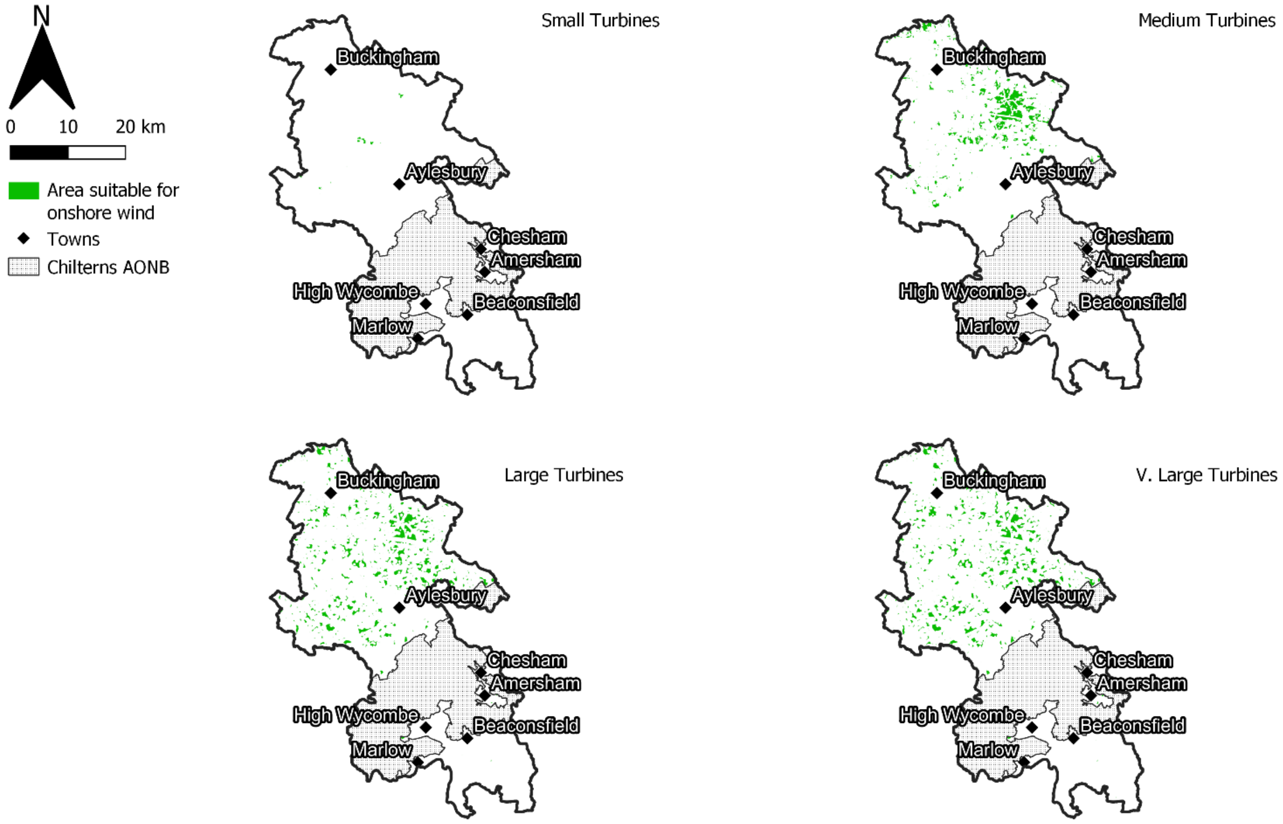

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Figure 23: Areas suitable for wind turbines after applying level 1 constraints and excluding SSSIs, NNRs and Local Plan allocations

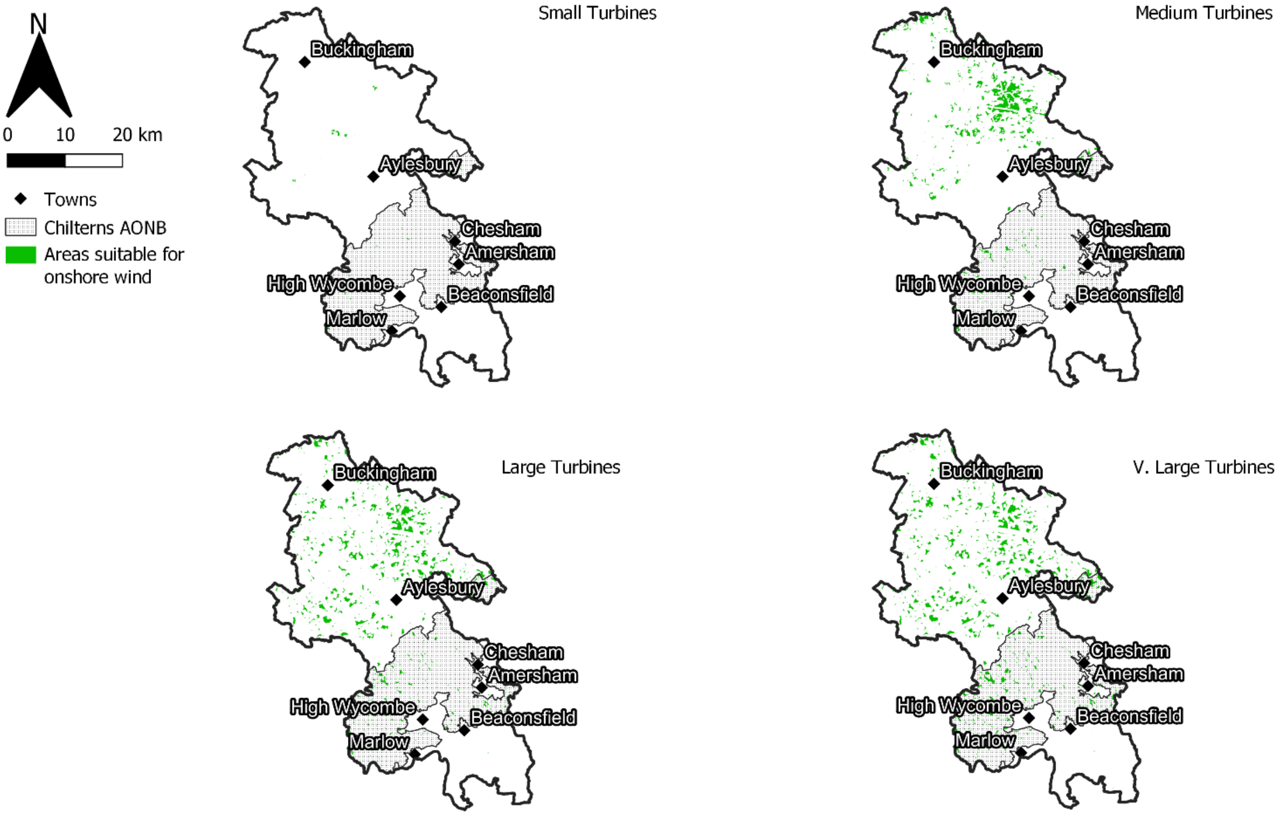

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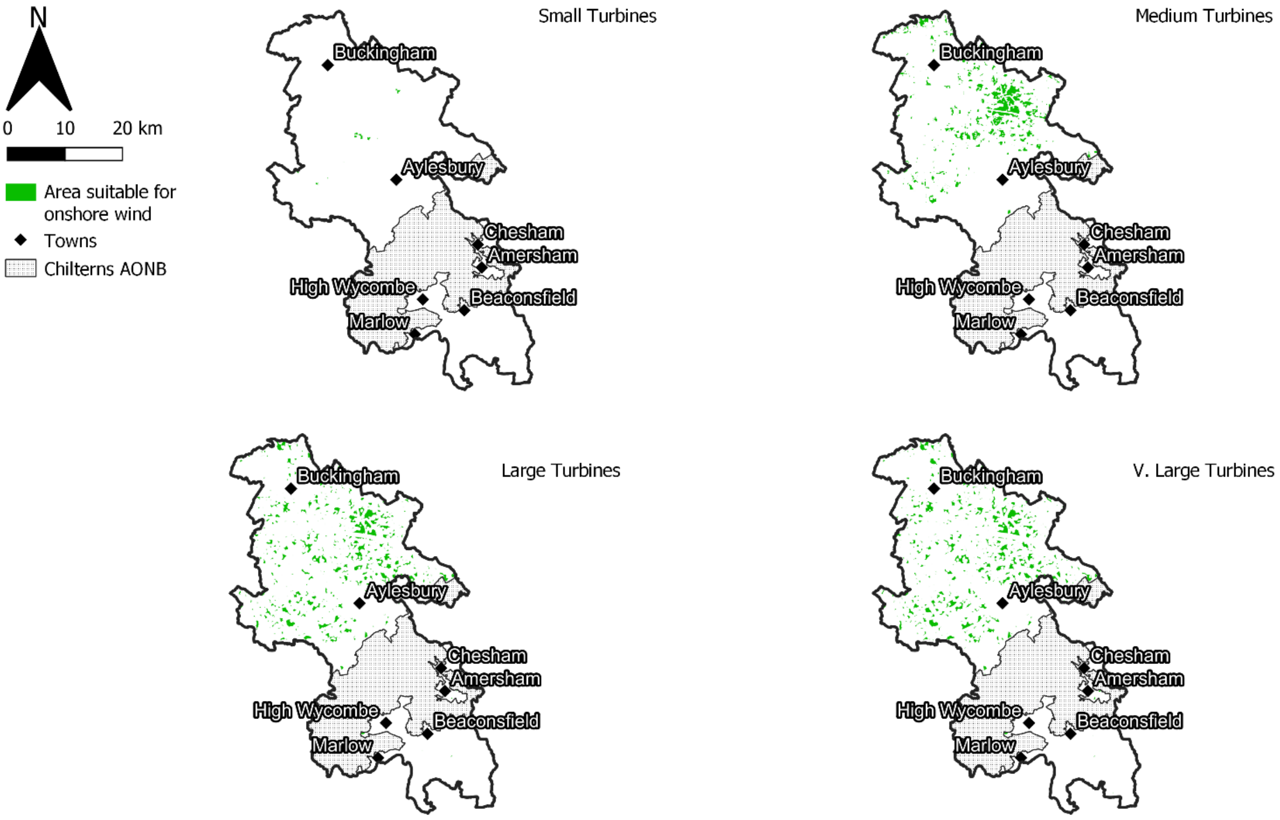
Figure 24: Areas suitable for wind turbines after applying level 1 and all level 2 constraints



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As with ground-mounted solar, the introduction of level 2 constraints further limits the extent of wind turbine opportunities. Once again, the AONB and green belt eliminate wind viability in the south of the county. Careful consideration should be given to the impact of designated areas on renewable energy potential.

Level 3 constraints give areas where there are statutory consultees when developing wind power. These statutory consultees are NATS (formerly the National Air Traffic Services), MOD (the Ministry of Defence), and airports. These consultees all have interest in air traffic control, the radars of which can be impacted by wind turbines. As these can act as a barrier to development but are different to level 1 or 2 constraints they should be considered separately. They will apply independently of whether level 1 constraints or both level 1 and 2 constraints are applied, so both situations are highlighted. Figure 25 shows level 3 constraints applied after level 1 constraints only. Figure 26 shows the application of all three levels of constraint. These figures show level 3 constraints as removing viability, but that is unlikely to be the case. It is likely the viable area will be somewhere between the situation with no level 3 constraints, and with the constraints fully applied. However, this will only be known during the consultation process on a specific site.

Figure 25: Suitable areas for wind turbines after applying level 1 and level 3 constraints

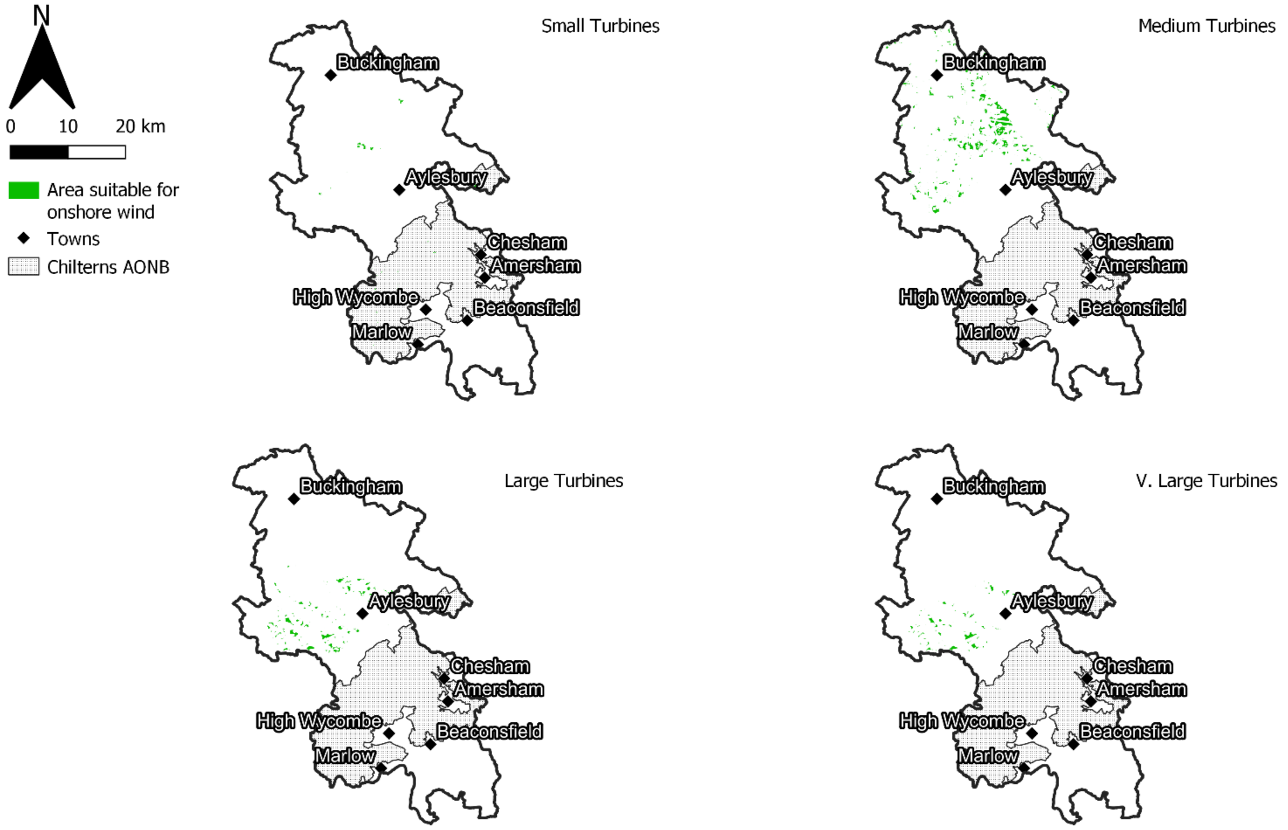

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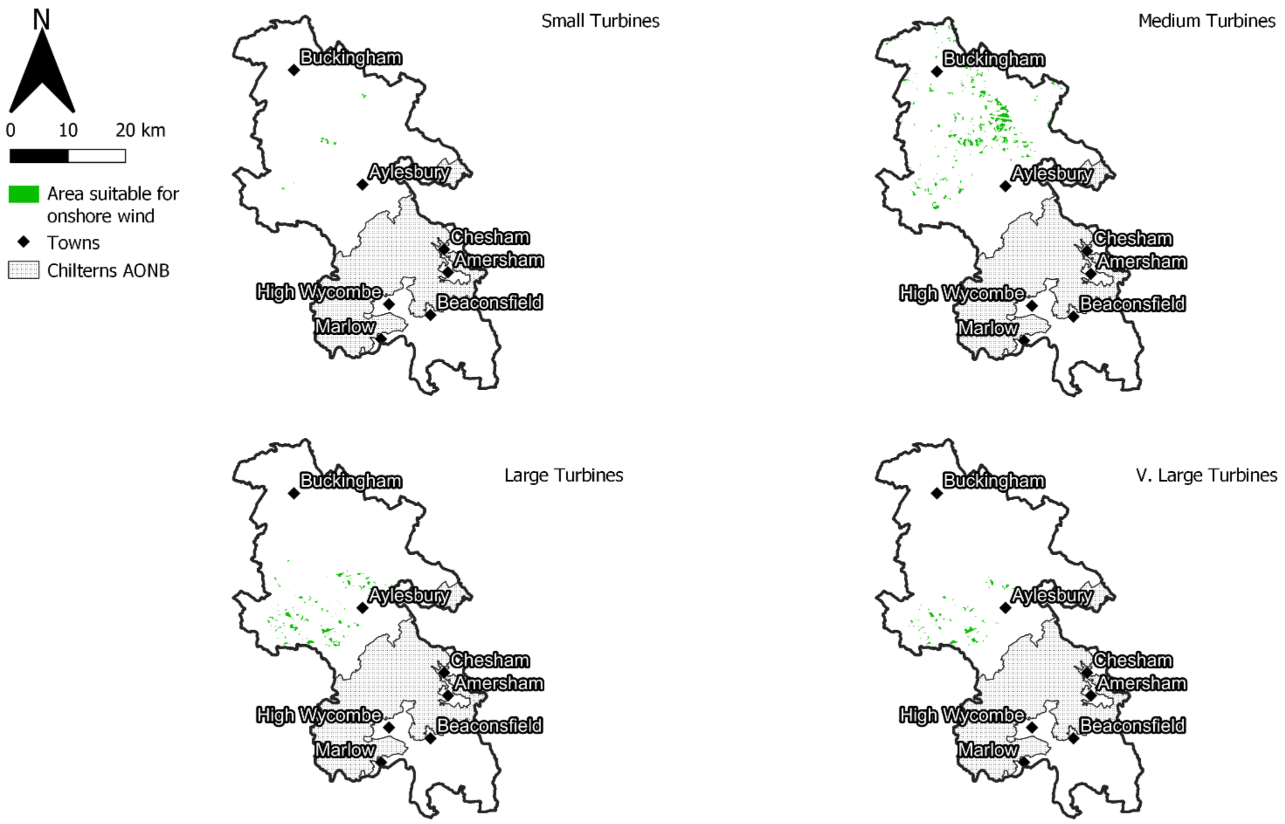
Figure 26: Suitable areas for wind turbines after applying level 1, 2 and 3 constraints



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The introduction of level 3 constraints reduces the area available for wind to a relatively small area. Level 3 constraints are not likely to completely eliminate this large an area – these areas are those that have mandatory consultees for wind development. The planning authority should take steps to engage with these mandatory consultees to understand how their opinions may affect the definition of areas for renewable energy development in the Local Plan.

Table 21 quantifies the above areas under the different levels of constraint. Table 22 gives the capacities as calculated using a turbine density figure as detailed in Appendix 3: Factors used in modelling. Table 23 uses a capacity factor for wind to convert this to a yearly generation.

Table 21: Suitable areas (km^2) for wind turbines after applying constraints

Constraints	Very large turbines	Large turbines	Medium turbines	Small turbines
With viable windspeeds	1,565.9	1,565.9	489.4	30.6
After applying level 1 constraints	78.2	68.5	53.4	2.7
Applying level 1 constraints and excluding AONB,	58.7	56.7	44.5	1.3

Constraints	Very large turbines	Large turbines	Medium turbines	Small turbines
greenbelt and Local Plan allocations				
Applying level 1 constraints and excluding SSSIs, NNRs and Local Plan allocations	77.9	68.2	53.0	2.4
After applying level 1 and 2 constraints	58.1	56.7	44.5	1.3
After applying level 1 and 3 constraints	5.7	9.6	23.9	1.8
After applying level 1, 2 and 3 constraints	5.7	9.6	23.9	1.1

Table 22: Potential capacities (MW) of wind turbines after applying constraints

Constraints	Very large turbines	Large turbines	Medium turbines	Small turbines
After applying level 1 constraints	782.0	685.0	640.8	13.1
Applying level 1 constraints and excluding AONB, greenbelt and Local Plan allocations	587.0	567.0	534.0	6.3
Applying level 1 constraints and excluding SSSI, NNRs and Local Plan allocations	779.0	682.0	636.0	11.6
After applying level 1 and 2 constraints	581.0	567.0	534.0	6.3
After applying level 1 and 3 constraints	57.0	96.0	286.8	8.7
After applying level 1, 2 and 3 constraints	57.0	96.0	286.8	5.3

Table 23: Potential generation (GWh/year) of wind turbines after applying constraints

Constraints	Very large turbines	Large turbines	Medium turbines	Small turbines
After applying level 1 constraints	1,837.1	1,609.3	1,505.4	30.8
Applying level 1 constraints and excluding AONB, greenbelt and Local Plan allocations	1,379.0	1,332.0	1,254.5	14.8
Applying level 1 constraints and excluding SSSI, NNRs and Local Plan allocations	1,830.1	1,602.2	1,494.1	27.3
After applying level 1 and 2 constraints	1,364.9	1,322.0	1,254.5	14.8
After applying level 1 and 3 constraints	133.9	225.5	673.8	20.5
After applying level 1, 2 and 3 constraints	133.9	225.5	673.8	12.5

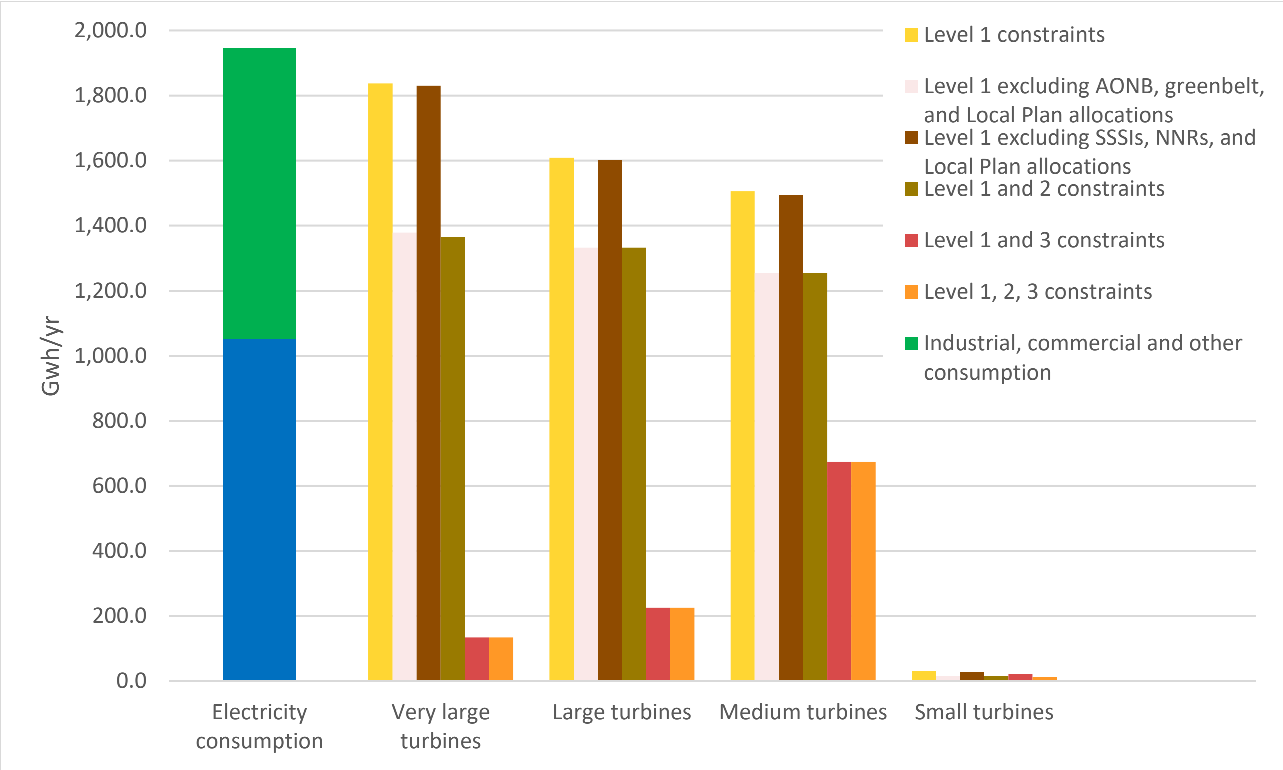
Table 24 shows the potential carbon offset from the development of Buckinghamshire's wind potential. Note that this table considers if wind was used to offset electricity emissions.

Table 24: Potential carbon offset from wind power (in ktCO_2e per year)

Constraints	Very large turbines	Large turbines	Medium turbines	Small turbines
After applying level 1 constraints	286.2	250.7	234.5	4.8
Applying level 1 constraints and excluding AONB, greenbelt and Local Plan allocations	214.9	207.5	195.5	2.3
Applying level 1 constraints and excluding SSSI, NNRs and Local Plan allocations	285.1	249.6	232.8	4.3
After applying level 1 and 2 constraints	212.7	207.5	195.5	2.3
After applying level 1 and 3 constraints	20.9	35.1	105.0	3.2
After applying level 1, 2 and 3 constraints	20.9	35.1	105.0	2.0

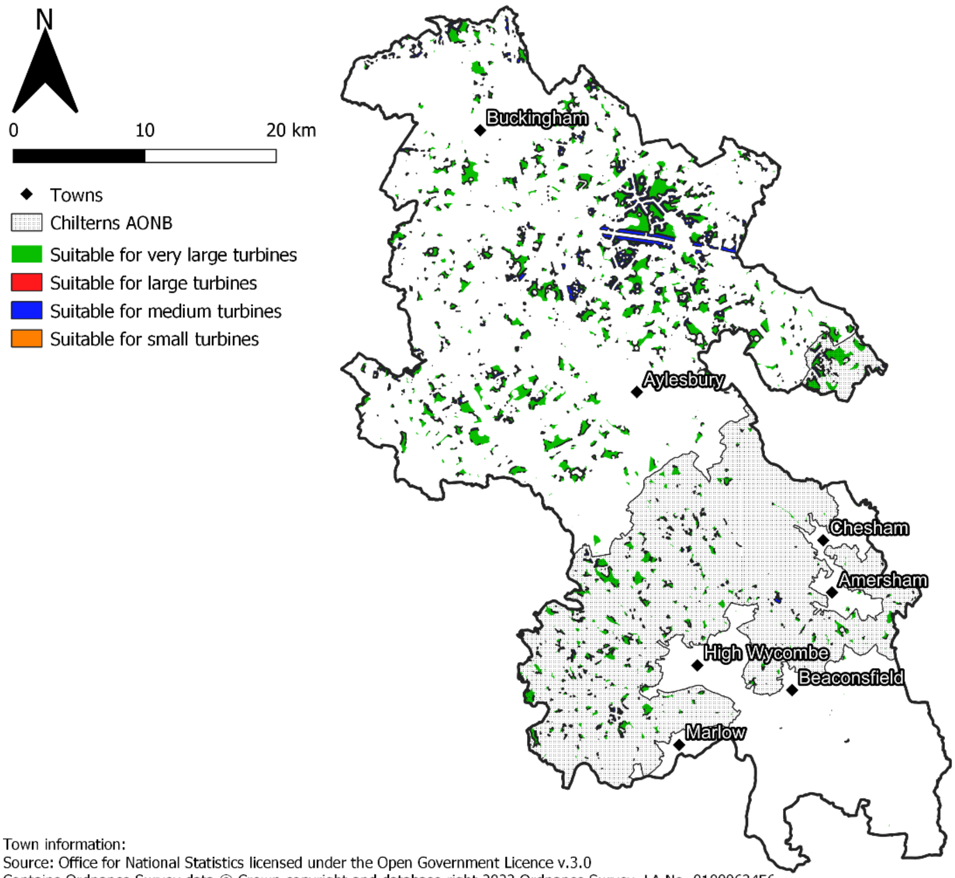
To contextualise the potential generation from different scales of turbines and with different constraints, Figure 27 compares the yearly generations to the current electricity consumption of Buckinghamshire.

Figure 27: Yearly generation of turbines scales with differing constraints against Buckinghamshire's current electricity consumption



The above analysis shows the potential for each turbine type individually. In reality, turbines of different scales will overlap in terms of where they are suitable. Therefore, Figure 28 shows the viable areas of wind turbines under level 1 constraints when considering the turbine hierarchy.

Figure 28: Suitable wind areas under level 1 constraints considering wind turbine hierarchy



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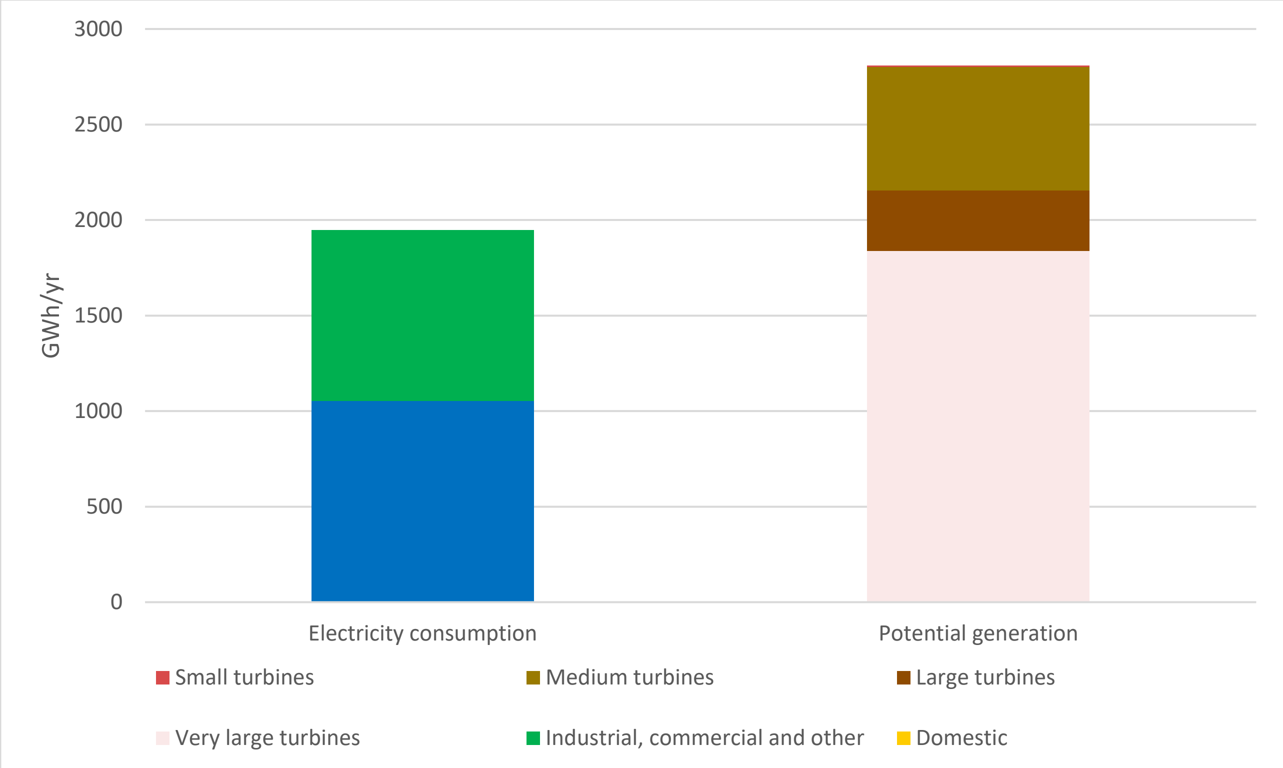
When hierarchies are introduced, the general pattern is that larger turbines dominate. Smaller turbines generally form boundaries to sites suitable for larger turbines, in the space where there is a difference in their constraints. Smaller turbines also take advantage of areas where large turbines are not viable. This largely reflects what we see across the country, where smaller turbines are only deployed in small amounts (not as wind farms). Where there is space for wind farms, there is space for larger turbines, which better capture the wind's potential.

Table 25 presents the viable area, potential capacity and generation when following the turbine hierarchy under level 1 constraints. Figure 29 contextualises this against the yearly electricity consumption in Buckinghamshire.

Table 25: Suitable area, and potential capacity and generation under level 1 constraints when applying the turbine hierarchy

	Very large turbines	Large turbines	Medium turbines	Small turbines	Total
Suitable area (km²)	78.2	13.6	22.9	0.6	115.3
Potential capacity (MW)	782	136	274.8	2.9	1,195.7
Potential generation (GWh/year)	1,837.1	319.5	645.6	6.8	2,809.1

Figure 29: Comparison of the yearly generation under level 1 constraints following the turbine hierarchy compared to Buckinghamshire's current electricity consumption



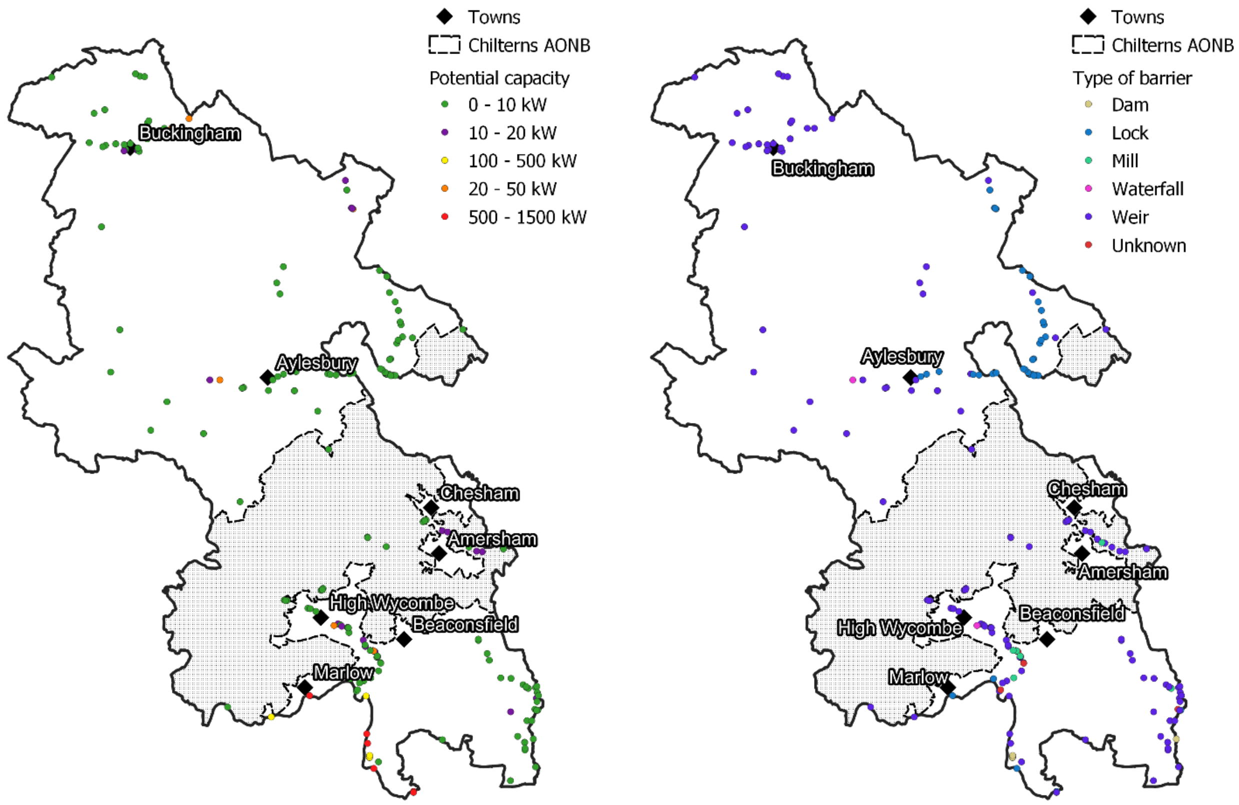
Under level 1 constraints, wind power is more than capable of meeting the entirety of Buckinghamshire's current electricity demand, leaving some headroom. This headroom could meet some of the increased requirements of electrification. As discussed in the section Renewable heat, there will likely be a need to move towards electrified sources of heat (and transport). Therefore, a large portion of current heat demand is likely to become electricity demand.

5.4. Hydropower

Hydropower is based on capturing energy from water flowing from a higher level to a lower level. Hydropower facilities convert this energy using a turbine and generator combination. The energy is proportional to volume of water and the difference in height. Hydropower is constrained in England due to relatively low-lying terrain, and significant environmental implications of large schemes. This means most potential is in the form of smaller-scale hydropower schemes. These small-scale schemes generally make use of existing features such as weirs, dams, locks, etc. Therefore, these features are the focus of this analysis. An Environment Agency report (Environment Agency, 2021) summarised the availability of these sites, where there is likely to be little environmental impact. This analysis draws on those results to highlight the hydropower potential in Buckinghamshire.

This study identified a total of 188 potential sites for hydropower in Buckinghamshire, with a total potential capacity of 8.2 MW, across a range of barrier types. Figure 30 shows these locations within Buckinghamshire, highlighting both the potential capacities and the type of barrier.

Figure 30: Potential hydropower locations in Buckinghamshire, by potential capacity and type of barrier



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Hydropower potential is reasonably well distributed through Buckinghamshire, though many of the opportunities appear to be at the borders of the county. This likely reflects the rurality of much of Buckinghamshire. Concentrations seem to largely be around towns. This is not unusual, as watercourses are more likely to be developed in these areas. Historically, towns were also more likely to be founded on watercourses such as rivers and streams, which often increases their proximity to water. Clusters of opportunity are highlighted in Figure 31, Figure 32, Figure 33, and Figure 34. There are few opportunities within the Chilterns AONB. This makes sense as these barriers likely follow the change in level as water flows away from the hills.

Figure 31: Clusters of hydropower opportunities near Aylesbury and Buckingham

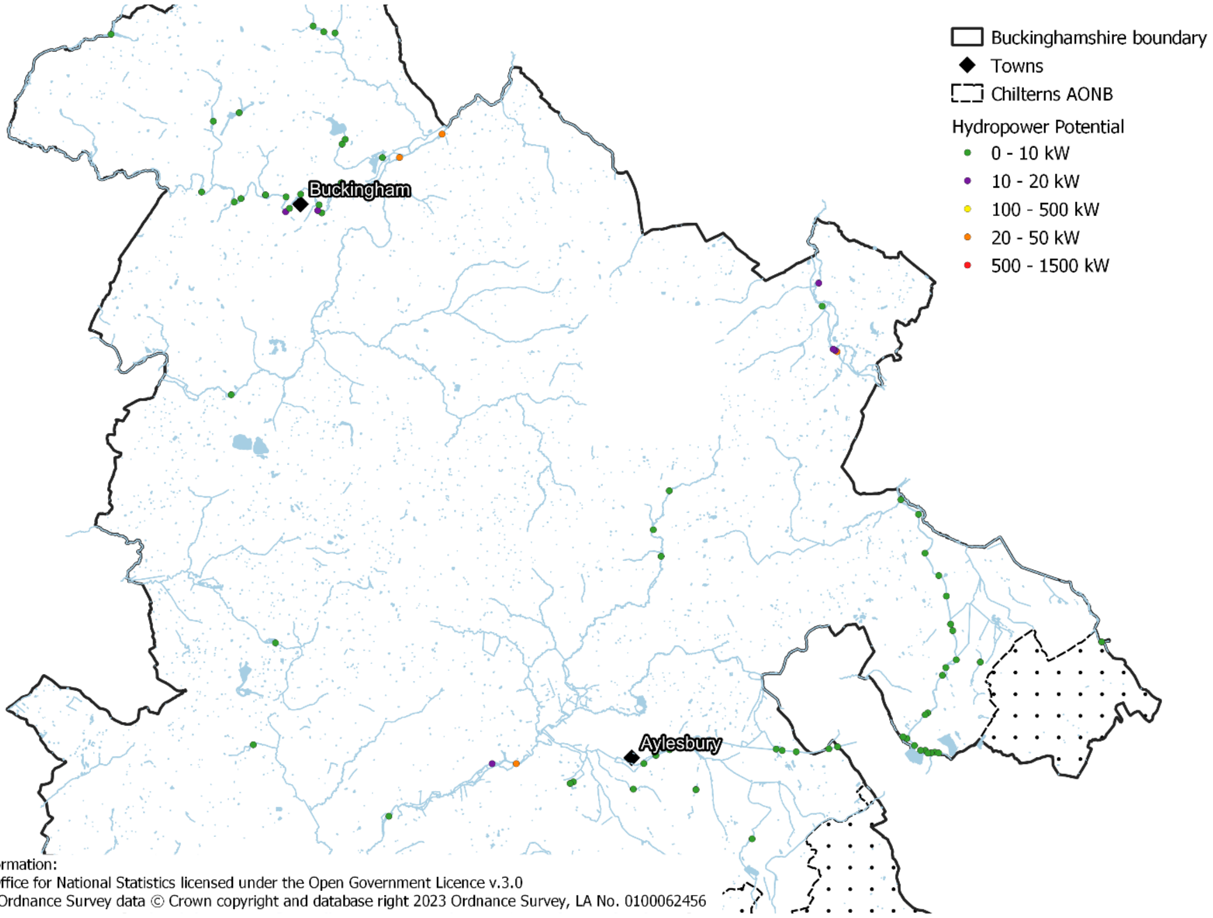

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Figure 32: Hydropower opportunities near Chesham and Amersham

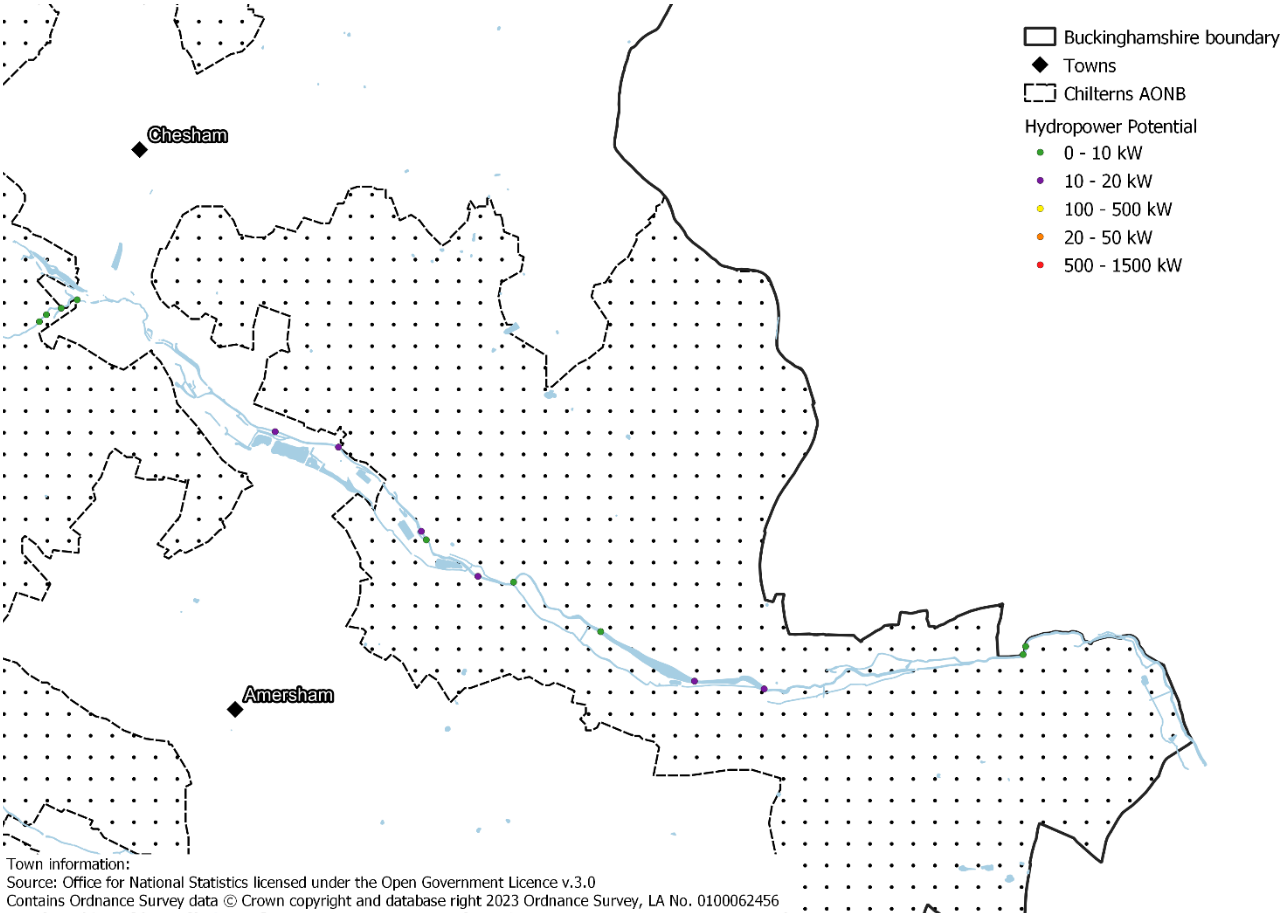


Figure 33: Hydropower opportunities near High Wycombe, Marlow and Beaconsfield

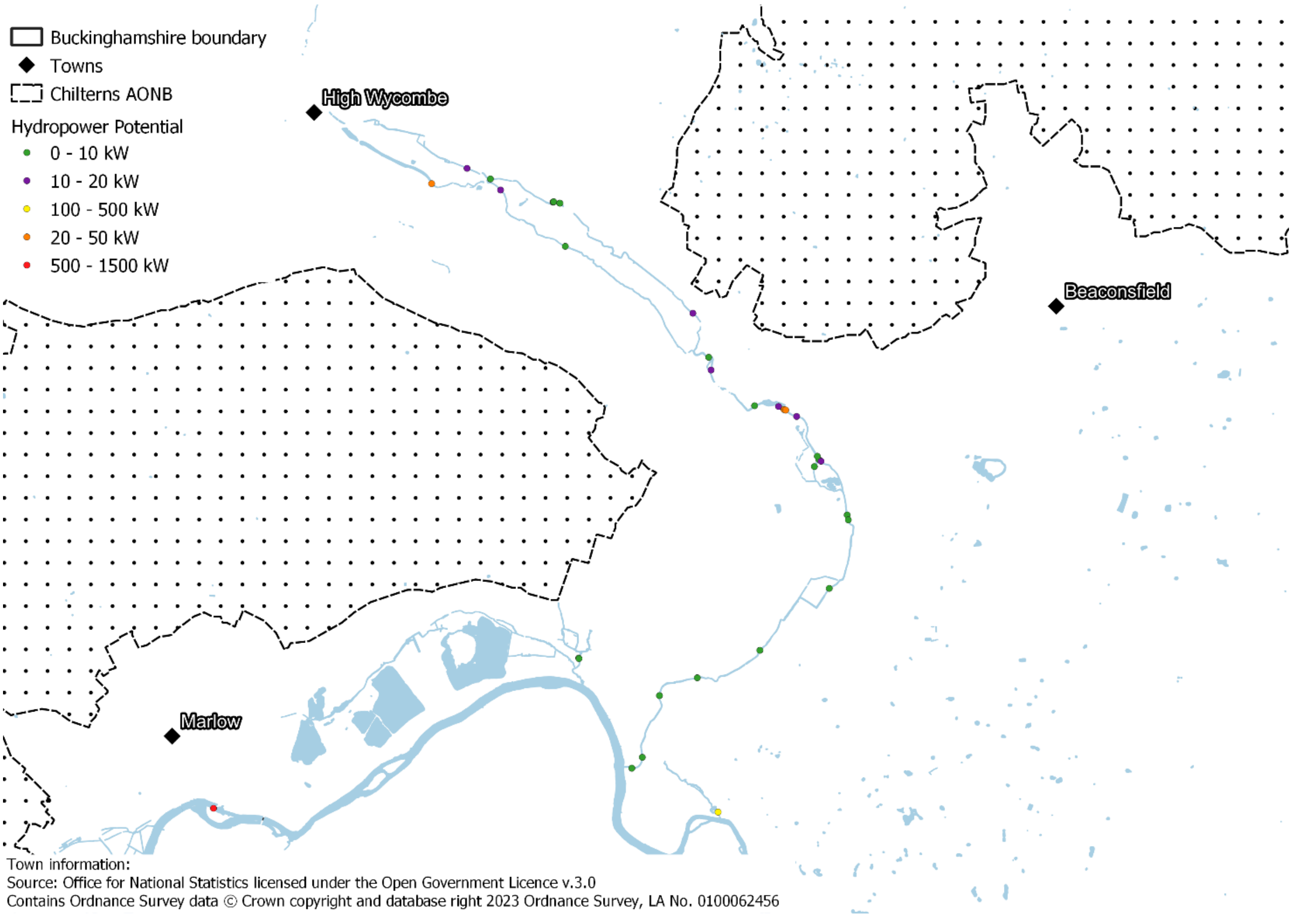
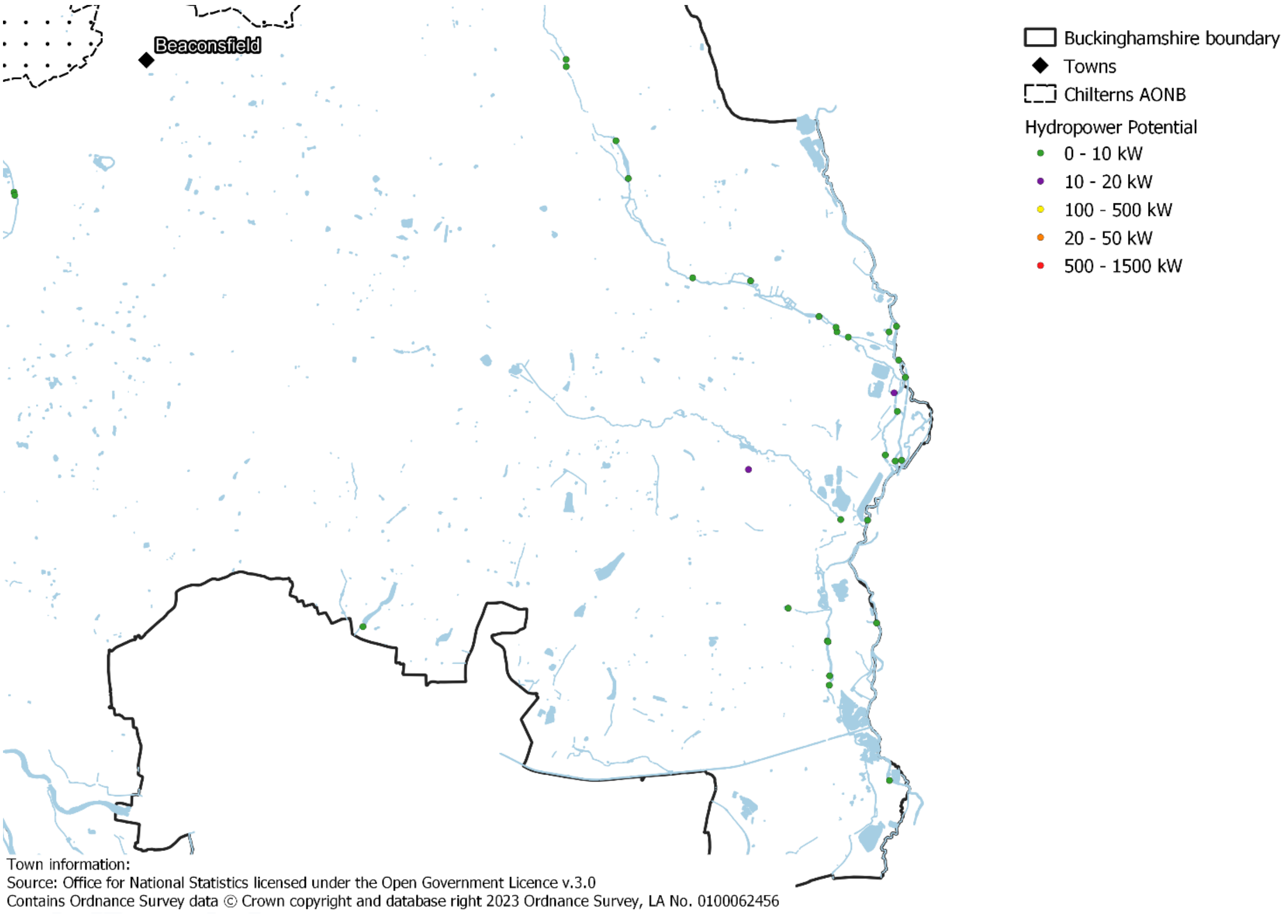


Figure 34: Hydropower opportunities in the southeast of Buckinghamshire



The total hydropower potential in Buckinghamshire is summarised by type of barrier in Table 26, and by potential capacity in Table 27. The total potential generation is 71.9 GWh per year. This is approximately 7% of Buckinghamshire's yearly domestic electricity consumption and 3.7% of Buckinghamshire's total yearly electricity consumption. If this resource were developed it could offset 11,200 tonnes of CO_2e per year from using grid electricity.

Table 26: Summary of hydropower opportunities in Buckinghamshire by type of barrier

Type of barrier	Number of barriers	Total potential (MW)	Potential generation (GWh/year)
Weir	136	4.3	18.9
Lock	36	2.7	12.0
Dam	4	1.0	4.5
Waterfall	2	0.0	0.2
Mill	6	0.1	0.3
Unknown	4	0.0	0.1
Total	188	8.2	35.9

Table 27: Summary of hydropower opportunities in Buckinghamshire by potential capacity

Potential capacity category (kW)	Number of barriers	Total potential capacity (MW)	Potential generation (GWh/year)
0 - 10	149	0.4	1.9
10 - 20	21	0.3	1.3
20 - 50	7	0.2	0.7
50 - 100	0	0.0	0.0
100 - 500	5	1.7	7.3
500 - 1500	6	5.6	24.8
Total	188	8.2	35.9

The most common type of barrier in Buckinghamshire is weirs. Weirs generally already have a flow over the barrier, as they are designed to control flowrates of water. This makes them very suitable for hydropower development. The second most common are locks. Locks may not prove to be such a good barrier to develop to hydropower as they operate intermittently as boats pass through. Conversion to hydropower may produce intermittent power or require disuse of the locks. These competing priorities would need to be weighed against one another.

If all the hydropower opportunities in Buckinghamshire were realised, this would offset grid electricity carbon of 5,600 tonnes of CO_2e per year.

Most hydropower opportunities in Buckinghamshire are in the order of 0-10kW. This is a relatively small amount of power, likely only suitable for a single user. While there are significantly less opportunities, the largest opportunities (500 – 1500 kW) have 69% of the potential generation capacity.

5.5. Woody biomass

Woody biomass is normally sourced from the sustainable management of existing woodland. The technical potential can be assessed by calculating the area of forests of various types within Buckinghamshire and estimating a sustainable yield. From this method, annual production of wood can be estimated and converted to a heat delivery potential.

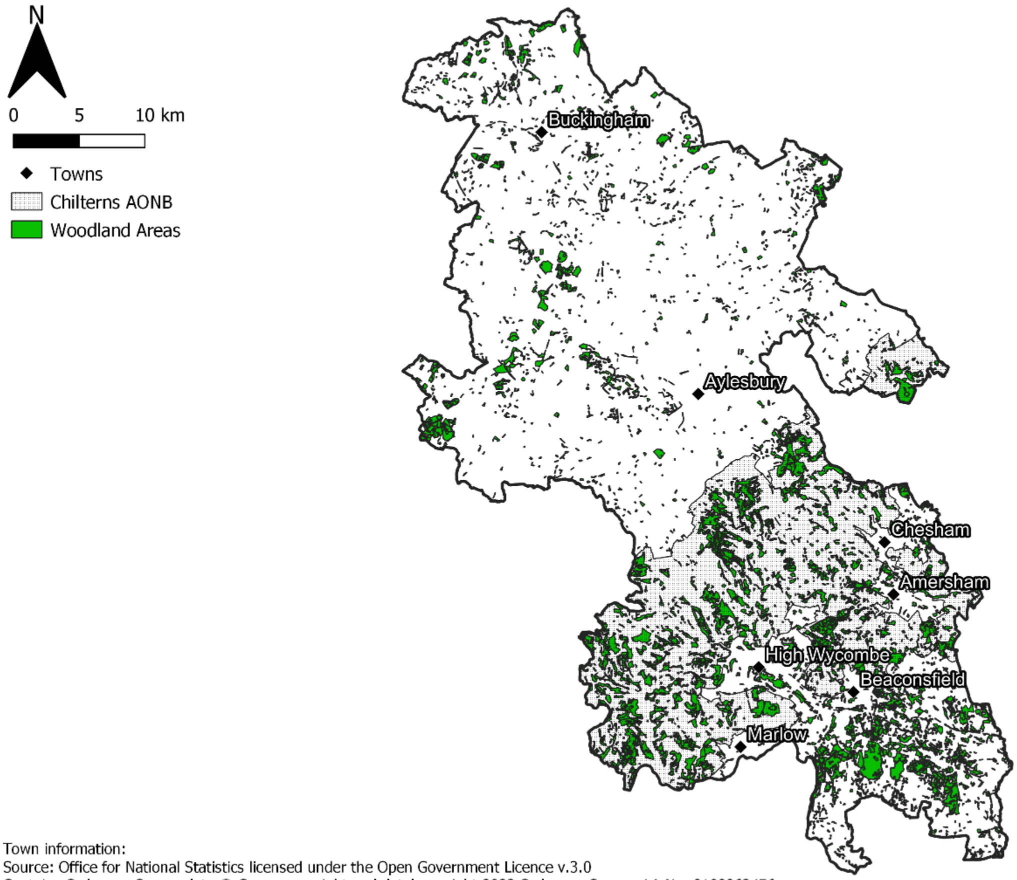
To conduct this analysis, the National Forest Inventory (NFI – Forest research, 2023a) has been consulted. This is produced by using satellite imagery to identify and classify areas of woodland. This method is supported by ground surveys of sample areas. Currently the NFI uses the following categories. The extent of these categories is shown in Figure 35.

- Assumed woodland
- Broad-leaved
- Conifer
- Felled
- Mixed – mainly broadleaf
- Mixed – mainly conifer
- Coppice
- Shrub
- Windblow
- Young trees
- Ground prep
- Low density

To ensure that any woodland that is recommended for sustainable forestry use will not pose detriment to the environs of protected areas, a series of constraint have been applied to the woodland displayed in Figure 35. The constraints applied are:

- SACs
- SSSIs
- Ancient Woodlands
- Historic parks and gardens

Figure 35: Woodland locations within Buckinghamshire



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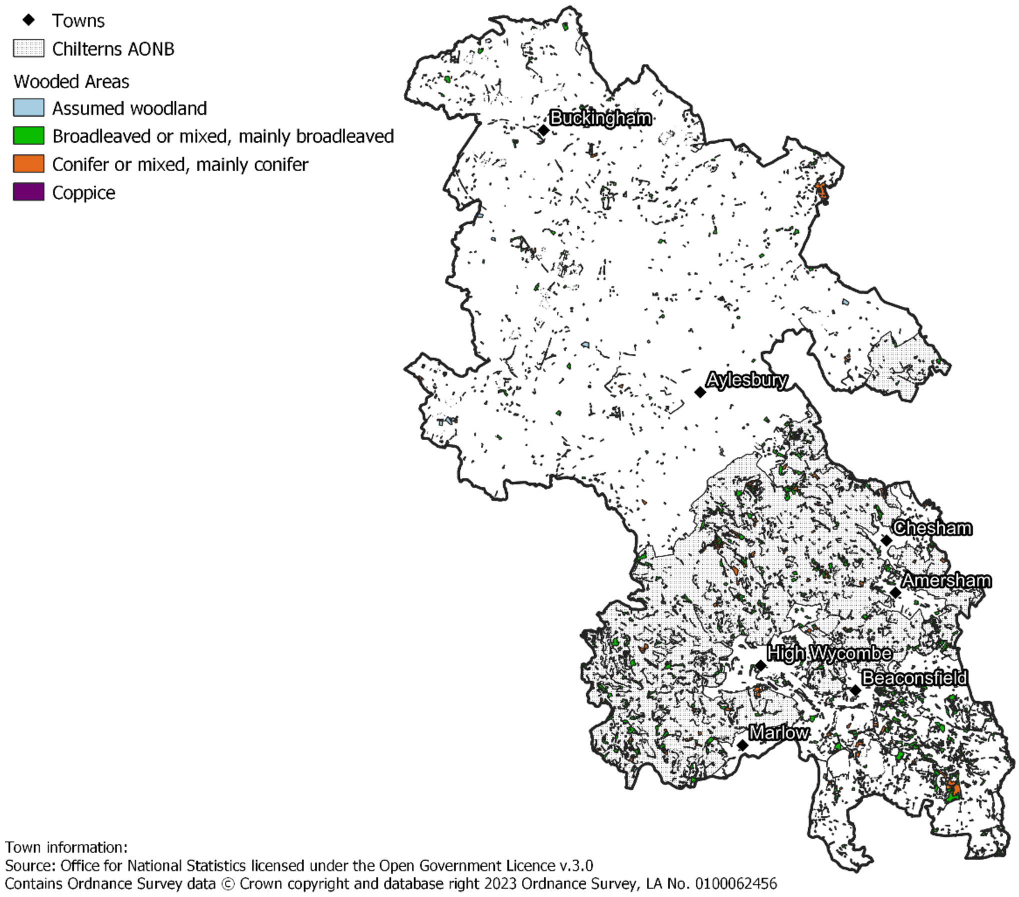
Woodland is distributed across Buckinghamshire, though it is weighted towards the south of the county. In particular, larger wooded areas are in the Chilterns AONB and further south, which is partially covered by the green belt.

Of the above types of woods, most are currently unsuitable for sustainable forestry production. For example, young trees will take several years until they reach maturity and so should not be examined under the current analysis. The types considered in the analysis are assumed woodland, broad-leaved, conifer, mixed (mainly broadleaved and mainly conifer), and coppice. Figure 36 shows the extent of the considered types of woodland.

Figure 36: Extent of woodland areas of the types considered in this analysis



The distribution of wooded areas, even when reduced to the categories relevant to this study, follows the same pattern as in Figure 35. Broadleaved forests dominate, with small pockets of coniferous forests present.

The sustainable yield of each wood is known (see Appendix 3: Factors used in modelling), and this combined with the areas of forest can be used to calculate the sustainable wood production. This figure is commonly given in oven-dried tonnes (odt) – this is the mass of wood containing no water (which helps to standardise energy content calculations). By applying an energy density figure, this can then be converted to a sustainable heat yield. These yields are shown in Table 28.

Table 28: Sustainable yields from woodland in Buckinghamshire

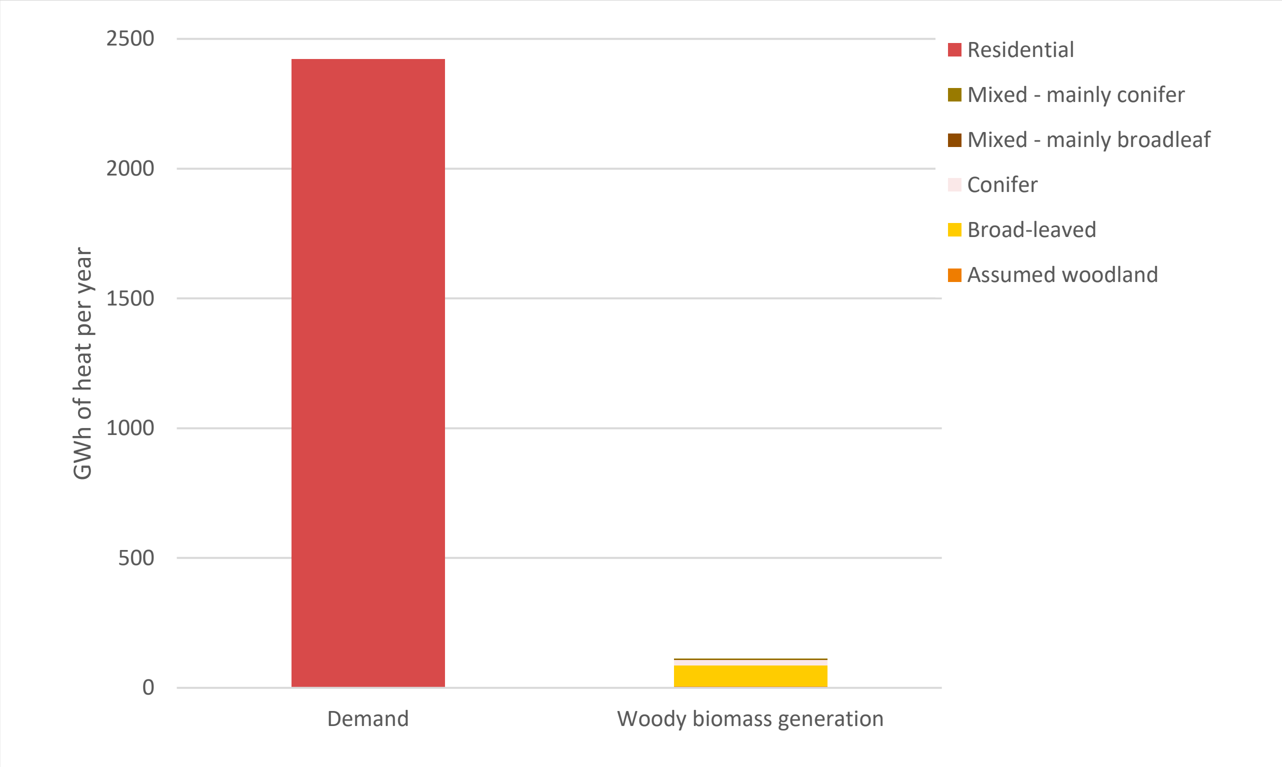
Type of woodland	Area (km^2)	Sustainable wood production (odt/year)	Sustainable heat potential (GWh/year)
Assumed woodland	2.5	821.0	4.4
Broad-leaved	58.3	15,626.3	82.8
Conifer	9.8	3,810.2	20.2
Mixed - mainly broadleaf	1.3	364.1	1.9
Mixed - mainly conifer	1.3	489.7	2.6
Coppice	0.0	0.0	0.0
Total	73.2	21,111.4	111.9

The total sustainable heat potential is 510.1 GWH/year. This is dominated by broadleaved woodland (207.7 GWh/year). For context, the current residential heat demand in Buckinghamshire is estimated to be 2,423.2GWh per year. Table 29 shows the resultant carbon offsets by using woody biomass to provide heating, compared to gas and electricity.

Table 29: Potential carbon offset of woody biomass compared to gas and electricity

Type of woodland	Estimated generation (GWh/year)	Carbon offset compared to gas ($ktCO_2e$/year)	Carbon offset compared to electricity ($ktCO_2e$/year)
Assumed woodland	4.4	0.8	0.7
Broad-leaved	82.8	15.2	12.9
Conifer	20.2	3.7	3.1
Mixed - mainly broadleaf	1.9	0.4	0.3
Mixed - mainly conifer	2.6	0.5	0.4
Coppice	0.0	0.0	0.0
Total	111.9	20.5	17.4

Figure 37: Comparison of woody biomass potential to current domestic heat demand



Woody biomass meets only a small portion of the current domestic heat demand. This does not mean that the resource should not be pursued. Rather, it should be weighed in the context of other renewable energy and form a part of Buckinghamshire's renewable strategy. Woody biomass may be suitable to meet some energy use that other options may not.

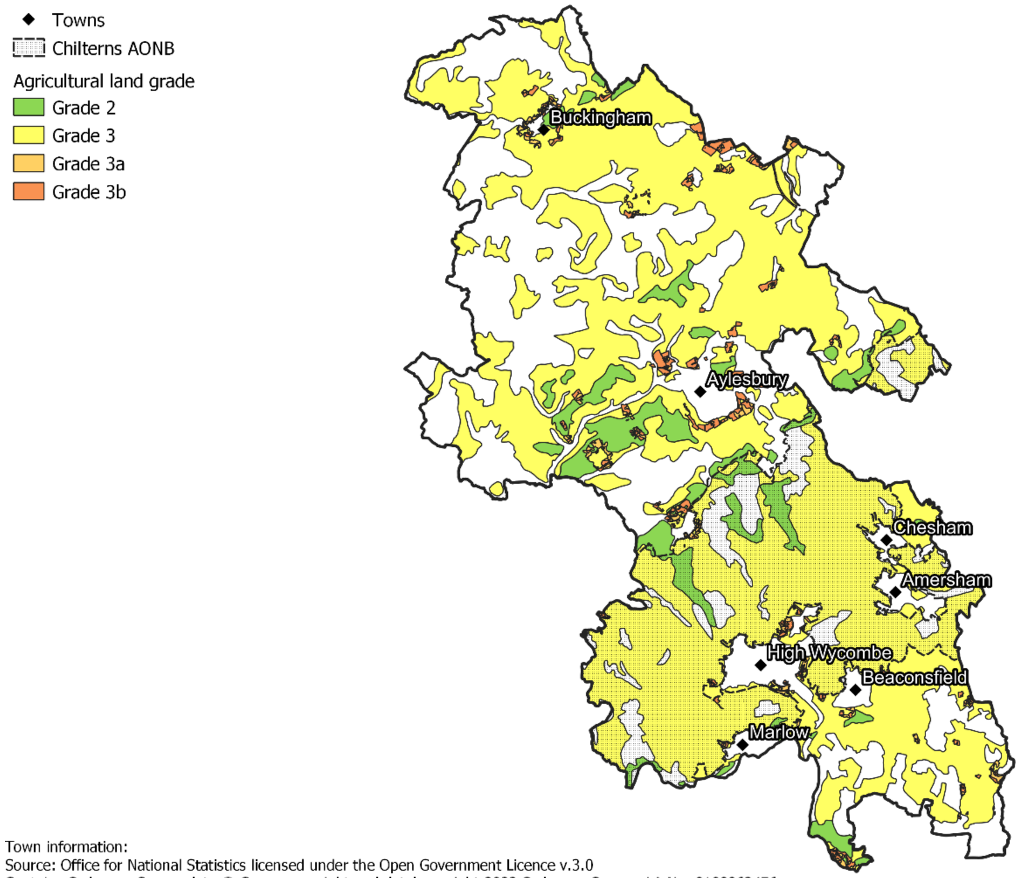
It should be noted that there are concerns around air quality when burning wood. A recent European report (European Environmental Bureau, 2021) highlighted the pollution impact of wood burning. In terms of non-methane volatile organic compounds, wood burning releases nearly 19 times as many particles as oil boilers, the next most polluting source. Wood burning also releases over 150 times as much carbon monoxide as gas boilers. This release is a significant concern, particularly in urban areas. The density of wood burning in urban areas can cause significant pollution to accumulate. This pollution can have a significant impact on health in the area in which wood is burned.

5.6. Energy crops

Energy crops in this context are those planted specifically for heat and/or electricity production. This is usually distinct from biofuel crops such as sugar cane, maize and oilseed rape which tend to be used for transport fuels. The two main energy crops are miscanthus and short rotation coppice (SRC).

This analysis assumes energy crops can be grown on agricultural land grades 2 and 3 (3a and 3b). This is based on the assumption that land grade 1 would be better utilised for food crops, and lesser grades would be unsuitable for energy crop production. Figure 38 shows the distribution of suitable land within Buckinghamshire. Note that land grade 3a and 3b are largely grouped, except where individual classifications have been identified. Other land grades are not shown in Figure 38.

Figure 38: Distribution of agricultural land grades 2 and 3 within Buckinghamshire



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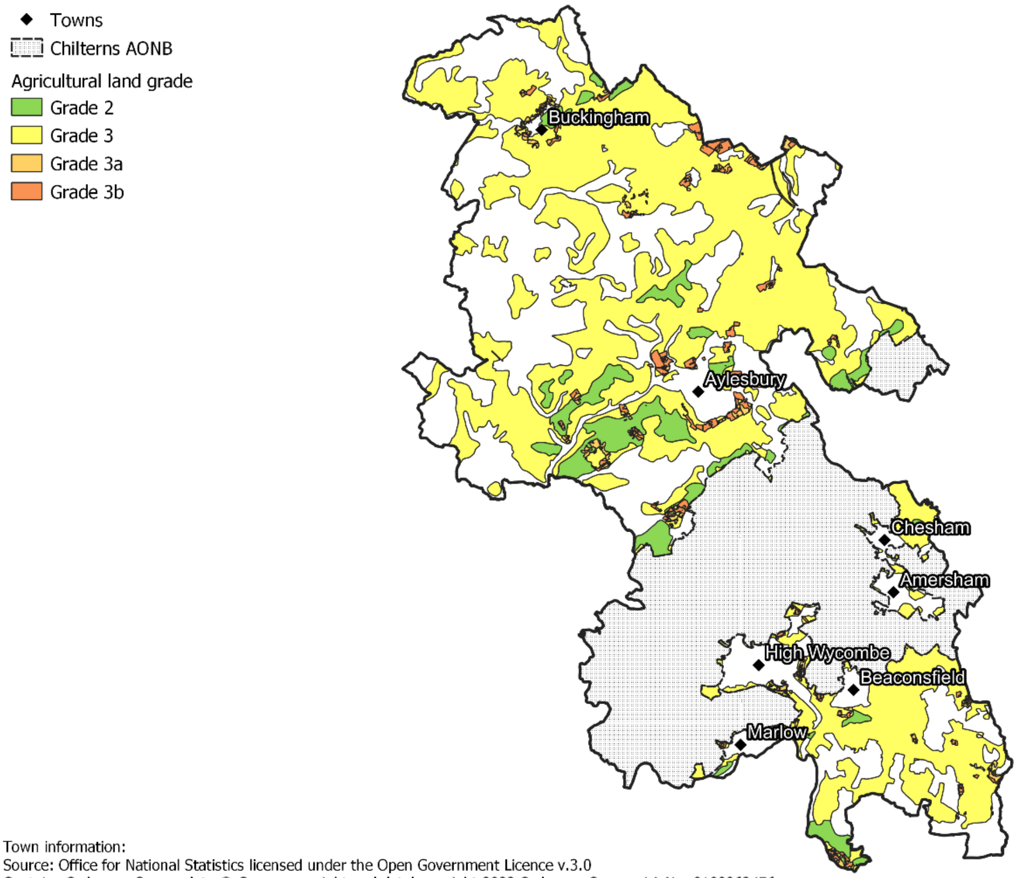
A large portion of Buckinghamshire is suitable agricultural land for energy crops. There is a relatively large amount of agricultural land situated in the AONB. Protected areas such as the AONB may face difficulty in conversion to new forms of agriculture such as energy crops. Therefore, Figure 39 shows the agricultural land grades 2 and 3 distribution, excluding such protected areas.

Figure 39: Distribution of agricultural land grades 2 and 3 within Buckinghamshire excluding the AONB, NNRs, SACs and SSSIs



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Assuming all this land is converted to cropland for energy crops, Table 30 shows the area available, as well the as the potential yearly yields. This is converted into a yearly heat potential by examining the heating value of each energy crop.

Table 30: Potential yields and heat from energy crops within Buckinghamshire

	Energy Crop	Potential cultivated area (km²)	Production (thousand odt/year)	Heat potential (GWh/year)
Including protected areas	Miscanthus	1,035.4	1,397.8	5,032.0
Including protected areas	SRC	1,035.4	476.3	2,524.3
Excluding protected areas	Miscanthus	681.8	920.4	3,313.5
Excluding protected areas	SRC	681.8	313.6	1,662.2

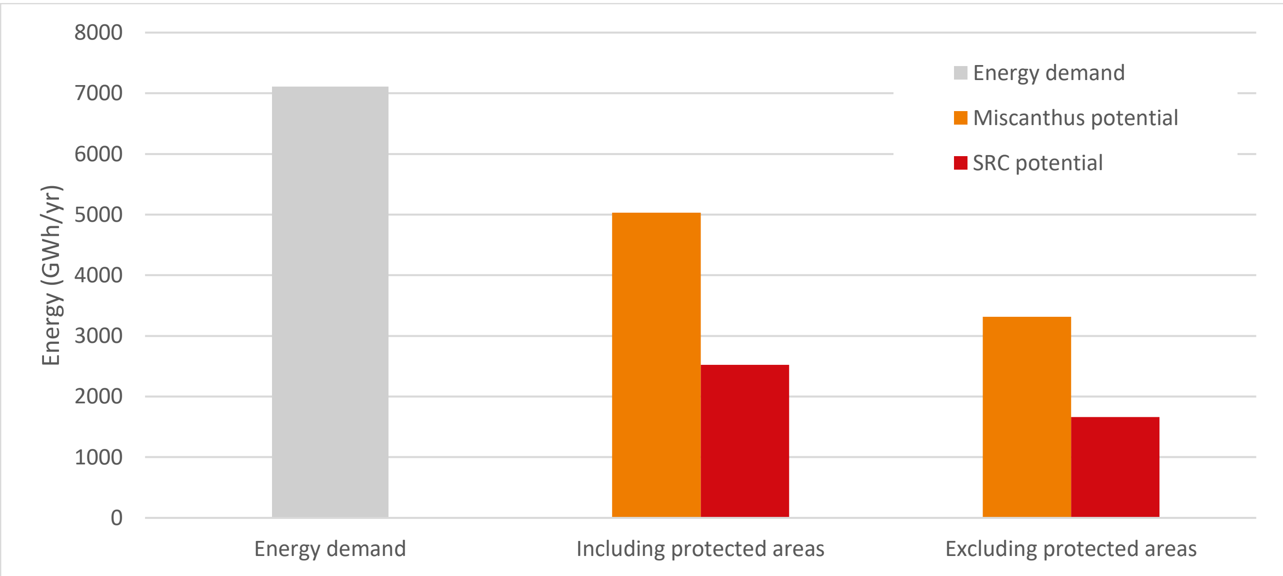
Miscanthus (silvergrass, a plant that can be used as a biofuel) would have a higher energy potential than SRC, with a yearly heat potential of 5,032.0 GWh per year if it could be cultivated in all agricultural land graded 2 or 3, or 3,313.5 GWh per year if only cultivated in those areas outside of protected areas. The upper estimate is equivalent to nearly 71% of Buckinghamshire's total yearly energy usage. The carbon emissions of these energy crops are compared to an equivalent energy use of gas and grid electricity to provide the same amount of heat in Table 31.

Table 31: Carbon offset potential of energy crops compared to gas and electricity

	Energy Crop	Heat potential (GWh/year)	Carbon offset compared to gas ($ktCO_2e$/year)	Carbon offset compared to electricity ($ktCO_2e$/year)
Including protected areas	Miscanthus	5,032.00	920.86	783.99
Including protected areas	SRC	2,524.30	461.95	393.29
Excluding protected areas	Miscanthus	3,313.50	606.37	516.24
Excluding protected areas	SRC	1,662.20	304.18	258.97

To contextualise the potential of energy crops, they are shown compared to Buckinghamshire's current total yearly energy usage in Figure 40.

Figure 40: Comparison of Buckinghamshire's current total energy usage to the potential generation of energy crops



Both energy crops potentially provide a reasonable portion of the energy required to meet Buckinghamshire's current energy demand. However, it is unlikely that the entirety of the agricultural land identified in this study (even excluding the protected areas) could be used for energy crops. This is because there is likely to be competition between energy crops and other crops even on lower-quality land. Additionally, because each energy crop potential is estimated using the same land area, a decision must be made on which to pursue. Miscanthus may seem the obvious choice due to its greater yield potential. However, SRC tends to have a lower impact on the environment and local conservation.

5.7. Batteries

The integration of grid-scale batteries is in its infancy in the UK. The Government is yet to publish any strategy or guidance on the use of batteries in the UK renewable future. Despite this, many batteries have already been deployed, and are in operation across the country. Batteries can be stand-alone, or co-located with other generation, for example a solar or wind farm.

Generally, batteries operate commercially by taking advantage of changes in energy prices over time, or by providing “grid services”. Grid services is where a battery operator is paid for helping to operate or stabilise the electricity grid. In simple terms, batteries buy electricity and charge when prices are low (for example during the night). They then sell this back when prices are high (for example during the evening). This helps balance the grid by reducing overgeneration at low demand periods and increases generation during high demand periods. This works because generation and demand on the national grid must match to prevent damage to the grid.

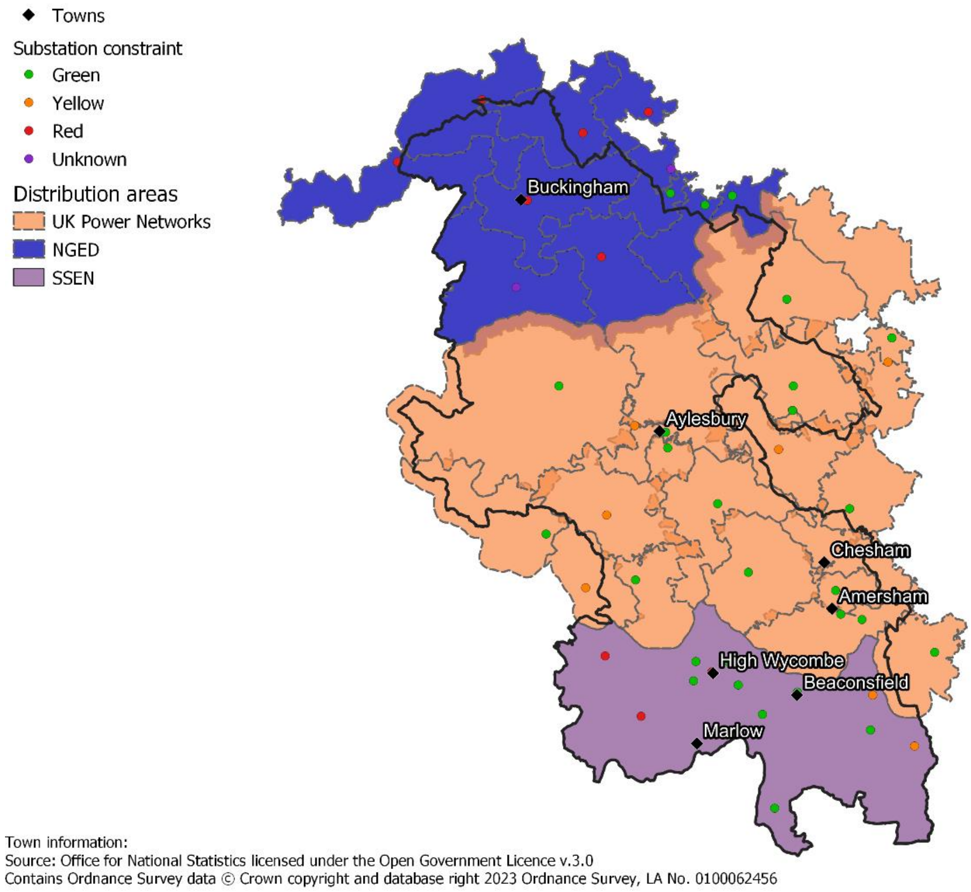
In reality, the electricity system is more complicated than a relatively simple balance at the national level. Many areas of the nation can also be “constrained” even when the national grid is not. Constraint happens when there is more electricity flowing through a part of the grid than it is designed to be able to accommodate. For example, if too many people want too much electricity on a street at once, the local substation may overload. Similarly, if there is lots of rooftop PV in an area, on a sunny day there may be too much electricity being generated. The time where demand or generation at their highest is known as peak demand or peak generation. A location is constrained where the difference between local generation and local demand at any time is larger than the equipment can handle.

This complex system of constraints is overseen by national grid (National Grid Electricity System Operator – NG ESO) and the distribution network operators (DNOs). In Buckinghamshire the DNOs are UK Power Networks, National Grid Electricity Distribution (NGED), and Scottish and Southern Electricity Networks (SSEN). DNOs are responsible for equipment such as substations, which bring the electricity from NG ESO’s transmission network to homes and businesses. They are also responsible for any excess local generation (such as rooftop PV) making its way to the transmission network. They will design heir equipment to cope with certain peaks in demand or generation, normally with some leftover space, known as headroom. Equipment that must handle larger peaks is more expensive, as is upgrading existing equipment. Therefore, DNOs may refuse connections if a grid area is too constrained, and they deem upgrading the equipment too costly. They may also charge a connection fee to upgrade their equipment.

However, batteries are very useful in areas where this constraint exists. Very rarely is a peak demand or generation constant over a long period, and so batteries can “smooth” the peaks in their areas. This can delay or avoid the costs of upgrading DNO equipment. As a result, when planning at a local level, the best place to develop new batteries would be in these constrained areas.

Analysis of existing grid constraints has been undertaken as part of this study. DNOs use a system of green for unconstrained, yellow for some constraint and red for highly constrained. In other words, substations which are green would probably not be aided by a battery, whereas those that are yellow or red may benefit from a battery within their area. This constraint system is shown in Figure 41, along with the distribution area of the substation.

Figure 41: Constraint on substations within Buckinghamshire, showing their distribution areas



Note: SSEN's distribution area data not available. The area shown in the map is the area of Buckinghamshire not covered by other DNOs.

The UK Power Networks distribution area in the centre of the county has the least constraint, being either unconstrained, or moderately constrained. The NGED distribution area in the north has significant constraint across many substations. This could be a priority area for batteries, particularly considering the presence of Buckingham, one of the largest urban centres in Buckinghamshire. The SSEN distribution area has some constrained areas, though these are further from urban centres.

In addition to what has been outlined above and shown in Figure 41, Buckinghamshire Council is aware that the committed and planned growth in the Vale of Aylesbury Local Plan would lead to substation constraint at Aylesbury, and therefore a new substation would be needed in this location to cope with the increased pressure on the grid.

5.8. Renewable heat

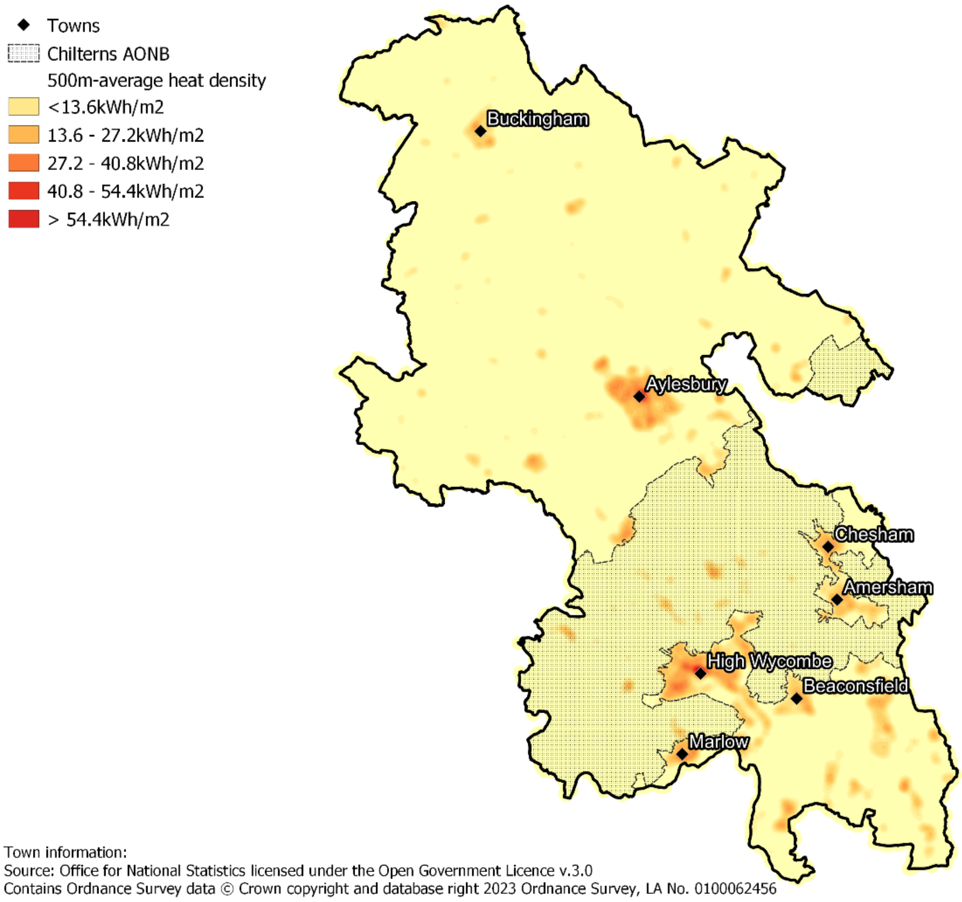
5.8.1. Buckinghamshire heat demand

Renewable heat is a broad category. Generally, it refers to any method of heating domestic and non-domestic properties using a renewable resource. Some examples already discussed include solar hot water, woody biomass, and energy crops. This section of analysis focusses on heat pumps and waste heat.

It is useful to examine the required scale of heat demand in Buckinghamshire to better understand the requirement of renewable heat. This was estimated using CSE's heat demand model, integrated into the THERMOS tool. This tool enables the modelling of heat networks by using heat demand estimations and route optimisation. THERMOS uses a hierarchal approach, by using the most accurate and complete data available. This means that the model attempts to use LiDAR data and OS Mastermap polygons to estimate the 3D shape of a building, falling back on 2D data and height estimates to estimate heat demand. This process also makes use of Energy Performance Certificates (EPC) and Display Energy Certificates (DEC) data to simulate insulation's effect on building performance. For each building in an area this process estimates both heating and hot water requirement.

The outputs of the heat demand model have been analysed to produce a heat density map (Figure 42) which highlights the areas of greatest heat demand. The outputs have also been analysed to understand the estimated heating requirements of Buckinghamshire as a whole. Those results are shown in Table 32.

Figure 42: Heat density map of Buckinghamshire



As is common, the densest heat demand is within urban areas. This is because the majority of heat consumers, both domestic and non-domestic, will be located in towns and cities. There are smaller areas of relatively dense heat demand throughout the county, likely reflecting the presence of smaller populated areas such as villages.

Table 32: Total heating and hot water requirement in Buckinghamshire

Residential heat and hot water (GWh/year)	Non-residential heat and hot water (GWh/year)	Total heating and hot water (GWh/year)
2,423.2	1,952.2	4,375.4

Heating and hot water form a significant proportion of Buckinghamshire's current energy requirement (61.6%). Therefore, it is essential that renewable sources for this heat are found. For context, this analysis estimates a total of 419,306 buildings in Buckinghamshire, with approximately 47% being residential (196,315) and 53% (419,306) being non-residential. This means the average heat demand of a residential household in Buckinghamshire is 12.3MWh per year.

5.8.2. Heat pumps

Whilst solar hot water, energy crops and woody biomass can meet some of the renewable heating requirements, they cannot meet the entirety. This is either because the resource is too small (such as for energy crops and woody biomass) or its characteristics make it unsuitable for meeting the entirety of the heating requirement. For example, solar hot water is generally not produced in sufficient quantities or at hot enough temperature to meet household heating requirements.

Because of the limitations of other resources, a significant proportion of the heat requirement must be electrified. There are several conventional options for this, including electric boilers (immersion heaters), storage heaters and panel heaters. Because electricity is more expensive than gas, electrification would have a significant impact on household finances. It would also greatly increase the electricity demand. This would require costly upgrades to electricity grid infrastructure. Whilst heat pumps require electricity to run, the heat they deliver to a building is much greater than the electricity they use. This makes heat pump an optimal solution to electrification of heat. The gap in the price between electricity and gas has narrowed lately. Whilst this makes conventional electrical heating more economically viable, it also makes heat pumps even more attractive.

Heat pumps have a coefficient of performance (COP) greater than one. This means that for every kWh of electricity put into a heat pump, more than one unit of heat is generated. Generally, heat pumps are capable of COPs of three – meaning three kWh of heat are obtained for each kWh of electricity. This brings their costs into line with that of gas. It also means that the increased load on the electricity network is much lower than if using conventional electric heaters – reducing the cost of upgrades to the grid. Additionally, a COP over one allows the use of fewer units of electricity per unit heat. Because of the greater cost of electricity than gas, heat pumps present an electrified solution which can help to limit or prevent inequalities in heating provision. Generally, the COP of heat pumps is thought to be high enough to bring electrified heating costs into line with those of gas.

Note that heat pumps come in many forms. They work by using electricity to draw energy from the environment, and use this to heat water, which can then be stored in a hot water tank. They are often compared to an air conditioner running in reverse (these reject heat to the surrounding environment). This gives rise to many forms of heat pump, generally divided into air source, ground source and water source. The most common is probably air source – these use electricity to draw heat out of the air surrounding the unit. There are also ground source heat pumps. These absorb heat from the ground, using a heat transfer fluid (normally water) heated by the ambient temperature of the soil, using either a horizontal or vertical ground loop. They have a higher coefficient of performance than air source heat pumps, but they are also more expensive and require more space. Finally, water source heat pumps also use a heat transfer fluid (normally water) to extract heat from a body of water, such as a lake or river. Generally, these are also more efficient than air source heat pumps but cost more and are very limited in where they may be deployed.

To illustrate the reduction in energy using heat pumps, Table 33 shows the total energy demand of Buckinghamshire with heating in its current form, if it were completely electrified with conventional electric heaters, and if heating was electrified with heat pumps. Note that this assumes a COP of three for heat pumps, and that currently there is no electrified heating. No electrified heating is assumed because the current amount of electrical heating in Buckinghamshire is not known. Based on national trends, gas heating will dominate.

Table 33: Energy demands under various heating scenarios

Demand	Current	100% Electrified with only immersion heaters	100% Electrified with only heat pumps
Heating demand (GWh/year)	4375.4	4375.4	1458.5
Electricity demand (GWh/year)	1946.2	6321.5	3404.6
Total demand (GWh/year)	7,108.5	7,108.5	4,191.6

As can be seen, heat pumps provide the opportunity to greatly reduce Buckinghamshire's energy demand not just for heating, but in total. However, heat pumps generally require significant insulation to be installed, as there must be relatively small heat loss from a building for heat pumps to work effectively. Due to providing water at lower temperature, they also normally require changing central heating systems – normally needing larger radiators, and the installation of a hot water tank.

Table 34 highlights the potential carbon emissions under current heating demand (assuming all heating is by gas) and under electrified scenarios.

Table 34: Potential changes in carbon with changed heating systems in Buckinghamshire in $ktCO_2e$ per year

Demand	Current emissions	100% Electrified with only immersion heaters	100% Electrified with only heat pumps
Heating	800.7	681.7	227.2
Electricity	303.2	984.9	530.4
Total	1103.9	1666.6	757.7

Emissions remain in both electrified scenarios as the current carbon factor for grid electricity is used. If Buckinghamshire was generating increased renewable electricity the emissions under electrified scenarios would be less. This would also occur if national renewable generation continues to increase, bringing down the grid electricity carbon factor.

5.8.3. Waste heat

Another option for renewable heat is that of waste heat. This is heat that is discarded from various sources which could be used to heat homes. Normally, this waste heat would be "upgraded" by a heat pump. This is because the waste heat itself is not of a high enough temperature to provide heating and hot water. However, having the heat pump source at a higher temperature increases the coefficient of performance. For example, if you were to run an air source heat pump from the exhaust of an industrial kiln, it would achieve a higher COP than from ambient-temperature air.

There are many variations on sources of waste heat. Generally, waste heat is a win-win for the heat producer, as well as for the consumer. This is because the heat producer will normally receive payment for their heat (which they were previously releasing for free). The receiver will get more efficiency out of their heat pump, and so lower operating costs. Some common waste heat producers are:

- Combined heat and power plants
- Incinerators
- Thermal power stations
- Cement production
- Lime production
- Iron and steel production
- Crematoria
- Chemical processes
- Cold stores
- Data centres
- Food and drink manufacturers
- Paper and pulp manufacturers
- Supermarkets
- Wastewater treatment
- Underground railways

- Minewater pumping stations

Generally, it is not feasible for a single heat receiver to connect to a waste heat source, because there is a significant amount of heat and the connections are expensive. Waste heat goes together with heat networks (also known as district heating), described in the next section.

5.8.4. Heat networks

Heat networks use a central energy centre to distribute heat to consumers through hot water pipes. These are normally more efficient than each consumer having an individual heat pump and can use a variety of heat sources. They are also easier to upgrade with evolving technologies than replacing multiple individual heating systems.

For example, most current heat networks use combined heat and power plants (CHP), normally powered by natural gas or petroleum products. These can continue to expand to cover more consumers. When the decision is taken to change to renewable heating, the CHP equipment could be replaced by a large heat pump, decarbonising all consumers connected to the heat network.

The options for heat sources for heat networks are incredibly varied. Waste heat is one of the most common motivators for a heat network, due to the decreased running costs. However, heat could come from large heat pumps without waste heat, immersion heaters, biomass boilers.

Heat networks work best in areas of concentrated heat demand. For Buckinghamshire this would likely be the areas around Aylesbury and High Wycombe, the darkest red areas in Figure 42. The Department for Energy Security and Net Zero are currently working on a heat network zoning project. The outcomes of this project are intended to inform and support policy development, and likely help local authorities focus heat network planning in the most suitable areas. Whilst timescales are uncertain, DESNZ is committed to introducing heat zoning in England by 2025 (Department for Business, Energy and Industrial Strategy, 2022b).

5.9. Other potential energy resources

5.9.1. Hydrogen

Hydrogen as a renewable energy source is much discussed today. It has been suggested as a replacement for natural gas within heating, as well as wider applications. Some examples are as an energy storage medium, for transport fuels and for high-temperature industrial processes.

To be considered renewable hydrogen must be “green” rather than “blue”. Green hydrogen comes from the electrolysis of water using a renewable energy source. Blue hydrogen is made from natural gas, and so cannot be considered renewable. Electrolysis requires large amounts of energy, and this must be met by renewable energy. This is then recovered by reacting hydrogen and oxygen in a fuel cell, which releases energy and water. Hydrogen may also be burned directly to produce heat, though as it is less efficient to capture heat into electricity, this is generally only used where heat is required directly.

Because electrolysis requires so much electricity, hydrogen is unlikely to be economical to use for most heating systems. A summary of reports by Lowes and Rosenow (2023) summarises literature on this topic. They quote that some reports say that hydrogen heating homes via the gas grid could increase heating costs by as much as 10 times. Other reports they reference show that hydrogen would increase bills by 70%, not considering the costs of converting the gas grid, nor balancing the electrical system for producing hydrogen. This all suggests the electrification of heating will be the most economical and preferred option in most cases.

However, this does not mean that there is no use for hydrogen in decarbonising the energy system. One area of heating that electrification is not able to cover is in high temperature industrial processes. This is because electrification is not able to provide the high temperatures required. Hydrogen could find a use in these areas. It is currently unclear whether hydrogen will be produced on-site for such applications, or whether more centralised hydrogen creation will be more suitable.

Similarly, hydrogen is likely to find some use in transportation – though this will not be widespread. Because of the same reasons as with heating – hydrogen is not likely to find widespread use in personal transport. It will cost too much for end users compared to electric vehicles. Hydrogen may find applications in heavy goods vehicles and other large vehicles. For reasons such as range and recharge time, electric version of these vehicles may not be suitable for all applications. This is also true when considering shipping, where range may not be achievable through electrification. Similarly, there is doubt about electrification within aviation – because batteries are very heavy compared to conventional fuels.

5.9.2. Geothermal

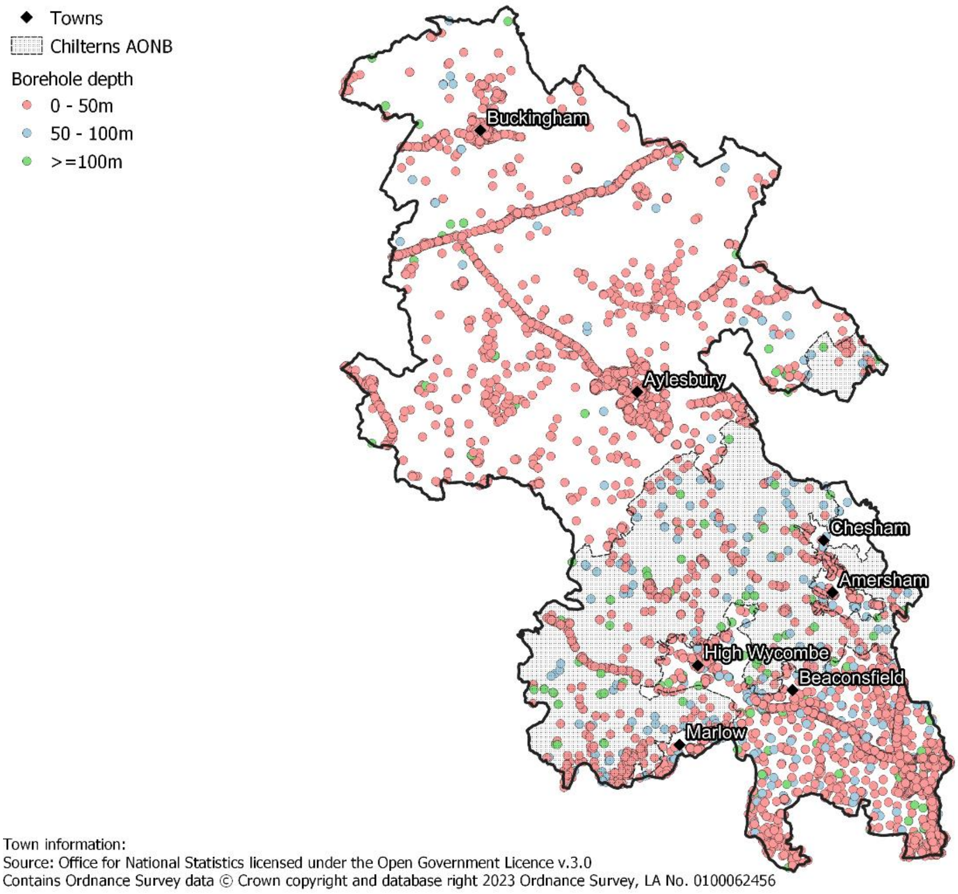
Geothermal energy in the UK is relatively limited due to the low level of seismic activity. High-temperature electricity generation systems are generally only found at the edge of tectonic plates. However, there are still several ways geothermal energy may be used.

The first has been touched upon briefly – through ground-source heat pumps. These can take advantage of shallow geothermal energy. This energy is either through making use of the relatively stable temperature just below the surface or making use of the slightly increased temperature at that level in urban areas. This would allow geothermal energy to be used to heat homes.

The legacy of mining in the UK also creates opportunities for geothermal energy. Across the country there are many disused mines which have become flooded. This water may be taken advantage of in open-loop ground source heat pumps. Similarly, other sources of water underground provide this option – for example aquifers. These are however difficult to quantify without site-specific inspections of flowrates.

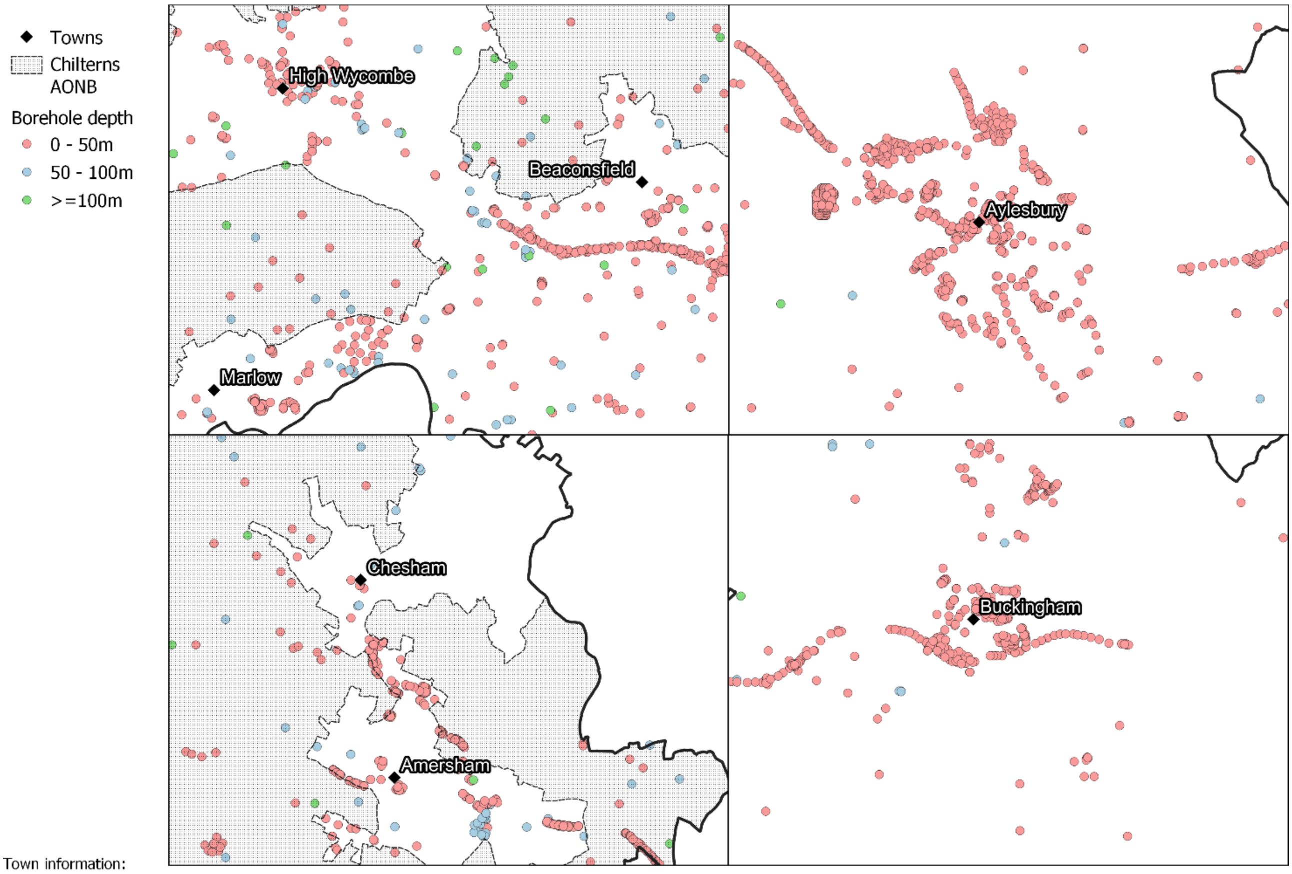
Another potential opportunity is in existing wells and boreholes. Whilst not all will be suitable to harness geothermal energy, the use of these would allow cheaper installation of shafts for ground source heat pumps. Where the borehole was used for water extraction, it can also function similarly to mine water. Most significant is that some boreholes will already extend several hundred meters below the surface. If these can be converted to shafts for ground source heat pumps, then higher temperature water can be abstracted, improving the heat pump's performance. These would be excellent locations for a heat network energy centre (assuming there is nearby heat demand). Buckinghamshire has over 9,000 existing boreholes, with 161 of these having a depth equal to, or greater than 100m. These are shown in Figure 43, with more information available in the British Geological Society's borehole index and register (British Geological Society, 2023).

Figure 43: Existing borehole locations in Buckinghamshire



Borehole opportunities in Buckinghamshire are concentrated in the south of the county. This likely reflects interest in the geology surrounding London. Other concentrations are around the larger towns within Buckinghamshire, which are shown in more detail in Figure 44. There does not appear to be a big difference between the number of boreholes within the AONB compared to outside. There are lines of boreholes that appear to largely follow the planned routes of HS2 and the East West Rail line. These were likely conducted as part of surveying work for these projects. The majority of boreholes are relatively shallow, so may not offer much advantage in terms of decreasing costs to access geothermal energy.

Figure 44: Boreholes near to major population centres



Town information:
Source: Office for National Statistics licensed under the Open Government Licence v.3.0
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Unfortunately, Buckinghamshire has little deep geothermal potential, as it lies outside of areas of higher temperature which are closer to the surface. This includes hot aquifers (such as are seen in Bath). This does not completely preclude deep geothermal. But this would require deeper shafts to be dug which may not be economical. It should be noted that deep geothermal is still of relatively low temperature (approximately 35°C), so would still be best used as a heat source for a ground-source heat pump.

There is some ongoing investigation of the possibility of enhanced geothermal systems in the UK, but this is not a mature technology, so it only mentioned here for completeness. This involves the drilling of very deep (up to 9km) shafts to capture heat. Trials of this are under development in the UK and may prove this technology viable even outside of areas with higher temperatures. However, the economics of this process are likely not suited to Buckinghamshire, due to the limited geothermal potential of the area.

5.9.3. Energy from waste

Municipal and commercial solid waste

Energy from municipal and commercial waste involves extracting energy on non-recyclable elements of waste streams. Solid dry materials are generally processed into refuse-derived fuel and incinerated in energy from wate plants. Currently, Buckinghamshire treats most of its waste at the Greatmoor energy from waste (EfW) facility with less than 0.3% of its waste going to landfill. This facility has the capacity to treat 345,000 tonnes of non-recyclable waste per year and generates 25MW of electricity. It is unclear how much of this waste is from renewable feedstock, but this could remain an asset for renewable generation in the future.

The majority of waste in Buckinghamshire is from non-renewable resources and so cannot be considered renewable. However, some portion of the waste could be renewable dependent on its organic, non-fossil fuel content. As this is likely a very small fraction, and difficult to separate economically from other waste, it has not been considered in this report.

Other waste portions are subject to anaerobic digestion (AD), where organic wastes are processed biologically to produce biogas. This can be combusted to produce heat or electricity or injected into the gas grid. Generally, this is most commonly performed on sewage and on organic waste.

Recycled wood waste
Recycled wood waste is difficult to quantify and would require a detailed survey to assess material collected within the county. Generally, recycled wood waste is contaminated with paint, preservatives, fixings, etc. Clean waste wood may be able to be sourced from wood-producing and working industries such as sawmills, carpenters, and joineries. As this waste should all be treated through existing waste practices, a significant proportion should already be treated as residual waste at the Greatmoor EfW facility.

Due to the likely contaminated nature of these feedstocks, waste wood is generally not suitable for small or medium scale thermal energy installations due to the need for exhaust gas clean-up equipment. This is only commercially viable at larger scales.

Food waste
Food waste in Buckinghamshire is currently collected and sent to two anaerobic digesters at Westcott and Aston Clinton. These facilities currently treat 16,000 tonnes of food waste from Buckinghamshire each year. Both facilities are recorded in the REPD, and their locations and capacities are shown in the Section Anaerobic digestion. Both facilities could provide renewable heat in addition to electricity, though it is unclear if that currently is undertaken.

Agricultural residues
Buckinghamshire is a relatively rural county. This means there is a good potential for agricultural waste as a potential renewable energy resource. One key agricultural waste for which there is potential is animal slurry. This can be fed to an anaerobic digestion process to produce biogas.

Defra statistics from 2022 (Department for Environment, Food and Rural Affairs, 2023) have been used to find the number of different livestock in Buckinghamshire. The amount of slurry produced has been estimated. This has then been converted to the potential volume of biogas, and the potential energy contained in that biogas. These results are shown in Table 35.

Table 35: Potential of biogas produced from animal slurry within Buckinghamshire

Livestock	Number in Buckinghamshire	Mass of slurry (thousand tonnes/year)	Biogas Yield (million m^3)	Energy potential (GWh/year)
Cattle	50,271	607.9	12.2	81.5
Pigs	14,056	34.6	0.7	4.6
Poultry	862,308	44.6	2.2	15.0
Total	926,635	687.1	15.1	101.0

Table 36 summarises the potential carbon offsets when the biogas produced from slurry replaces an equivalent amount of energy from gas and electricity.

Table 36: Potential carbon offsets from using biogas from animal slurry in place of gas and electricity

Livestock	Energy potential (GWh/year)	Carbon offset compared to gas ($ktCO_2e$/year)	Carbon offset compared to electricity ($ktCO_2e$/year)
Cattle	81.5	14.9	12.7
Pigs	4.6	0.8	0.7
Poultry	15.0	2.7	2.3
Total	101.0	18.5	15.7

The biogas produced would be considered renewable and could be used for electricity or heat generation. In a CHP plant it could produce both, perhaps providing heat to a heat network as well as providing electricity to the grid.

6. Conclusions and recommendations

6.1. Summary of renewable potential

This renewable energy study has examined the potential for a variety of renewable energy in Buckinghamshire. As has been shown, there is significant technical potential within the Buckinghamshire local plan area, enough to cover the energy requirements of Buckinghamshire twice over. Table 37 summarises the maximum technical potentials from all sources assessed. These are also shown as a percentage of current electricity, heat, and stationary energy demand in Buckinghamshire.

Table 37: Summary of the maximum technical potential of renewable energy sources

Renewable energy source	Maximum technical potential (GWh/year)	Current electricity demand which could be met	Current heat demand which could be met	Current total energy demand which could be met
Ground-mounted solar	11,452.2	588%	262%	161%
Rooftop PV	576.2	30%	13%	8%
Rooftop hot water	1,017.3	52%	23%	14%
Wind	2,809.1	144%	64%	40%
Hydropower	35.9	2%	1%	1%
Woody biomass	111.9	6%	3%	2%
SRC (Energy crop)	2,524.3	130%	58%	36%
Miscanthus (Energy crop)	5,032.0	259%	115%	71%
Slurry	101.0	5%	2%	1%

Note that this study does not consider losses in production. For example, were woody biomass to be used in a thermal power plant to generate electricity, the conversion efficiency could be as low as 25%. This would mean that the electrical output would be approximately 1.5% of Buckinghamshire's electricity demand. In other words, this table summarises the resource potential, not the output of all renewable technologies. The reasoning for this is that there are many different conversion technologies and setups that could exist and using a single conversion efficiency could be significantly misleading. Comparisons to electricity, heat, and energy use are provided to contextualise the quantity of the resource, rather than give a prediction of output.

Furthermore, not all of the above technical potential is compatible with one another. Ground-mounted solar and wind potential may use the same land. The two can co-exist, with solar panels filling gaps between wind turbines, but there will be a decrease in output from the panels. This is both because of the shading of panels, and the physical space taken up by the turbine. Similarly, solar PV and SHW may compete for roof space. The two energy crops (miscanthus and SRC) are calculated using the same land area – therefore one must be chosen on a site over the other.

Despite the above limitations and decisions, there is significant potential for renewable energy development and deployment in Buckinghamshire. If planned well, this potential should be enough to cover the area's energy needs.

Renewable energy sources can also offer wider benefits beyond decarbonisation, including better air quality, improved health and wellbeing, jobs and income generation, and many others. These could result from the deployment of most of the renewable energy technologies that Buckinghamshire has potential for: wind and ground-mounted solar, roof mounted solar (PV and SHW), energy from waste, hydropower, energy crops and woody biomass.

6.2. Recommendations

The main aim of this assessment is to provide a robust technical analysis of renewable energy potential within the study area to inform the preparation of the Local Plan for Buckinghamshire . This report seeks to provide the information required to aid plan-makers in their decision making.

Buckinghamshire Council should consider using their powers as a local authority to engage with the local community and key stakeholders and seek their support in making decisions on an appropriate technology mix and the rate of deployment desired. Buckinghamshire could aim to become a net-exporter of renewable energy or at least self-sufficient in most categories of energy provision, but this will depend on factors that go beyond the technical potential of the study area.

The Council should consider facilitating discussions and maximising its influence to promote renewable energy development and deployment in the local area. This social process should aim to understand those non-technical factors that will play a key role in the successful deployment of renewable energy development. These include local ambitions, initiative-taking, and appetite for change, but also considerations of funding and commercial interests, socio-demographic factors, and the wider benefits of renewable energy development (e.g. improved air quality, health and wellbeing, reduced rates of fuel poverty, etc.).

In addition, the planning authority has direct influence in shaping policies and places. It is recommended that Buckinghamshire Council considers the following in the development of their Local Plan:

1. **Supportive policy on renewable energy**: whilst the specific technology mix to be adopted is uncertain, it is clear from the NPPF that local plans are required to encourage, or in some cases require (e.g. in proposals for major developments), renewable energy development by adopting appropriate and supportive criteria-based policies that aim to maximise deployment whilst minimizing adverse harmful impacts. These policies should be shaped by stakeholder consultation and should be pitched at levels of ambition that align with, or where appropriate go beyond, national policy.

2. **Low or zero carbon heat networks**: the Local Plan could be developed in line with national heat network zoning ambitions to ensure that suitable areas of Buckinghamshire Council are designated within which heat networks are the lowest cost solution for decarbonising heat. Although these will predominantly feature in larger settlements and dense urban areas, provisions for designating heat network zones should be made in developing planning policy.
3. **Individual building heat supplies**: where connection to a heat network is shown to be unviable for new development, the decarbonisation of heat supplies to individual buildings can be enforced via appropriate energy performance standards in local policy. Energy performance standards should encourage the phase-out of gas boilers, but along with heat pumps they should also permit other low or zero carbon heating options where appropriate, such as use of specific types of bioenergy or solar water heating.
4. **Appropriate use of bioenergy**: to varying extents, bioenergy is factored into all major national scenarios being proposed to achieve net zero by 2050, however this technology carries a risk relating to how soon it can be successfully developed and rolled out because it is not yet technologically or economically proven at scale. The Council should consider exploring criteria-based local policies to encourage renewables which include bioenergy where its use can be demonstrated as beneficial and fit for purpose.

A number of further studies could integrate this evidence base with regards to renewable energy within Buckinghamshire and complement it in underpinning renewable energy policies, such as:

- A district-wide heat mapping and prioritisation exercise to identify local areas which are likely to hold the most potential for developing low or zero carbon heat networks
- Pre-feasibility analysis of one or more heat network zones to explore options for heat supply, network routing and optimisation
- A landscape sensitivity assessment for various scales of wind and solar energy generation
- Development of carbon emission reduction trajectories based on future targets and energy generation deployment scenarios
- Identification of opportunities and constraints resulting from proposed new development sites
- A review of non-technical opportunities and constraints associated with renewable energy infrastructure development, including financial considerations, planning requirements, building regulations, and wider socio-economic and environmental impacts
- A Local Area Energy Plan, which would include some of the elements listed above
- Carbon auditing of the Local Plan proposals

The Local Plan should consider how it is best to designate and allocate suitable areas and sites for renewable energy development taking into account all other underpinning evidence. As noted above, further work is recommended to the local authority to understand in more detail the impact of different renewable resources on the area and where sites can be allocated for renewable generation.

In allocating sites, consideration must also be given to other land uses that may compete with renewable energy development, as well as the impact of exploitation of resources. For example, solar and wind farms, and energy crops may take land away from food production, therefore decisions need to be made about the most desirable use of land.

Effective stakeholder and public engagement are key to this process and would allow the Council to better understand local needs, wants and barriers. The outcomes of this engagement can inform policy proposals for the Local Plan and help prioritise certain resources. This is necessary to understand if Local Plan recommendations align with local intentions.

Stakeholder and public engagement is likely to vary depending on the renewable energy technologies and the scale of their deployment. The Local Plan should consider establishing the role the Council will play in deploying different renewable energy technologies. In particular, it should consider the role the Council can play as a convenor and facilitator in the process, even where it may not be directly involved in the delivery of renewable energy projects.

The council should consider contacting and working closely with the three distribution network operators (DNOs): National Grid Electricity Distribution, UK Power Networks, and Scottish and Southern Electricity Networks – that operate networks within Buckinghamshire. These should have teams that can support the Council in energy planning for the local area. These teams will be experts in the electricity grid and should be able to highlight areas where there is capacity for renewable generation, or where that may be constrained. They may also be able to better highlight desirable areas for energy storage and batteries.

Furthermore, whilst this study has focussed on the renewable energy potential within Buckinghamshire, cooperation between local authorities is likely to help Buckinghamshire fully realise its renewable energy potential, for example through joint ventures to develop renewable energy infrastructure.

Finally, it is recommended the Council develop an energy strategy that is in line with and in support of emerging policies of the Local Plan. This will help Buckinghamshire Council understand and consider likely future changes that will take place under the renewable transition. Key considerations that relate to renewable energy are: the increased electrification of heating; increased need for flexibility in the electricity grid; a change to electric vehicles; and insulation.

Appendix 1: REPD-recorded sites in Buckinghamshire

Table 38: Complete list of REPD-recorded sites in Buckinghamshire

Allocations under the REPD are:

- Operational: Installations which are active and producing power (Total 92.7 MW)
- Under construction: Installations currently under construction (Total 79.9 MW)
- Awaiting construction: Planning permission granted, but construction has not started (Total 348.91 MW)
- Application submitted: A planning application has been submitted (Total 279 MW)
- Revised: A revised planning application has been submitted (Total 89.9 MW)
- Application refused: Planning permission for the installation has been refused (Total 101.7 MW)
- Application withdrawn: The planning application has been withdrawn by the submitter (Total 11.2 MW)
- Planning permission expired: Planning permission was granted, but construction has not started within the time limit attached to the permission (Total 11.2 MW)
- Abandoned: The planning application is considered abandoned by the submitter (Total 20 MW)

Site	Postal Town	Type	Capacity MW	Status
Gib Lane (Aston Clinton solar park)	Bierton	Solar PV	24.2	Operational
Turweston Solar Farm	Biddlesden	Solar PV	16.7	Operational
Bumpers Lane Solar Farm	Ilmer	Battery	13.3	Operational
Gawcott Fields Farm	Buckingham	Solar PV	9.2	Operational
Land At Potash Farm	Beachampton	Solar PV	7	Operational
Church Farm	Slapton	Solar PV	6.2	Operational
Church Farm	Slapton	Solar PV	6.2	Operational
Great Seabrook Farm	Cheddington	Solar PV	5	Operational
Bumpers Farm Phase 1	Ilmer	Solar PV	5	Operational
Arla Dairy Site	Aston Clinton	Anaerobic Digestion	5	Operational
Land at Thornborough Grounds	Thornborough	Solar PV	5	Operational
Gib Lane Solar farm (Extension)	Bierton	Solar PV	5	Operational
Long Meadow Farm	Leighton Buzzard	Solar PV	4.1	Operational
Westcott Venture Park	Westcott	Anaerobic Digestion	2	Operational
Quarrendon Fields	Aylesbury	Wind Onshore	1.5	Operational
Westcott Venture Park Phase 2 & 3	Westcott	Solar PV	1.3	Operational
Buckingham Tesco Superstore	Buckingham	Solar PV	0.2	Operational
Stony Energy Storage Facility	Stony Stratford	Battery	79.9	Under Construction

Site	Postal Town	Type	Capacity MW	Status
Whirlbush Farm, Kingsey - Solar Farm & Battery Storage	Kingsey	Solar PV	49.9	Awaiting Construction
Bury Farm - Solar Farm	Leighton Buzzard	Solar PV	49.9	Awaiting Construction
Callie's Solar Farm	Owlswick	Solar PV	49.9	Awaiting Construction
Whirlbush Farm, Kingsey - Solar Farm & Battery Storage	Kingsey	Solar PV	49.9	Awaiting Construction
Tuckey Farm	Winslow	Solar PV	25	Awaiting Construction
Tuckey Farm	Winslow	Solar PV	25	Awaiting Construction
Moat Farm - Solar Farm	Aylesbury	Solar PV	24.06	Awaiting Construction
Fox Covert Solar Farm	Milton Keynes	Solar PV	22	Awaiting Construction
Fox Covert Solar Farm	Milton Keynes	Solar PV	22	Awaiting Construction
Bumpers Farm Phase 2	Ilmer	Solar PV	12	Awaiting Construction
Manor Farm	Buckingham	Solar PV	12	Awaiting Construction
Stratford Road Solar Farm	Stratford	Solar PV	5	Awaiting Construction
Safren Power Uk Limited - Solar Photovoltaic	Pitstone	Solar PV	0.99	Awaiting Construction
Silverstone Road, Biddlesden - Solar Panels	Biddlesden	Solar PV	0.87	Awaiting Construction
Brackley Sewage Treatment Works, Brackley Road - Solar Array	Turweston	Solar PV	0.24	Awaiting Construction
Newlands Meadow, Eden - Solar Panels	High Wycombe	Solar PV	0.15	Awaiting Construction
Slough Road - Battery Storage	Iver	Battery	57	Application Submitted
Derehams Farm, Derehams Lane - Battery Storage	Loudwater	Battery	50	Application Submitted
Derehams Farm, Derehams Lane - Battery Storage	Loudwater	Battery	50	Application Submitted
Lower Waldridge Farm, Ford - Solar Farm	Owlswick	Solar PV	49.9	Revised
Hale Solar Farm	Hulcott	Solar PV	40	Application Submitted
Loudwater Battery Storage Site	Loudwater	Battery	40	Revised
Manor Farm, Beachampton - Solar Farm	Beachampton	Solar PV	25	Application Submitted
Wicken Farm, Leckhampstead - Solar Farm	Leckhampstea d	Solar PV	21	Application Submitted
Gerrards Cross Sewage Treatment Works	Gerrards Cross	Battery	20	Application Submitted

Site	Postal Town	Type	Capacity MW	Status
Calvert Landfill Site Solar Array	Calvert	Solar PV	16	Application Submitted
Acorn Bioenergy Limited - Anaerobic Digestion Facility	Chilton	Anaerobic Digestion	0	Application Submitted
Globe Business Park, Fieldhouse Lane - PV Panels	Marlow	Solar PV	0	Application Submitted
Bicester Road, Long Crendon - Anaerobic Digestion Facility	Long Crendon	Anaerobic Digestion	0	Application Submitted
Mursley Road	Milton Keynes	Solar PV	36	Application Refused
Lye Green Energy Storage	Chesham	Battery	25	Application Refused
Salden Wind Farm	Newton Longville	Wind Onshore	10	Application Refused
Dorcas Lane Wind Farm	Stoke Hammond	Wind Onshore	10	Application Refused
Litchlake Farm	Silverstone	Battery	10	Planning Permission Expired
Knapps Hook Farm	Aylesbury	Solar PV	8.9	Application Withdrawn
Forty Green Farm	Bledlow	Solar PV	7.5	Application Refused
Coldmoorholme Lane Battery Storage	Bourne End	Battery	7.2	Application Refused
Land North of Marlow Landfill Site	Marlow	Solar PV	5	Application Refused
Land Adjacent to A422	Turweston	Solar PV	3.4	Application Withdrawn
Land adjacent to A422	Brackley	Solar PV	3.4	Application Withdrawn
Prospect Farm	Milton Keynes	Solar PV	1.2	Planning Permission Expired
Wapseys Wood	Gerrards Cross	Anaerobic Digestion	1	Application Refused
Westcott Venture Park Solar Farm	Westcott	Solar PV	15	Abandoned
Oakwood Farm	Mentmore	Solar PV	5	Abandoned

Appendix 2: Buffers used in modelling

Ground-mounted solar photovoltaics

Table 39: Buffers applied and reasoning for ground-mounted solar constraints

Constraint	Level of constraint	Buffer applied (m)	Reasoning
Roads	Level 1	Motorway: 30m Dual Carriageway: 20m All other roads: 10m	Roads are line data, buffers consider width of road.
Rail	Level 1	10m	Rails are line data, buffers consider width of rail.
Ministry Of Defence (MOD) land	Level 1	0	MOD land is not likely to be able to be developed with renewables.
Residential properties	Level 1	300m	There is no statutory distance required between residential buildings and ground-mounted solar. 300m is commonly used to minimise negative impacts such as glare.
Employment sites	Level 1	0	Can't develop on enterprise/employment sites.
Water	Level 1	50m	The environment agency recommends a minimum 50m separation between water and potentially low-hazardous activities (such as concrete mixing). Development of renewables may involve such processes.
Woodland	Level 1	0	Woodland can't be developed without first being cut down.

Constraint	Level of constraint	Buffer applied (m)	Reasoning
Scheduled monuments	Level 1	0	Scheduled monuments have statutory protection and are unlikely to be able to be developed
Historic parks and gardens	Level 1	0	Historic parks and gardens have statutory protection and are unlikely to be able to be developed.
Flood zones 2 and 3	Level 1	0	Development of flood risk zones 3a and 3b is highly discouraged due to risk of damage to developments.
Existing settlements	Level 1	300m	Settled areas generally have a majority of residential properties, so the same buffer has been applied.
Agricultural land grades 1 – 3a	Level 1	0	Grades 1-3a agricultural land has been excluded as this land is categorised as best, most versatile (BMV). Renewables development, particularly solar, is heavily discouraged here, and may be banned in the future.
Minerals commitments and safeguarding areas	Level 1	0	Minerals sites and safeguarded areas are designated to prevent development which could prevent access to the minerals. Whilst renewables are considered temporary development and land can be restored at the end of their lifetime, there is risk in developing renewables in safeguarded areas, particularly due to competing interests.
Special areas of conservation (SAC)	Level 1	0	SAC restrictions may make it difficult to develop renewables.
Local plan and neighbourhood plan sites	Level 1	300m	Development set out under existing local plans and neighbourhood plans are mostly residential or commercial so the same buffer has been applied.

Constraint	Level of constraint	Buffer applied (m)	Reasoning
Area of outstanding natural beauty (AONB)	Level 2	0	AONB restrictions may make it difficult to develop renewables.
Sites of special scientific interest (SSSIs)	Level 2	0	SSSI restriction may make it difficult to develop renewables.
National nature reserves	Level 2	0	NNR restriction may make it difficult to develop renewables.
Green belt	Level 2	0	Green belt restrictions may make it difficult to develop renewables.

Wind power

Table 40: Buffers applied and reasoning for wind turbine constraints

Constraint	Level of constraint	Buffer applied	Reasoning
Roads	Level 1	Lesser of turbine tip height + 50, turbine tip height + 50%. Added to: Motorway: 30m Dual carriageway: 20m All other roads: 10m	Recommended distance to make roads safe from turbine toppling. Road buffers because roads are line data, so buffered to consider for width of road.
Rail	Level 1	360m	National rail guidance requires all developments to be assessed for noise and vibration impacts alongside railways. This buffer set as below for residential based on that recommendation.

Constraint	Level of constraint	Buffer applied	Reasoning
Transmission lines (and pylons)	Level 1	Three rotor diameters	Cables must be protected from wake effects from wind turbines. National grid recommends three rotor diameters to achieve this.
MOD Land	Level 1	0	MOD land is unlikely to be able to be developed with renewable energy.
Residential properties	Level 1	350m	There is no statutory requirement for wind turbines to be sited away from residential properties. Guidance suggests that 350m is sufficient to reduce wind turbine noise to less than that of cars on a country road and considered acceptable.
Employment Sites	Level 1	350m	Applied in line with the residential recommendation to reduce any noise impacts on employment sites
Existing wind	Level 1	875m	A spacing figure derived from the turbine spacings discussed elsewhere, relevant to the single wind site existing in Buckinghamshire.
Water	Level 1	Lesser of turbine tip height + 50m, or turbine tip height + 50%. A minimum of 50m is applied.	As with roads, this reduces toppling risk. 50m minimum based on environment agency minimum safe distance for certain low-hazard processes likely to be associated with renewable development.
Woodland	Level 1	$\sqrt{(50 + rotor\ radius)^2 - (hub\ height - 60)^2}$	Based on Natural England guidance regarding spacing wind turbines from forests to prevent impacting bat populations

Constraint	Level of constraint	Buffer applied	Reasoning
Scheduled monuments	Level 1	Blade radius	To prevent oversweeping of Scheduled monuments. Oversweeping is where the rotation of turbine blades causes them to pass over an area, which they may not hang over when not in motion.
Historic parks and gardens	Level 1	Blade radius	To prevent oversweeping of Historic parks and gardens.
Flood zones 2 and 3	Level 1	0	Development of flood risk zones 3a and 3b is highly discouraged due to risk of damage to developments.
Existing settlements	Level 1	350m	Existing settlements are predominately residential, therefore the same buffer has been applied
Local plan and neighbourhood plan sites	Level 1	350m	Sites under the local and neighbourhood plans are predominately residential, therefore the same buffer has been applied.
Agricultural land	Level 1	0	Whilst there is less concern with regards to wind compared to solar on best, most versatile land (BMV) there is still significant pressure against developing this land for renewables.
Windspeed	Level 1	0	Areas where the windspeed is below the set threshold of 7m/s at the hub height of the turbine.
Minerals commitments and safeguarding areas	Level 1	0	Minerals sites and safeguarded areas are designated to prevent development which could prevent access to the minerals. Whilst renewables are considered temporary development and land can be restored at the end of their lifetime, there is risk in developing renewables in safeguarded areas, particularly due to competing interests.

Constraint	Level of constraint	Buffer applied	Reasoning
Special areas of conservation (SACs)	Level 1	Blade radius	To prevent oversweeping of SACs.
Local plan and neighbourhood plan sites	Level 2	350m	Sites under the local and neighbourhood plans are predominately residential, therefore the same buffer has been applied.
Area of outstanding natural beauty (AONB)	Level 2	Blade radius	To prevent oversweeping of AONBs.
Sites of special scientific interest (SSSIs)	Level 2	Blade radius	To prevent oversweeping of SSSIs.
National nature reserves (NNRs)	Level 2	Blade radius	To prevent oversweeping of National Nature Reserves.
Green Belt	Level 2	Blade radius	To prevent oversweeping of Green Belt
Airports	Level 3	18km	Airports have a 15km statutory consultation radius. 3km added to approximate airport size as airport locations come from point data.
NATS Safeguarding Areas	Level 3	0	NATS has statutory consultation in line of sight of their radar systems, given by these safeguarding areas.
MOD Safeguarding area	Level 3	0	An area where the MOD has statutory consultation, which may present barriers to development.

Appendix 3: Factors used in modelling

Load factors

Table 41: Load factors used in renewable energy generation modelling

Load Factors	Factor	Unit	Source
Ground-mounted solar	10.1	%	Department for Energy Security and Net Zero (2023e)
Wind	26.8	%	Department for Energy Security and Net Zero (2023e)
Hydropower	50	%	International Renewable Energy Agency (2014)

Spacing factors

Table 42: Spacing factors used in renewable energy capacity modelling

Spacing Factor	Factor	Unit	Source	Notes
Ground-mounted solar	0.02	km^2 per MW	Renewable Energy Hub (2023)	
Ground-mounted solar	0.02	km^2 per MW	Solar Trade Association (2015)	
Wind spacing behind turbines	5	rotor diameters	Renewables First (2015)	
Wind spacing behind turbines	7	rotor diameters	Danish Wind Industry Association (2003)	
Wind spacing behind turbines	8	rotor diameters	Ideas Medioambientales (2021)	
Wind spacing behind turbines	8	rotor diameters	Clayton (2022)	
Wind spacing beside turbines	4	rotor diameters	Danish Wind Industry Association (2003)	
Wind spacing beside turbines	2	rotor diameters	Ideas Medioambientales (2021)	
Wind spacing behind turbines	7	rotor diameters		Average of above

Spacing Factor	Factor	Unit	Source	Notes
Wind spacing beside turbines	3	rotor diameters		Average of above
Small turbine spacing	97	Turbines per km^2		Elliptical area using the above spacing, and the typical turbine characteristics. These characteristics based on review of turbines on the market.
Medium turbines spacing	24	Turbines per km^2		Elliptical area using the above spacing, and the typical turbine characteristics. These characteristics based on review of turbines on the market.
Large turbine spacing	4	Turbines per km^2		Elliptical area using the above spacing, and the typical turbine characteristics. These characteristics based on review of turbines on the market.
Very large turbine spacing	2.5	Turbines per km^2		Elliptical area using the above spacing, and the typical turbine characteristics. These characteristics based on review of turbines on the market.

Emissions factors

Table 43: Emissions factors used in carbon offset estimation

Emissions Factors	Factor	Unit	Source	Notes
Grid electricity	0.156	$kgCO_2e/kWh$	National Grid ESO (2022)	
Grid gas	0.183	$kgCO_2e/kWh$	Department for Energy Security and Net Zero (2023a)	
Coal (domestic)	0.347	$kgCO_2e/kWh$	Department for Energy Security and Net Zero (2023a)	
LPG	0.214	$kgCO_2e/kWh$	Department for Energy Security and Net Zero (2023a)	
Average other fuels	0.281	$kgCO_2e/kWh$		Average of domestic coal and LPG - used for "other fuels" in the assessment
Biogas	0.00022	$kgCO_2e/kWh$	Department for Energy Security and Net Zero (2023a)	

Crop and woodland yield factors

Table 44: Crop and woodland yield factors

Yield factors	Factor	Unit	Source	Notes
Conifer	18	m^3/ha.year	Carbon Store (2021)	Based on Sitka Spruce - the most common conifer in the UK
Broadleaved	8	m^3/ha.year	Carbon Store (2021)	Based on mixed broadleaf
Conifer dry wood density	450	kg/m^3	-	-
Broadleaved dry wood density	698	kg/m^3	-	-
Moisture content of green wood	52	%	-	Volume basis
Moisture content of oven dried wood	0	%	-	Volume basis
SRC yield	460	odt/km^2.year	Department for Environment, Food and Rural Affairs (2021)	-
Miscanthus	1350	odt/km^2.year	-	-
Oven dry wood calorific value	5.3	kWh/kg	Forest Research (2023b)	-
Miscanthus calorific value	3.6	kWh/kg	Forest Research (2023b)	-

Animal slurry data and factors

Table 45: Animal slurry data and factors

Livestock data	Data	Unit	Source
Number of cattle	50,271	-	Department for Environment, Food and Rural Affairs (2023)
Number of pigs	14,056	-	Department for Environment, Food and Rural Affairs (2023)
Number of poultry	862,308	-	Department for Environment, Food and Rural Affairs (2023)
Slurry per head cattle	0.228	m^3/week	Agriculture and Rural Economy Directorate of the Scottish Government (2018)
Slurry per pig	0.046	m^3/week	Agriculture and Rural Economy Directorate of the Scottish Government (2018)
Slurry per chicken	4	kg/month	Ritz and Merka (2016)
Biogas yield per kg of cattle slurry	20	m^3/tonne	The Andersons Centre (2010)
Biogas yield per kg of pig slurry	20	m^3/tonne	The Andersons Centre (2010)
Biogas yield per kg of poultry slurry	50	m^3/tonne	The Andersons Centre (2010)
Biogas calorific value	7	kWh/m^3	International Energy Agency (2020)

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