# UK Anaerobic Digestion Mapping Application

## Technical Specification Document v5.0

**Date:** January 2025  
**Status:** Enhanced Implementation with Land Registry Integration

## 1. Executive Summary

The UK Anaerobic Digestion Mapping Application is a comprehensive interactive web application designed for visualizing and analyzing anaerobic digestion (AD) plants across the United Kingdom. The application integrates livestock manure distribution data, environmental constraints, infrastructure information, and freehold land registry data to support renewable energy site selection, planning, and policy development.

### Key Features

* **Interactive Mapping**: MapLibre GL JS-powered visualization with 50,000+ mapped features
* **Multi-layer Analysis**: 20+ data layers including AD plants, boundaries, environmental, infrastructure, and land registry data
* **Advanced Search & Site Finder**: Fuzzy search across 2,000+ AD plants plus intelligent site selection based on multiple criteria
* **Spatial Analysis**: Proximity calculations, detailed LAD/LPA analysis, and multi-criteria site suitability assessment
* **Real-time Data**: Live data feeds from Google Cloud Storage with automatic updates
* **Land Registry Integration**: Freehold land parcel visualization with ownership and property details
* **Infrastructure Mapping**: Direct CSV integration for instant DNO and water company data display

## 2. System Architecture

### 2.1 Frontend Architecture (Primary Implementation)

**Standalone HTML/CSS/JavaScript Application** - **Technology Stack**: MapLibre GL JS, Vanilla JavaScript, Tailwind CSS - **Data Processing**: Papa Parse (CSV), TopoJSON Client, Turf.js (geospatial) - **Search Engine**: Fuse.js fuzzy search - **Visualization**: Chart.js for data graphics - **Accessibility**: ARIA-compliant interface elements

### 2.2 Backend Architecture

**Express.js Server** - **Framework**: Node.js with TypeScript - **Storage**: In-memory development storage with PostgreSQL interface - **API**: RESTful endpoints for data management - **Middleware**: Request logging, JSON parsing, error handling - **Development**: Vite integration with hot module replacement

### 2.3 Data Architecture

**External Data Sources** - **Primary Storage**: Google Cloud Storage for geospatial datasets - **AD Plants**: 2,000+ facilities with enhanced infrastructure mapping (DNO, water company) - **Boundaries**: LAD (361 districts), LPA (379 authorities) - **Environmental**: AONB, SSSI, NVZ, flood zones, ALC grades (5 classifications) - **Infrastructure**: DNO regions, water companies, brownfield sites (34,855), NTS pipeline - **Manure Data**: 8 livestock categories with volume distribution and biomethane potential - **Land Registry**: Freehold property data via vector tiles with ownership information

**Enhanced CSV Data Structure**

AD Plants Fields (37 columns):  
- Location: Site name, Postcode, County, LAD/LPA codes  
- Technical: Capacity, Technology type, Feedstock mix, Completion date  
- Planning: Application reference, Status, Developer  
- Infrastructure: DNO (direct field), WaterCo (direct field) \*\*NEW\*\*  
- Coordinates: Latitude, Longitude, Easting, Northing

**Vector Tile Architecture for Land Registry** - **Format**: Mapbox Vector Tiles (MVT) - **Zoom Levels**: progressive detail disclosure - **Properties**: Title number, ownership type, land use, constraints - **Geometry**: Precise boundary polygons with area calculations - **Performance**: Client-side caching with 500ms load times

## 3. User Interface Design

### 3.1 Layout Structure

**Primary Interface Components** - **Left Sidebar**: Collapsible layer controls with grouped categories - **Map Canvas**: Full-screen interactive MapLibre GL JS view - **Right Panel**: Slide-out information panels for detailed analysis - **Top Bar**: Search functionality and navigation controls - **Bottom Bar**: Legend, scale, and attribution information

### 3.2 Layer Control System

**Hierarchical Organization** 1. **Boundaries** - Local Authority Districts (LAD) - Local Planning Authorities (LPA)

1. **AD Plants**
   * Operational facilities (multiple subcategories)
   * Planning stages (Construction, Granted, Submitted)
   * Non-operational (Refused, Withdrawn)
2. **Manure Volumes**
   * 8 Individual livestock category toggles:
     + Beef FYM (Farmyard Manure),
     + Beef Slurry
     + Dairy FYM (Farmyard Manure),
     + Dairy Slurry
     + Broilers (Poultry),
     + Layers (Egg-laying Poultry)
     + Pigs,
     + Sheep
   * Data source: manure\_volumes\_wgs84.topojson
   * Hexagonal polygon visualization with tonnage data
3. **Environmental**
   * Areas of Outstanding Natural Beauty (AONB)
   * Sites of Special Scientific Interest (SSSI)
   * Nitrate Vulnerable Zones (NVZ)
   * Historic Flood Zones
   * Agricultural Land Classification (5 individual grades)
4. **Infrastructure**
   * Distribution Network Operators (DNO) - 14 regions
   * Water Company Boundaries - 432 boundaries
   * Brownfield Land Sites - 34,855 Point locations
   * National Transmission System (NTS) - 954 features
   * Roads (MBTiles format) - GB road network
5. **Land Registry**
   * Freehold Land Parcels - Vector tiles (zoom-dependent loading)
   * Property ownership information
   * Land parcel boundaries and dimensions
   * Title registry details and constraints

### 3.3 Color Coding System

**AD Plant Status Colors** - Operational: #0f5132 (Dark Green) - Under Construction: #2574ce (Blue) - Planning Granted: #854ec2 (Purple) - Planning Application: #f38c1d (Orange) - Refused/Withdrawn: #b6222b (Red)

**Manure Volume Colors** - Beef FYM: #8B4513 (Dark Brown) - Beef Slurry: #A0522D (Saddle Brown) - Dairy FYM: #4682B4 (Steel Blue) - Dairy Slurry: #5F9EA0 (Cadet Blue) - Broilers: #FF6347 (Tomato) - Layers: #FF7F50 (Coral) - Pigs: #DA70D6 (Orchid) - Sheep: #32CD32 (Lime Green)

**ALC Grade Colors** (Green to Red Gradient) - Grade 1: #22c55e (Best Agricultural Land) - Grade 2: #65a30d - Grade 3: #eab308 - Grade 4: #f97316 - Grade 5: #ef4444 (Poorest Agricultural Land)

## 4. Enhanced Site Selection Platform

### 4.1 Site Finder Algorithm NEW

The Site Finder implements a sophisticated multi-criteria decision analysis (MCDA) system for identifying optimal locations for anaerobic digestion facilities.

**Scoring Methodology:** - **Weighted Criteria**: User-configurable importance weights (1-10 scale) - **Distance Penalties**: Exponential decay functions for proximity requirements - **Boolean Constraints**: Hard exclusions (e.g., AONB buffers, flood zones) - **Resource Scoring**: Logarithmic scaling for feedstock availability

**Criteria Categories:**

1. **Location Requirements**
   * Land parcel size (minimum acres)
   * Current land use compatibility
   * Access road classification (M/A/B road proximity)
   * Topographical constraints (slope, elevation)
2. **Infrastructure Access**
   * Gas grid connection (NTS pipeline distance)
   * Electrical grid capacity (DNO availability)
   * Water supply infrastructure
   * Waste disposal routes
3. **Environmental Compliance**
   * AONB exclusion buffers (5-20km configurable)
   * SSSI protection zones (2-15km configurable)
   * Historic flood zone avoidance
   * Air quality considerations
4. **Feedstock Security**
   * Manure availability by radius (10-100km)
   * Minimum tonnage thresholds by livestock type
   * Seasonal availability patterns
   * Transport cost optimization
5. **Planning Feasibility**
   * Agricultural Land Classification restrictions
   * Existing planning permissions
   * Local authority development policies
   * Community acceptance indicators

## 6. Implementation Specifications

### 6.1 Site Finder User Interface

### 6.2 Land Registry Vector Tile Implementation

### 6.3 Multi-Criteria Analysis Engine NEW

### 6.4 Performance Optimization

## 7. Core Functionality

**Map Navigation** - Pan, zoom, and rotate with mouse/touch controls - Zoom-dependent layer loading for optimal performance - Vector tile streaming for land registry data at high zoom levels - Smooth transitions and animations between zoom levels

**Multi-layer Visualization** - Simultaneous display of up to 20 data layers - Z-index management for proper layer stacking - Dynamic opacity controls for layer blending - Color-coded legend with real-time updates

**Click Interaction System** - Priority-based feature selection (AD plants > boundaries > other features) - Comprehensive info panels with detailed facility information - LAD/LPA boundary analysis with integrated manure data - Freehold land parcel property details and ownership information

### 4.2 Enhanced Search Functionality

**Fuzzy Search Engine (Fuse.js)** - Search across 2,000+ AD plants by name, developer, location, or status - Auto-complete suggestions with relevance scoring - Real-time filtering as user types - Search history and favorites

**Site Finder - Multi-Criteria Analysis** The Site Finder is an intelligent tool for identifying suitable freehold land parcels for new AD plant development based on multiple constraints and requirements:

**Infrastructure Criteria:** - Gas grid proximity (NTS pipeline access within specified distance) - Electrical grid capacity (DNO region and connection availability) - Road network access (A-road or M-road proximity requirements) - Water supply availability (water company service area)

**Environmental Constraints:** - AONB exclusion zones (minimum distance requirements) - SSSI protection buffers (customizable distance thresholds) - Flood risk assessment (historic flood zone avoidance) - Agricultural land classification restrictions (exclude Grade 1-2 ALC land)

**Feedstock Availability:** - Manure resource analysis within defined radius (e.g., 50-mile catchment) - Minimum tonnage thresholds by livestock type - Biomethane potential calculations - Seasonal availability considerations

**Site Physical Requirements:** - Minimum land parcel size (e.g., 10+ acres) - Topographical suitability - Existing land use compatibility - Planning permission probability assessment

**Usage Example:**

Find sites with:  
- NTS pipeline within 5km  
- Min 10km from AONB/SSSI  
- A-road access within 2km  
- Min 10 acres  
- 100,000+ tonnes broiler manure within 50 miles  
- Exclude ALC Grade 1-2 land  
- Brownfield sites preferred

### 4.3 Land Registry Integration

**Vector Tile Architecture** - Dynamic loading based on zoom level (activated at zoom xx+) - Efficient rendering of large land registry datasets - Progressive disclosure of property details

**Property Information Display** - Freehold ownership details - Property boundaries and dimensions - Title registry numbers and constraints - Sale history and valuation data - Planning restrictions and covenants

**Site Suitability Integration** - Cross-reference with environmental layers - Infrastructure proximity calculations - Planning constraint identification - Development potential assessment

### 4.4 Infrastructure Data Enhancement

**Direct CSV Integration** - AD plants now include direct DNO and Water Company fields - Eliminated spatial query performance bottlenecks - Instant infrastructure data display in plant info panels - 884 plants mapped to specific infrastructure providers

**Real-time Infrastructure Analysis** - Dynamic calculation of connection distances - Grid capacity and availability indicators - Utility contact information and application processes - Cost estimation for infrastructure connections - Pan, zoom, and rotate controls - Initial view: Center [-2.5, 54.5], Zoom level 6 - Zoom range: 5 (country view) to 18 (detailed site view) - Smooth transitions and performance optimization

**Layer Management** - Toggle visibility for 15+ individual layers - Real-time layer loading and rendering - Dynamic legend updates based on active layers - Layer opacity and styling controls

### 4.2 Search and Discovery

**Plant Search System** - Fuzzy search across 2,000+ AD facilities - Search by: Name, Location, Operator, Technology - Real-time results with autocomplete - Geographic focusing on search results

**Location Search** - UK place name geocoding - Postcode lookup functionality - Coordinate-based search - Map centering on search results

### 4.3 Information Panels

**LAD Analysis Panel** - Comprehensive district information - AD plant inventory with status breakdown - Manure volume statistics by livestock type - Proximity analysis to key infrastructure - Population and land use data - Environmental constraint summary - Export functionality for detailed reports

**LPA Analysis Panel** - Planning authority specific data - Application status tracking - Capacity analysis by planning stage - Infrastructure relationship mapping - Environmental compliance summary

**AD Plant Details** - Facility specifications (capacity, technology) - Operational status and timeline - Operator information and contacts - Proximity to key infrastructure - Environmental constraints analysis - Planning history and documentation

### 4.4 Spatial Analysis Tools

**Proximity Calculations** - Multiple distance radii: 1km, 2km, 5km, 10km - Analysis categories: - Nearby AD plants with capacity aggregation - Manure volume availability by livestock type - Environmental constraints (AONB, SSSI, flood zones) - Infrastructure access (DNO, water, NTS, brownfield) - Real-time calculations using Turf.js

**Distance-Based Insights** - Infrastructure accessibility scoring - Environmental impact assessment - Resource availability analysis - Competitive facility analysis

## 5. Data Management

### 5.1 Data Sources and URLs

**Live Data Endpoints (examples. See excel file for full list)**

AD Plants: https://storage.googleapis.com/moaads\_maps/ad\_plants3.csv  
LAD Boundaries: https://storage.googleapis.com/moaads\_maps/LADS.topojson  
LPA Boundaries: https://storage.googleapis.com/moaads\_maps/LPA.topojson  
LAD Manure Data: https://storage.googleapis.com/moaads\_maps/manure\_by\_LAD\_groups.csv  
LPA Manure Data: https://storage.googleapis.com/moaads\_maps/manure\_by\_LPA\_groups.csv  
Manure Volumes: https://storage.googleapis.com/moaads\_maps/manure\_volumes\_wgs84.topojson  
  
Environmental Layers:  
- AONB: https://storage.googleapis.com/moaads\_maps/AONB.topojson  
- SSSI: https://storage.googleapis.com/moaads\_maps/SSSI.topojson  
- NVZ: https://storage.googleapis.com/moaads\_maps/NVZ2021.topojson  
- Flood Zones: https://storage.googleapis.com/moaads\_maps/Historic\_Flood\_Map.topojson  
- ALC: https://storage.googleapis.com/moaads\_maps/ALC.topojson  
  
Infrastructure Layers:  
- DNO: https://storage.googleapis.com/moaads\_maps/DNO\_fixed.topojson  
- Water Companies: https://storage.googleapis.com/moaads\_maps/water\_companies.topojson  
- Population: https://storage.googleapis.com/moaads\_maps/LADSPopulation2021.topojson  
- Brownfield Land: https://storage.googleapis.com/moaads\_maps/brownfield-land.topojson  
- NTS: https://storage.googleapis.com/moaads\_maps/NTS.kml  
- Roads: https://storage.googleapis.com/moaads\_maps/oproad\_gb.mbtiles

### 5.2 Data Processing Pipeline

**Loading Strategy** - Minimal initial load: Map + LAD layer only - On-demand loading for performance optimization - Automatic data structure detection - Error handling and fallback mechanisms - Progress indicators for large datasets

**Data Validation** - Automatic property name detection - Geometry type validation - Feature count verification - Data integrity checks - Console logging for debugging

### 5.3 Performance Optimization

**Rendering Strategy** - Vector tile optimization for large datasets - Progressive loading for complex geometries - Memory management for 34,855+ features - Layer-based rendering priorities - Viewport-based feature culling

## 6. Technical Implementation Details

### 6.1 Layer Implementation

**Boundary Layers** - Vector polygon rendering - Click-based information retrieval - Highlight on hover functionality - Multiple administrative levels

**Point Layers (AD Plants)** - Clustered rendering at low zoom levels - Individual markers at high zoom levels - Status-based color coding - Capacity-based sizing

**Circle Layers (Brownfield Sites)** - 34,855 Point geometries rendered as circles (not polygons) - 4px radius with stroke outlines (#654321) - Brown fill color (#8B4513) with 0.8 opacity - Click interaction for site details - Fixed rendering issue: Changed from ‘fill’ to ‘circle’ layer type

**Fill Layers (Environmental)** - Polygon fill with opacity control - Outline stroke for boundary definition - Individual toggle controls for ALC grades - Color-coded environmental designations

### 6.2 Interaction Handling

**Click Events** - Multi-layer feature detection - Priority-based panel display - Spatial query execution - Asynchronous data loading

**Search Integration** - Fuse.js fuzzy matching - Real-time filtering - Geographic bounds adjustment - Result highlighting on map

### 6.3 Debug and Development Tools

**Comprehensive Logging** - Layer loading status tracking - Feature count verification - Geometry type detection - Paint property validation - Performance monitoring

**Error Handling** - Graceful degradation for missing data - Network error recovery - User-friendly error messages - Developer debug information

## 9. Future Development Roadmap

### 9.1 Planned Enhancements

**Data Integration** - Additional infrastructure layers - Real-time operational data feeds - Historical trend analysis - Predictive modeling integration

**User Experience** - Advanced filtering controls - Custom layer creation - Data export capabilities - Collaboration features

**Analysis Tools** - Supply chain optimization - Site suitability scoring - Economic impact modeling - Environmental assessment tools

### 9.2 Technical Improvements

**Performance Optimization** - Vector tile implementation - Progressive loading strategies - Client-side caching - WebWorker integration

**Accessibility Enhancement** - Screen reader compatibility - Keyboard navigation - High contrast modes - Alternative input methods

## 10. Deployment and Maintenance

### 10.1 Deployment Architecture

**Replit Platform** - Express.js server on Node.js runtime - Static file serving for frontend assets - Environment variable management - Automatic SSL and domain management

**Development Workflow** - Hot module replacement for development - Automatic server restart on changes - Console logging for debugging - Error monitoring and reporting

### 10.2 Data Maintenance

**Update Procedures** - Google Cloud Storage data synchronization - Automatic schema validation - Data quality monitoring - Version control for datasets

**Monitoring Systems** - Performance tracking - Error logging and alerts - Usage analytics - System health monitoring