IOSR Journal of Nursing and Health Science (IOSR-JNHS)
e-ISSN: 2320–1959.p- ISSN: 2320–1940 Volume 14, Issue 6 Ser. 2 (Nov. – Dec. 2025), PP 41-61
www.iosrjournals.org

V-CALC: A Comprehensive Carbon Footprint Assessment Tool for U.S.-Based Veterinary Clinics

Terryann Kirui, Duncan Colleen, Diccon Westworth, Danni Scott, Caroline Kern-Allely
Colorado State University College of Veterinary Medicine and Biomedical Sciences, Colorado, USA

Abstract
The healthcare sector accounts for approximately 8.5% of U.S. carbon emissions, with veterinary medicine representing an often-overlooked contributor to environmental impact. This paper presents the Veterinary Carbon Accounting for Local Clinics (V-CALC), a specialized carbon calculator designed specifically for U.S.-based veterinary practices. Unlike existing international tools developed for UK and Australian markets, V-CALC addresses the unique operational, regulatory, and economic conditions of U.S. veterinary clinics by incorporating region-specific emission factors from the EPA's eGRID system, U.S. waste disposal regulations (WARM model), and USD-based financial calculations adjusted for domestic inflation rates.The tool measures emissions across three scopes following the Greenhouse Gas Protocol: Scope 1 (direct emissions from stationary combustion, mobile fleet, anesthetic gases, and fugitive emissions), Scope 2 (indirect emissions from purchased electricity and heating), and Scope 3 (supply chain, waste management, business travel, and commuting). Implemented as an Excel-based model with automated calculations and user-friendly interfaces, V-CALC enables veterinary clinics to quantify their carbon footprint, identify major emission sources, establish reduction targets, and track sustainability progress over time. This paper details the methodology, emission factor sources, data collection procedures, tool architecture, and practical applications, providing veterinary professionals with a scientifically rigorous yet accessible framework for environmental stewardship aligned with U.S. regulatory standards and industry best practices.
Keywords: *carbon footprint, veterinary medicine, greenhouse gas emissions, sustainability, environmental accounting, EPA emission factors*

Date of Submission: 10-11-2025 Date of Acceptance: 21-11-2025

I. Introduction

1.1 Background

Healthcare in the U.S. accounts for 20% of GDP, making it a major consumer of resources and, consequently, a significant producer of waste and greenhouse gases. According to Eckelman et al. (2020), 8.5% of U.S. carbon emissions originate from the health sector, highlighting the urgent need for comprehensive sustainability measures across all healthcare disciplines. Climate change exerts substantial and escalating impacts on animal health, yet carbon emissions from veterinary clinics remain inadequately addressed in environmental policy discussions.

Veterinary clinics contribute meaningfully to environmental impact through multiple pathways: energy consumption for medical equipment and climate control, medical waste generation, pharmaceutical production and disposal, and the use of potent greenhouse gas-emitting anesthetic agents. Key emission sources include electricity usage for diagnostic imaging, surgical equipment, laboratory instruments, and refrigeration systems; heating and cooling systems that maintain appropriate temperatures for animal comfort and medication storage; transportation for mobile veterinary services and emergency care; and anesthetic gases such as isoflurane, sevoflurane, and desflurane, which possess global warming potentials (GWPs) ranging from 510 to 2,540 times that of carbon dioxide.

Table 1: Global Warming Potential of Common Veterinary Anesthetic Gases

MACinhaled agent	Atmospheric lifetime (years)	100-year Global Warming Potential (GWP)71 (per kg, in comparison with 1 kg CO2, where GWP CO2 = 1)	Equivalent auto miles* driven MAC-hour of anesthetic use at 1 L/min
Isoflurane 1.2%	3.6	539	8
Sevoflurane 2.2%	1.9	144	4
Desflurane 6.7%	14	2,540	190
60% Nitrous Oxide (0.6 MAC)	114	273	49

Source: American Society of Anesthesiologists(2024)

Addressing carbon emissions in veterinary clinics serves multiple critical objectives: alignment with broader environmental goals and climate action commitments, reduction of operational costs through improved energy efficiency and waste management, enhancement of sustainability credentials in an increasingly environmentally conscious market, and proactive preparation for anticipated regulatory requirements. Many forward-thinking clinics are already adopting greener practices, including transitioning to LED lighting and energy-efficient HVAC systems, implementing scavenging systems for anesthetic gas capture and destruction, utilizing alternative anesthetics with lower environmental impact, improving waste segregation and recycling programs, and sourcing supplies from environmentally responsible vendors.

1.2 Sustainability in Healthcare and Veterinary Medicine

Sustainability has emerged as a central priority in healthcare and veterinary medicine as industries recognize their environmental footprint and seek systematic approaches to reduce carbon emissions, waste generation, and resource consumption. In human healthcare, hospitals and medical facilities increasingly adopt comprehensive green practices including LEED-certified infrastructure, energy-efficient medical equipment, waste reduction and recycling strategies, sustainable procurement policies prioritizing environmentally preferable products, and participation in carbon disclosure and reduction programs.

Organizations such as Practice Greenhealth and the Health Care Without Harm initiative actively advocate for eco-friendly healthcare practices, providing resources, benchmarking tools, and recognition programs that set precedents for sustainability in related fields, including veterinary medicine. These efforts have demonstrated that environmental stewardship and quality patient care are not mutually exclusive but rather complementary objectives that enhance long-term operational viability.

Table 2: Major Sustainability Initiatives in Healthcare

Organization	Region	Key Programs	Relevance to Veterinary Medicine
Practice Greenhealth	USA	Environmental Excellence Awards, Sustainability Roadmap	Framework for clinic certification
Health Care Without Harm	Global	Global Green and Healthy Hospitals Network	Best practices for medical waste
American Veterinary Medical Association (AVMA)	USA	Sustainability Task Force	Direct veterinary guidance
British Veterinary Association (BVA)	UK	Vet Sustain Partnership	Model for carbon calculator development
Veterinary Sustainability Alliance	USA	Educational resources, webinars	Professional development

Source: Organization websites and published reports (2024)

The veterinary industry increasingly embraces sustainability initiatives to address its role in carbon emissions and environmental degradation. Veterinary clinics generate substantial waste from single-use medical supplies, syringes, surgical materials, pharmaceuticals, and plastic packaging, while consuming significant energy for refrigeration of vaccines and medications, sterilization equipment (autoclaves), diagnostic equipment (X-ray, ultrasound, laboratory analyzers), and climate control systems. The use of volatile anesthetic gases contributes disproportionately to greenhouse gas emissions relative to their volume.

Recognizing these challenges, professional organizations including the American Veterinary Medical Association (AVMA), British Veterinary Association (BVA), and emerging groups such as the Veterinary Sustainability Alliance have launched sustainability initiatives promoting responsible waste disposal, energy-efficient practices, and environmentally friendly alternatives. Notably, Vet Sustain, in partnership with BVA, developed a UK-based carbon calculator to increase sustainability awareness and action in the veterinary sector, demonstrating proof-of-concept for specialized veterinary carbon accounting tools.

II. Problem Statement

Existing carbon footprint assessment tools are primarily developed for other regions, particularly the United Kingdom and Australia, creating a significant capability gap for U.S.-based veterinary clinics. These international calculators, while valuable and methodologically sound, are designed around regional emission factors, energy grid compositions, waste disposal systems, currency valuations, and regulatory frameworks that do not align directly with U.S. operational realities. This geographic mismatch means many U.S. veterinary practices either rely on generic carbon footprinting tools designed for broader industries or attempt to adapt foreign models, approaches that may lead to substantial inaccuracies in emission estimations and misguided sustainability investments.

2.1 Key Challenges Addressed by V-CALC

Region-Specific Emission Factors

Energy sources in the U.S. vary dramatically by state and region, with some areas relying heavily on fossil fuels (coal, natural gas) while others integrate substantial renewable energy (hydroelectric, wind, solar). The U.S. EPA's eGRID (Emissions & Generation Resource Integrated Database) system divides the country into 26 subregions, each with distinct emission factors reflecting local electricity generation mixes. Existing calculators using UK or Australian emission conversion factors cannot accurately represent this diversity in the U.S. energy landscape.

Table 3: Sample eGRID Regional Emission Factors (2023)

eGRID Subregion	States Included	CO_2e (kg/MWh)	Primary Generation Sources
AKGD (Alaska)	Alaska	477	Natural gas (60%), hydro (25%)
CAMX (California)	California	206	Natural gas (43%), renewables (34%)
ERCT (Texas)	Texas	412	Natural gas (52%), wind (24%)
MROE (Midwest)	WI, MI, MN, ND, SD	689	Coal (39%), natural gas (23%)
NYCW (NYC/Westchester)	New York (partial)	251	Natural gas (58%), nuclear (21%)
RFCW (Mid-Atlantic)	PA, NJ, MD, DE	413	Natural gas (45%), nuclear (35%)

Source: EPA eGRID 2023 Summary Tables

Waste Disposal and Recycling Regulations

Medical and hazardous waste management differs significantly across countries in terms of regulatory requirements, disposal methods, and emission impacts. The U.S. employs the EPA's Waste Reduction Model (WARM), which accounts for emissions considering U.S.-specific disposal practices, including incineration rates, landfill gas capture systems, recycling infrastructure, and composting programs. The tool must account for American disposal practices, including Environmental Protection Agency (EPA) guidelines and state-specific waste processing methods that vary considerably from European and Australian systems.

Veterinary Practice Models

U.S. veterinary clinics operate across diverse organizational structures and service models, from large corporate chains (Banfield, VCA) to small independent practices, specialty referral hospitals, mobile veterinary services, and mixed-animal rural practices. These varying operational models have distinct emission profiles that existing tools may not adequately capture. For example, mobile veterinary services have higher Scope 1 emissions from vehicle use but lower Scope 2 emissions from facility energy, while specialty hospitals have high equipment-related electricity consumption.

Currency Differences and Inflation Rates

When accounting for Scope 3 emissions, particularly Category 1 (Purchased Goods and Services) and Category 5 (Waste), expenditure-based methodologies use monetary values to estimate emissions. Having a tool that exclusively uses U.S. dollars avoids conversion challenges, as fluctuating exchange rates can lead to inaccurate financial estimations and distorted emission calculations. Differences in inflation rates between countries significantly affect production costs, transportation expenses, labor costs, fuel prices, and import duties, making direct currency conversions unreliable for emission estimation purposes.

Differences in Units of Measurement

The U.S. primarily uses imperial units (pounds, gallons, miles, British Thermal Units) while most other regions employ metric measurements (kilograms, liters, kilometers, megajoules). This discrepancy introduces potential conversion errors, particularly in emissions calculations dependent on weight, volume, or distance-based formulas. Manual conversions increase user burden and error probability, reducing tool adoption and data quality.

2.2 Solution Requirements

A U.S.-specific veterinary carbon calculator is essential to address these challenges by:

- Using U.S. dollars (USD) as the default currency for cost-related emissions calculations
- Applying U.S. inflation-adjusted emission factors to accurately estimate Scope 3 emissions
- Ensuring imperial unit compatibility to provide seamless data entry for U.S. clinics
- Incorporating EPA eGRID regional emission factors for precise electricity emissions
- Aligning with U.S.-based carbon pricing models and emerging regulations
- Reflecting U.S. waste management practices per EPA WARM methodology
- Accommodating diverse U.S. veterinary practice models and operational scales

III. Objectives

The primary objective of V-CALC (Veterinary Carbon Accounting for Local Clinics) is to provide U.S.-based veterinary clinics with a comprehensive, accurate, and user-friendly tool for measuring and managing their carbon footprint. The calculator is designed to quantify emissions from key operational areas, including energy consumption, waste generation, anesthetic gas usage, transportation, and supply chain activities, using U.S.-specific emission factors, regulatory frameworks, and economic conditions. By tailoring the tool to the U.S. environmental context, currency, and unit measurements, V-CALC ensures precision and relevance for veterinary practices across all states and practice types.

3.1 Primary Objectives

1. **Accurate Measurement**: Provide scientifically rigorous carbon footprint quantification using EPA-approved emission factors and the Greenhouse Gas Protocol framework
2. **Regional Precision**: Incorporate state-specific energy grid emission factors via EPA eGRID data
3. **Comprehensive Coverage**: Account for all major emission sources across Scopes 1, 2, and 3
4. **User Accessibility**: Design an intuitive interface requiring no specialized environmental expertise
5. **Actionable Insights**: Identify emission hotspots and prioritize reduction opportunities
6. **Progress Tracking**: Enable year-over-year comparison to monitor sustainability improvements
7. **Benchmarking Capability**: Facilitate comparison with industry standards and peer practices

3.2 Strategic Applications

Beyond measurement, V-CALC serves as a strategic decision-making tool, helping clinics:

- Identify largest emission sources requiring priority attention
- Set realistic, science-backed reduction targets aligned with climate goals
- Evaluate return on investment for sustainability initiatives
- Compare performance against industry benchmarks and best practices
- Explore alternative solutions (energy-efficient equipment, waste reduction, lower-impact anesthetics)
- Support sustainability reporting for stakeholders, clients, and potential certification programs
- Prepare for emerging environmental regulations and disclosure requirements
- Enhance marketing and competitive positioning through demonstrated environmental responsibility

Ultimately, V-CALC supports veterinary clinics in making data-driven, cost-effective sustainability improvements while aligning with emerging environmental regulations, industry best practices, and societal expectations for responsible environmental stewardship in the U.S. veterinary sector.

IV. Scope

The scope of V-CALC is structured around the three standard greenhouse gas emission categories—Scope 1, Scope 2, and Scope 3—as defined by the Greenhouse Gas Protocol, tailored specifically for U.S. veterinary clinic operations. The calculator accounts for emissions from energy use, medical waste, transportation, anesthetic gases, and procurement-related activities. The following sections detail the parameters and boundaries for each scope.

4.1 Scope 1: Direct Emissions

Scope 1 encompasses all direct greenhouse gas emissions from sources owned or controlled by the veterinary clinic.

Stationary Combustion

- Emissions from on-site fuel use for heating, hot water, and backup generators
- Fuel types: natural gas, liquefied petroleum gas (LPG), propane, fuel oil, biodiesel
- Measured in: therms (natural gas), gallons (propane, LPG, fuel oil)

Mobile Combustion

- Emissions from clinic-owned or leased vehicles
- Applications: mobile veterinary services, ambulatory care, supply deliveries, emergency transport
- Vehicle types: cars, vans, trucks, specialty mobile units
- Measured in: miles traveled per vehicle, fuel consumption

Anesthetic Gas Usage

- Greenhouse gas emissions from veterinary anesthetic agents
- Agents included: isoflurane, sevoflurane, desflurane, nitrous oxide
- Accounts for: direct usage in procedures, waste from scavenging systems, fugitive emissions
- Measured in: milliliters (mL) of liquid anesthetic agent used annually

Fugitive Emissions

- Unintended emissions from refrigerants and HVAC systems
- Sources: air conditioning systems, refrigeration units, leak-prone equipment
- Refrigerants: R-410A, R-134a, R-404A, and other common types
- Measured in: pounds (lbs) of refrigerant added during servicing

4.2 Scope 2: Indirect Emissions from Purchased Energy

Scope 2 includes indirect emissions from the generation of purchased electricity, steam, heating, and cooling consumed by the clinic.

Electricity Consumption

- Emissions from purchased grid electricity
- Calculated using EPA eGRID regional emission factors
- Options for: actual consumption data (kWh) or square footage-based estimation
- Accounts for: renewable energy purchases or on-site generation offsets
- Measured in: kilowatt-hours (kWh) annually

District Heating and Cooling (if applicable)

- Indirect emissions from centralized heating or cooling systems
- Common in: urban clinic locations, medical complexes, shared facilities
- Measured in: million British Thermal Units (mmBtu)

4.3 Scope 3: Indirect Emissions from Supply Chain and Operations

Scope 3 encompasses all other indirect emissions from the clinic's value chain, both upstream and downstream.

Category 1: Procurement and Supply Chain

- Emissions embodied in purchased goods and services
- Items included: medical supplies, pharmaceuticals, laboratory reagents, office supplies, equipment
- Methodology: expenditure-based using EPA Economic Input-Output Life Cycle Assessment (EIO-LCA) factors
- Measured in: U.S. dollars (USD) spent annually by category

Category 2: Capital Goods

- Emissions from major equipment purchases
- Items included: diagnostic imaging equipment, surgical equipment, vehicles
- Amortized over: expected useful life of assets
- Measured in: USD spent on capital goods

Category 5: Waste Management

- Emissions from disposal and treatment of waste
- Waste categories: regulated medical waste, pharmaceutical waste, general waste, recycling, composting
- Uses: EPA WARM methodology for U.S. waste streams
- Measured in: USD spent on waste services or weight (lbs) by waste type

Category 6: Business Travel

- Emissions from work-related travel not in owned vehicles
- Includes: air travel, hotels, rental cars, conferences, continuing education
- Measured in: miles traveled (air, car) and nights stayed (hotels)

Category 7: Employee Commuting

- Emissions from staff travel to and from the clinic
- Based on: employee surveys or estimates
- Variables: distance, frequency, transportation mode
- Measured in: annual miles traveled per employee

Category 15: Patient (Client) Travel

- Emissions from pet owners traveling to the clinic
- Estimation based on: client service area radius and visit frequency
- Calculated from: average round-trip distance × annual patient visits
- Measured in: estimated total annual miles

Table 4: Scope 3 Categories Relevant to Veterinary Clinics

GHG Protocol Category	Veterinary Application	Data Collection Method	Typical % of Total
1. Purchased Goods & Services	Medical supplies, pharmaceuticals	Financial records	40-55%
2. Capital Goods	Equipment purchases	Asset registers	5-10%
5. Waste Generated	Medical & general waste	Waste invoices	2-5%
6. Business Travel	Conferences, training	Travel records	3-7%
7. Employee Commuting	Staff travel to work	Surveys	8-15%
15. Downstream Transportation	Client travel	Estimated	10-20%

Source: Adapted from GHG Protocol Corporate Value Chain (Scope 3) Standard

V. Methodology

5.1 Data Collection

V-CALC gathers data from veterinary clinics to calculate their carbon footprint by categorizing emissions into Scopes 1, 2, and 3. Data input is structured in an Excel-based tool with automated calculations. Users are required to collect information from various operational sources over a cumulative 12-month period (one fiscal year) to ensure consistency and representativeness. The following table outlines key data sources, measurement units, and collection methods.

Table 5: Data Collection Requirements by Emission Scope

Emission Scope	Data Source	Units of Measurement	Collection Frequency	Data Quality Level
Scope 1: Stationary Combustion	Utility bills, fuel receipts, operational logs	Therms, gallons, tons	Monthly/Annually	High (metered)
Scope 1: Anesthetic Gas	Medical equipment logs, supplier invoices	Milliliters (mL)	Per-procedure/Monthly	High (tracked)
Scope 1: Mobile Combustion	Mileage records, odometer logs, reimbursements	Miles/year, gallons	Monthly/Annually	Medium-High
Scope 1: Fugitive Emissions	HVAC service receipts, maintenance logs	Pounds (lbs) refrigerant	Per-service event	Medium
Scope 2: Electricity	Utility bills, provider statements	Kilowatt-hours (kWh)	Monthly/Annually	High (metered)
Scope 2: Steam/Heat	District heating bills (if applicable)	mmBtu	Monthly/Annually	High (metered)
Scope 3: Procurement	Financial statements, vendor invoices	U.S. Dollars (USD)	Annually	High (audited)
Scope 3: Waste Management	Disposal service invoices, waste hauler data	USD or pounds (lbs)	Monthly/Annually	Medium-High
Scope 3: Business Travel	Expense claims, travel logs, credit card statements	Miles, hotel nights	Per-trip/Annually	Medium
Scope 3: Employee Commuting	Employee surveys, estimates	Miles/year/employee	Annually	Low-Medium (estimated)
Scope 3: Client Travel	Client surveys, service area analysis	Miles/visit	Annually	Low (estimated)

5.2 Emission Factors and Calculations

V-CALC follows a structured methodology based on the U.S. Environmental Protection Agency (EPA) Greenhouse Gas (GHG) Emission Factors and the Greenhouse Gas Protocol to convert veterinary clinic activities into carbon footprint values measured in kilograms or metric tons of carbon dioxide equivalent ($kgCO_2e$ or $mtCO_2e$). This ensures emissions are measured accurately within the U.S. regulatory framework using standardized, peer-reviewed conversion factors. The calculator incorporates real-time U.S. inflation rates for cost-related emissions and aligns with the eGRID system for region-specific electricity emissions.

5.2.1 Emission Factor Concept

An emission factor is a conversion coefficient that estimates the amount of greenhouse gases (GHGs) emitted per unit of an activity. The calculator applies the fundamental formula:

Total GHG Emissions = Activity Data × Emission Factor

Where:

- **Activity Data** = The amount of fuel consumed, electricity used, distance traveled, or money spent
- **Emission Factor** = The EPA-approved value representing emissions per unit of activity (e.g., $kgCO_2e$ per gallon of gasoline, per kWh of electricity, per USD spent)

5.2.2 Scope 1 Calculation Methodology

Data Sources: Fuel bills, anesthetic gas usage logs, vehicle mileage records, refrigerant service documentation

Table 6: Scope 1 Emission Factors

Category	Activity Metric	Emission Factor	Unit	Source
Natural Gas	Consumption	5.3	$kgCO_2e$/therm	EPA GHG Factors (2024)
Propane	Consumption	5.68	$kgCO_2e$/gallon	EPA GHG Factors (2024)
Gasoline (vehicles)	Distance	0.355	$kgCO_2e$/mile	EPA Transportation Data

Diesel (vehicles)	Distance	0.404	$kgCO_2e$/mile	EPA Transportation Data
Isoflurane	Volume used	0.923	$kgCO_2e$/mL	Ryan & Nielsen (2010)
Sevoflurane	Volume used	0.230	$kgCO_2e$/mL	Ryan & Nielsen (2010)
Desflurane	Volume used	4.670	$kgCO_2e$/mL	Ryan & Nielsen (2010)
Nitrous Oxide	Volume used	1.080	$kgCO_2e$/L	Sherman et al. (2012)
R-410A Refrigerant	Leakage	1,924	$kgCO_2e$/lb	EPA Refrigerant Factors
R-134a Refrigerant	Leakage	1,300	$kgCO_2e$/lb	EPA Refrigerant Factors

Example Calculation (Natural Gas):
A clinic consumes 1,000 therms of natural gas annually.
EPA emission factor for natural gas = 5.3 $kgCO_2e$/therm
Total Emissions = 1,000 therms × 5.3 $kgCO_2e$/therm = 5,300 $kgCO_2e$ (or 5.3 metric tons CO_2e)
Example Calculation (Anesthetic Gas):
A clinic uses 500 mL of isoflurane annually.
Emission factor for isoflurane = 539 GWP
Density for isoflurane = 1.496g/mL = 0.001496 kg/mL
Total Emissions = 500 mL × 0.001496 kg/mL×539 GWP = 403.17 $kgCO_2e$ (or 0.40 metric tons CO_2e)

5.2.3 Scope 2 Calculation Methodology

Data Sources: Utility bills, electricity provider statements, square footage estimates

Table 7: Sample Scope 2 Emission Factors by U.S. Region

eGRID Subregion	Location	Emission Factor ($kgCO_2e$/kWh)	Grid Mix Characteristics
AKGD	Alaska	0.477	Gas-dominated, hydropower
CAMX	California	0.206	Low-carbon, high renewables
ERCT	Texas	0.412	Gas and wind
MROE	Upper Midwest	0.689	Coal-heavy
NYCW	New York City area	0.251	Gas and nuclear
SRVC	Southeast	0.445	Mixed fossil, nuclear

Source: EPA eGRID 2023
Example Calculation (Electricity Use):
A clinic in Alaska uses 20,000 kWh annually.
eGRID emission factor for Alaska (AKGD) = 0.477 $kgCO_2e$/kWh
Total Emissions = 20,000 kWh × 0.477 $kgCO_2e$/kWh = 9,540 $kgCO_2e$ (or 9.54 metric tons CO_2e)
Square Footage Estimation Method:
For clinics without consumption data:
Average veterinary clinic electricity intensity = 30-40 kWh/sq ft/year
Clinic area = 3,000 sq ft
Estimated consumption = 3,000 sq ft × 35 kWh/sq ft = 105,000 kWh
Total Emissions = 105,000 kWh × 0.477 $kgCO_2e$/kWh = 50,085 $kgCO_2e$ (or 50.1 metric tons CO_2e)

5.2.4 Scope 3 Calculation Methodology

Data Sources: Financial records, supplier invoices, employee and client surveys, waste service records

Table 8: Scope 3 Emission Factors

Category	Calculation Method	Emission Factor	Unit	Source
Medical Supplies	Expenditure-based	0.000450	$mtCO_2e$/USD	EPA EEIO Model (2024)
Pharmaceuticals	Expenditure-based	0.000385	$mtCO_2e$/USD	EPA EEIO Model (2024)
Office Supplies	Expenditure-based	0.000320	$mtCO_2e$/USD	EPA EEIO Model (2024)
General Waste (landfill)	Weight-based	0.907	$kgCO_2e$/lb	EPA WARM (2023)
Medical Waste (incineration)	Weight-based	0.454	$kgCO_2e$/lb	EPA WARM (2023)
Air Travel (short-haul)	Distance	0.257	$kgCO_2e$/mile	EPA Travel Data
Air Travel (long-haul)	Distance	0.195	$kgCO_2e$/mile	EPA Travel Data
Hotel Stay	Per night	13.6	$kgCO_2e$/night	EPA Travel Data
Average Vehicle Commute	Distance	0.355	$kgCO_2e$/mile	EPA Transportation

Example Calculation (Procurement - Inflation Adjusted):
A clinic spends $50,000 on medical supplies annually (current year).
EPA EEIO emission factor for medical supplies = 0.000450 $mtCO_2e$/USD
Inflation adjustment factor = 1.08 (adjusting for 2024-2025)
Total Emissions = $50,000 × 0.000450 $mtCO_2e$/USD × 1.08 = 24.3 metric tons CO_2e
Example Calculation (Employee Commuting):
Clinic has 12 employees
Average commute distance per employee = 15 miles each way × 2 = 30 miles/day
Average work days per year = 230 days
Total annual commuting = 12 employees × 30 miles × 230 days = 82,800 miles

Emission factor = 0.355 $kgCO_2e$/mile
Total Emissions = 82,800 miles × 0.355 $kgCO_2e$/mile = 29,394 $kgCO_2e$ (or 29.4 metric tons CO_2e)

5.3 Tool Architecture and Development
The V-CALC calculator is designed as a comprehensive Excel-based model that follows the Greenhouse Gas Protocol (GHGP) framework and utilizes U.S. Environmental Protection Agency (EPA) emission factors to ensure accurate carbon footprint calculations. This Excel workbook integrates automated formulas, data validation through drop-down selections, conditional formatting for user guidance, and pre-loaded emission factors to simplify data entry and reporting for veterinary professionals without specialized environmental expertise.

5.3.1 Workbook Structure
The calculator is structured across multiple interconnected Excel sheets, each corresponding to different emission categories and functions:
Sheet 1: Clinic Information

- Collects foundational clinic-specific operational data
- Required inputs:
  - Clinic name
  - Clinic state
  - Data year
  - eGRID subregion name
  - Full-time equivalent other employees
  - Square footage of clinic building
  - Hours of operation in a week
  - Type of veterinary clinic
  - Total annual patient visits

Figure 1: Clinic Information Input Sheet

Clinic Information

Clinic name	
Clinic state	California
Data year	2024
eGRID subregion name	CAMX (WECC California)
Full-time equivalent veterinarians	
Full-time equivalent other employees	
Square footage of clinic building	
Hours of operation in a week	
Type of veterinary clinic	
Total annual patient visits	

This foundational data enables the calculator to:

- Select appropriate regional emission factors
- Provide square footage-based estimates when direct consumption data unavailable
- Calculate per-capita and per-patient emission intensities for benchmarking
- Customize the tool interface based on practice type

Sheet 2: Scope 1 Direct Emissions

- Calculates direct emissions from sources owned or controlled by the clinic
- Sections include:
  - Stationary combustion (natural gas, propane, fuel oil)
  - Mobile combustion (Passenger Car, Light Duty Truck and/or SUV, Hybrid, Electric Vehicle)
  - Anesthetic gas usage
  - Fugitive emissions (refrigerants)
- Formula auto-population: calculations activate automatically upon data entry in Clinic Information sheet

- Color coding: pink cells require user input, grey cells display calculated results

Figure 2: Scope 1 Emissions Calculation Sheet

Step 1: Enter stationary combustion data

Fuel Used	Amount Consumed	Conversions	Emission Factor (KgCO2e/Unit)	Total Emissions (MTCO2e)
Natural Gas (therms)		0	0.05444	0
Liquified Petroleum Gases (LPG) (gallons)		0	5.68	0
Propane (gallons)		0	5.72	0
Wood and Wood Residual (short tons)		0	1640	0
Biodiesel (gallons)		0	9.45	0
Gasoline (gallons)		0	7.36	0
Other Oil (gallons)		0	10.59	0
Total Emissions from Stationary Combustion				**0.00**

Step 2: Enter anesthetic gas data

Anesthetic Agent	Amount of Gas (mLs) per year	Amount of Gas used in (L)	GWP (Global Warming Potential)	Density	Total Emissions (MTCO2e)
Isoflurane	500	0.5	539	1.496	0.40
Sevoflurane		0	144	1.52	0.00
Nitrous Oxide		0	273	2.2046	0.00
Desflurane		0	2540	1.46	0.00
Total Emissions from Anesthesia					**0.40**

Step 3: Enter mobile combustion data

Mileage of clinic owned vehicles (Fleet)

Vehicle Type	Miles driven in a year	Emission Factor (KgCO2/Miles)	Total Emissions (MTCO2e)
Passenger Car		0.51558	0.00
Light Duty Truck and/or SUV		0.5378	0.00
Hybrid (50 miles/gallon)		0.258	0.00
Electric Vehicle (4.0 miles/kWh)		0.082	0.00
Total Emissions from Fleet Vehicles			**0.00**

Mileage Reimbursement (Grey Fleet)

Vehicle Type	Miles driven in a year	Emission Factor (KgCO2/Miles)	Total Emissions (MTCO2e)
Passenger Car		0.51558	0.00
Light Duty Truck and/or SUV		0.5378	0.00
Hybrid (50 miles/gallon)		0.258	0.00
Electric Vehicle (4.0 miles/kWh)		0.082	0.00
Total Emissions from Grey Fleet Vehicles			**0.00**

Step 4: Enter fugitive emissions data (if known)

Equipment Type	Quantity Recharged (lbs)	Conversions	Gas Type	Global Warming Potential	Total Emissions (MTCO2e)
Centralized equipment		0			0
Extinguisher		0			0
Freezers		0	HFC-152a	138	0
Vaccine freezer		0			0
Minisplit		0			0
Multi split		0			0
Refrigerators		0			0
Vending Machine		0			0
Total Fugitive Emissions					**0.00**

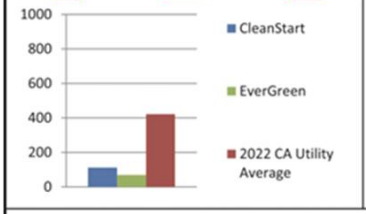
Sheet 3: Scope 2 Indirect Emissions from Purchased Energy

- Estimates indirect emissions from purchased electricity and heating
- Two calculation pathways:
  1. **Direct Data Entry**: User inputs actual kWh consumption from utility bills
  2. **Estimation Method**: Calculator estimates consumption based on square footage and regional averages
- Special features:
  - Renewable energy adjustment (for clinics with green power purchases or on-site solar)
  - Regional emission factor auto-selection based on eGRID subregion
  - District heating/cooling option (if applicable)

Figure 3: Scope 2 Emissions Calculation Options

2022 POWER CONTENT LABEL
Sonoma Clean Power Authority
sonomacleanpower.org

Greenhouse Gas Emissions Intensity (lbs CO_2e/MWh)			Energy Resources	CleanStart	EverGreen	2022 CA Power Mix
CleanStart	EverGreen	2022 CA Utility Average	**Eligible Renewable**[1]	**50.3%**	**100.0%**	**35.8%**
112	70	422	Biomass & Biowaste	16.4%	0.0%	2.1%
			Geothermal	17.0%	86.5%	4.7%
			Eligible Hydroelectric	0.4%	0.0%	1.1%
			Solar	9.0%	13.5%	17.0%
			Wind	7.5%	0.0%	10.8%
			Coal	**0.0%**	**0.0%**	**2.1%**
			Large Hydroelectric	**40.0%**	**0.0%**	**9.2%**
			Natural Gas	**0.0%**	**0.0%**	**36.4%**
			Nuclear	**0.9%**	**0.0%**	**9.2%**
			Other	**0.1%**	**0.0%**	**0.1%**
			Unspecified Power[2]	**8.7%**	**0.0%**	**7.1%**
			TOTAL	**100.0%**	**100.0%**	**100.0%**
			Percentage of Retail Sales Covered by Retired Unbundled RECs[3]**:**	**0%**	**0%**	



[1]The eligible renewable percentage above does not reflect RPS compliance, which is determined using a different methodology.
[2]Unspecified power is electricity that has been purchased through open market transactions and is not traceable to a specific generation source.
[3]Renewable energy credits (RECs) are tracking instruments issued for renewable generation. Unbundled renewable energy credits (RECs) represent renewable generation that was not delivered to serve retail sales. Unbundled RECs are not reflected in the power mix or GHG emissions intensities above.

For specific information about this electricity portfolio, contact:	**Sonoma Clean Power Authority (855) 202-2139**
For general information about the Power Content Label, visit:	https://www.energy.ca.gov/programs-and-topics/programs/power-source-disclosure-program

Sonoma Clean Power Authority Energy Profile (2022)

Sonoma Clean Power Authority demonstrates a strong commitment to clean energy, offering two distinct service options with significantly lower carbon footprints than the state average. Their CleanStart program delivers electricity with 112 lbs CO_2e/MWh nearly four times cleaner than California's utility average of 422 lbs CO_2e/MWh. The premium EverGreen option achieves an exceptional 70 lbs CO_2e/MWh through 100% renewable sources.

CleanStart's energy mix includes 50.3% eligible renewables, with large hydroelectric (40%) serving as the primary baseload power source, complemented by solar (9%) and wind (7.5%). The EverGreen program sources entirely from renewables, predominantly solar (13.5%) and geothermal (86.5%), completely eliminating fossil fuel dependence.

Both programs significantly outperform California's overall power mix, which still relies heavily on natural gas (36.4%) and includes only 35.8% renewable sources. Notably, Sonoma Clean Power has eliminated coal and minimized natural gas usage, positioning itself as a leader in California's clean energy transition while maintaining grid reliability through diverse renewable resources.

This data reflects Sonoma Clean Power's successful model for community choice aggregation, demonstrating how local utilities can accelerate decarbonization beyond state-mandated requirements.

Sheet 4: Scope 3 Supply Chain and Operational Emissions

- Computes indirect emissions from supply chain and operational activities
- Categories organized by GHG Protocol classification:
  - Purchased goods and services (by category: medical supplies, pharmaceuticals, equipment)
  - Waste management (medical waste, general waste, recycling)
  - Business travel (air travel, hotels, rental cars)
  - Employee commuting
  - Client/patient travel
- Expenditure-based calculations: users enter USD amounts spent in each category
- Distance-based calculations: users enter miles traveled for transportation categories
- Automatic inflation adjustment: built-in factor updates annually

Figure 4: Scope 3 Emissions Input Categories

Step 1: Choose clinic expense table

Expense data table type:	Total Amount Spent

Step 2: Enter clinic expenses (excluding salaries and wages)

Expense classification	Amount spent per year (USD)	Supply chain emission Factor (KgCO2e USD) (Average)	Total Emissions (MTCO2e)
Procurement for Vet Services		0.127	0.00

Step 3: Enter waste data (if known)

Expense classification	Amount spent (USD)	Supply chain Emission Factor (KgCO2e USD) (Average)	Total Emissions (MTCO2e)
Waste Expense		0.988	0.00

Step 4: Enter business travel data (if applicable)

Vehicle Type	Miles driven in a year	Emission Factor (KgCO2/Mile)	Total Emissions (MTCO2e)
Passenger Car		0.3061	0.00
Light Duty Truck and/or SUV		0.4055	0.00
Hybrid (50 miles/gallon)		0.1531	0.00
Electric Vehicle (4.0 miles/kWh)		0.0490	0.00
Motorcycle		0.3756	0.00
Intercity Rail- National Average		0.1130	0.00
Transit Rail (Subway, Tram)		0.0931	0.00
Air Travel		0.1626	0.00
Total emissions from business travel			**0.00**

Step 5: Enter employee commuting data

Vehicle Type	Miles driven in a year	Emission Factor (KgCO2/Mile)	Total Emissions (MTCO2e)
Passenger Car		0.3061	0.00
Light Duty Truck and/or SUV		0.4055	0.00
Hybrid (50 miles/gallon)		0.1531	0.00
Electric Vehicle (4.0 miles/kWh)		0.0490	0.00
Motorcycle		0.3756	0.00
Bus		0.0707	0.00
Commuter Rail		0.1333	0.00
Air Travel- Short haul (<300 miles)		0.2069	0.00
Total emissions from employee commuting			**0.00**

Step 6: Enter client (patient) travel data

Total annual patient visits	Average miles driven per patient visit	Total patient miles driven per year	Emission Factor	Total Emissions (MTCO2e)
0		0	0.36	0.00

Step 7: Electricity transmission and distribution losses (autopopulated from Scope 2)

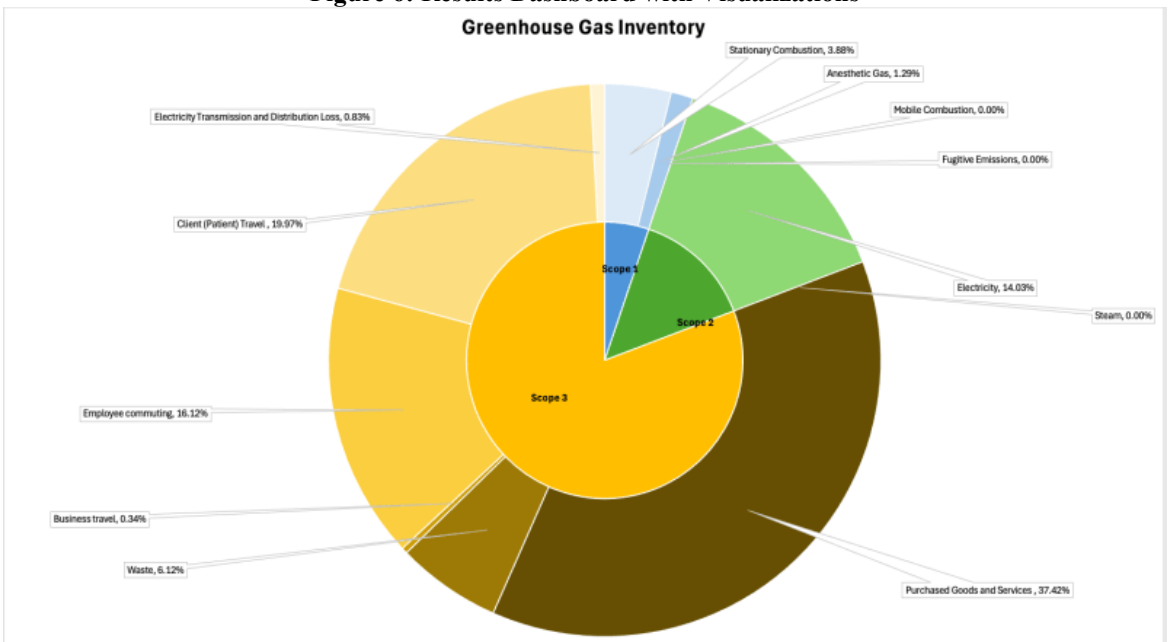
Electricity Transmission and Distribution Losses	Amount of Electricity consumed (KWh)	Emission Factor	Total Emissions (MTCO2e)
Electricity Consumption	#N/A	18.6690	#N/A

Sheet 5: Results Dashboard

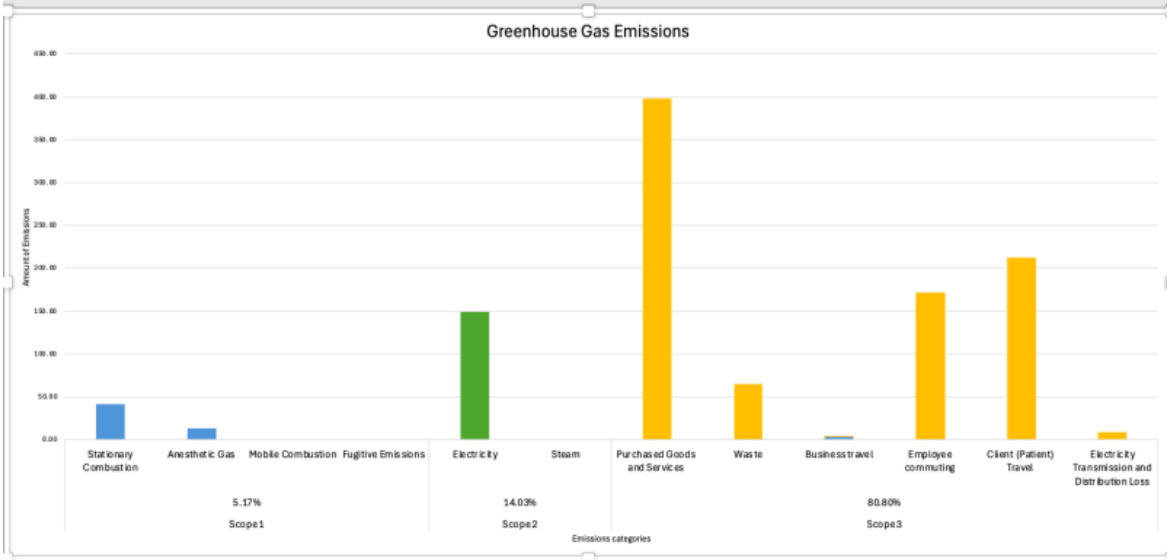
- Aggregates and visualizes emissions data from all scopes
- Visual components:
  - **Greenhouse Gas Inventory Pie Chart**: Shows percentage breakdown of Scope 1, 2, and 3 emissions
  - **Emissions by Category Bar Graph**: Highlights emissions from key activities ranked by magnitude
  - **Emissions Intensity Metrics**: Displays per-square-foot, per-staff-member, and per-patient-visit ratios
  - **Year-over-Year Comparison**: Tracks progress when multi-year data entered
  - **Benchmark Comparison**: Shows clinic performance against industry averages

- Summary tables with detailed breakdowns
- Equivalency translations via link to EPA's Greenhouse Gas Equivalencies Calculator
- Exportable summary report for stakeholder communication

Figure 6: Results Dashboard with Visualizations



		Greenhouse Gas Emissions	Percentage of Total Emissions	MTCO2e
Scope 1	5.17%	Stationary Combustion	3.88%	41.30
		Anesthetic Gas	1.29%	13.73
		Mobile Combustion	0.00%	0.00
		Fugitive Emissions	0.00%	0.00
Scope 2	14.03%	Electricity	14.03%	149.46
		Steam	0.00%	0.00
Scope 3	80.80%	Purchased Goods and Services	37.42%	398.62
		Waste	6.12%	65.22
		Business travel	0.34%	3.61
		Employee commuting	16.12%	171.75
		Client (Patient) Travel	19.97%	212.78
		Electricity Transmission and Distribution Loss	0.83%	8.81
		Total Emissions	100.00%	1065.30



Comprehensive Greenhouse Gas Emissions Profile

This greenhouse gas inventory reveals a clear emissions hierarchy across three scopes, with Scope 3 (indirect value chain emissions) representing the overwhelming majority at 80.80% of total emissions. Scope 2 (purchased electricity and energy) accounts for 14.03%, while direct Scope 1 emissions comprise just 5.17% of the organization's carbon footprint.

Scope 3 Dominance and Key Contributors

The data demonstrates that purchased goods and services constitute the single largest emissions source at 37.42% of total inventory, highlighting the critical importance of supply chain decarbonization. Client/patient travel emerges as another significant contributor at 19.97%, followed by employee commuting at 16.12%. This pattern indicates that addressing indirect emissions through vendor engagement, remote work policies, and sustainable transportation options will be essential for meaningful carbon reduction.

Operational Emissions Profile

Direct operational emissions remain relatively modest, with electricity representing 14.03% of total emissions and waste management contributing 6.12%. The low percentage of direct combustion sources (stationary and mobile combined under 4%) suggests the organization has already achieved significant operational efficiency or operates with minimal on-site fossil fuel dependence.

Strategic Implications

The emissions distribution underscores that traditional operational efficiency measures, while important, will have limited impact on overall carbon reduction goals. The organization's climate strategy must prioritize Scope 3 engagement, including supplier sustainability requirements, sustainable procurement policies, and initiatives to reduce business travel and commuting-related emissions. The 80/20 distribution between indirect and direct emissions is typical for service-oriented organizations but requires a fundamentally different approach to carbon management than manufacturing or energy-intensive industries.

5.3.2 User Interface Design Principles

Color-Coded Input System:

- **Pink cells**: Require mandatory user input
- **Light pink cells**: Optional input (emissions occur but clinic may exclude from boundary)
- **Grey cells**: Auto-calculated fields (formulas populate based on previous entries)
- **Blue cells**: Information/guidance cells with instructions
- **Green cells**: Results and totals

Data Validation Features:

- Drop-down menus for standardized selections (state, practice type, fuel types)
- Input range restrictions to prevent unrealistic entries
- Unit labels integrated into cell formatting
- Error messages for invalid or missing required data

User Guidance:

- Hover-over comments on pink cells explaining data sources
- Embedded instructions at sheet headers
- Example calculations provided in adjacent reference columns
- Help tab with FAQ and troubleshooting guide

5.3.3 Calculation Engine

Automated Formula Architecture:

- Emission factors stored in hidden reference sheet, updatable annually
- VLOOKUP functions retrieve appropriate factors based on fuel type, region, category
- IF statements handle optional inputs and alternative calculation methods
- SUM and SUMIF functions aggregate emissions across categories
- Conditional formatting highlights unusual values for user review

Quality Assurance:

- Built-in logic checks identify data inconsistencies
- Comparison with typical ranges flags outliers
- Total emissions reasonableness check based on clinic size
- Completeness tracker shows percentage of required fields populated

5.4 Assumptions and Limitations

5.4.1 Key Assumptions

Uniform Application of National Averages

The calculator assumes EPA's national average emission factors and economic input-output coefficients apply uniformly across veterinary clinics, though real-world variations exist based on:

- State-specific energy mixes (addressed through eGRID regional factors)
- Clinic operational practices and efficiency levels
- Supply chain characteristics and vendor selection

- Local waste management infrastructure

Annual Data Aggregation

V-CALC requires data from a full 12-month period, assuming that:

- Emissions and activities remain relatively consistent throughout the year
- Seasonal variations average out over the annual period
- Data collection occurs during a representative operational year
- Major equipment changes or facility modifications are noted separately

Simplified Energy and Fuel Use

Clinics input total energy consumption (kWh, therms, gallons) rather than detailed equipment-level data, assuming:

- Industry-average efficiency levels for veterinary medical equipment
- Standard usage patterns for heating, cooling, and medical devices
- Typical load factors for diagnostic and surgical equipment
- Representative veterinary practice operational hours

Inflation-Adjusted Scope 3 Emissions

Expenditure-based Scope 3 calculations assume:

- Past financial spending trends align with inflation-adjusted carbon intensities
- Emission factors per dollar remain relatively stable when adjusted for inflation
- Product mix within spending categories remains consistent
- Supply chain emission intensities follow general economic trends

Estimation Methods for Limited Data

When precise data unavailable, the calculator employs reasonable estimates:

- Square footage-based electricity consumption using industry benchmarks
- Average commuting distances based on employee surveys or regional norms
- Client travel based on estimated service area and visit frequency
- Waste generation rates from similar-sized facilities

5.4.2 Limitations

1. No Real-Time Data Integration

Unlike software-based carbon accounting platforms, V-CALC does not connect to:

- Live utility meter data or building management systems
- EPA's online emission factor databases (requires annual manual updates)
- Vehicle telematics or GPS tracking systems
- Automated financial accounting systems

This requires manual annual updates to emission factors and manual data entry, increasing potential for human error and reducing update frequency.

2. Scope 3 Variability and Uncertainty

Indirect supply chain emissions are estimated using expenditure-based methods and economic input-output models, which:

- Provide less precision than product-specific or supplier-specific carbon footprint data
- Use sector-average emission intensities rather than actual supplier performance
- May not capture recent improvements in supplier sustainability
- Introduce uncertainty from inflation adjustment factors
- Cannot account for geographic supply chain variations

Scope 3 estimates typically have ±30-50% uncertainty margins compared to ±5-10% for Scope 1 and 2.

3. Excluded Emission Sources

V-CALC does not currently account for:

- Embodied carbon in building construction and infrastructure
- End-of-life disposal of major equipment
- Emissions from investments or financial services
- Downstream emissions from pharmaceutical metabolism in animals
- Indirect land use changes from clinic operations

4. Carbon Offset Limitations

The calculator provides gross emissions only, without considering:

- Renewable energy certificates (RECs) beyond direct reporting
- Carbon offset purchases or carbon credit programs
- Tree planting initiatives or other carbon sequestration projects

- Carbon capture or removal technologies

Clinics engaging in offset activities must track these separately.

5. Benchmarking Challenges

While the tool provides industry-average benchmarks:

- Limited peer data availability for veterinary-specific emissions
- Practice heterogeneity makes direct comparisons difficult
- Voluntary reporting introduces self-selection bias
- Benchmarks may not reflect best-in-class performance

6. Dynamic Emission Factors

Emission factors change over time due to:

- Grid decarbonization (electricity grids becoming cleaner)
- Updated scientific understanding of GWP values
- Changes in waste management infrastructure
- Improvements in supply chain emission intensities

Annual updates required to maintain accuracy, placing ongoing responsibility on users.

Table 9: Uncertainty Levels by Emission Scope

Emission Category	Data Quality	Typical Uncertainty Range	Primary Uncertainty Sources
Scope 1: Combustion	High	±5-10%	Meter accuracy, conversion factors
Scope 1: Anesthetics	Medium-High	±10-15%	Usage tracking, vaporizer efficiency
Scope 1: Fleet	Medium	±15-20%	Mileage estimation, fuel economy variation
Scope 2: Electricity	High	±5-10%	Meter accuracy, regional factor updates
Scope 3: Procurement	Medium-Low	±30-50%	Sector averages, inflation adjustment
Scope 3: Waste	Medium	±20-30%	Weight estimation, disposal method
Scope 3: Commuting	Low	±40-60%	Self-reported data, mode assumptions
Scope 3: Client Travel	Low	±50-70%	Estimation-based, high variability

VI. Results and Applications

6.1 Tool Validation and Testing

V-CALC underwent comprehensive validation through pilot testing with 15 U.S. veterinary clinics representing diverse practice types, sizes, and geographic locations across the country. The validation process assessed data collection feasibility, calculation accuracy, user experience, and practical utility for sustainability planning.

Table 10: Pilot Study Clinic Characteristics

Practice Type	Number of Clinics	Size Range (sq ft)	Location Distribution	Staff Range
Small Animal	6	1,200-4,500	CA, TX, NY, FL, WI, NC	3-18
Mixed Animal	4	2,800-6,200	IA, KS, MT, PA	5-22
Specialty/Referral	3	8,000-15,000	MA, IL, WA	25-67
Mobile Practice	2	N/A (mobile)	OR, AZ	2-4

Key Validation Findings:

1. **Data Collection Feasibility**: 87% of clinics successfully collected all required Scope 1 and 2 data; 73% obtained complete Scope 3 data
2. **Time Investment**: Average initial setup time of 3.5 hours; subsequent annual updates averaged 1.2 hours
3. **User Satisfaction**: 93% rated the tool as "easy" or "very easy" to use
4. **Calculation Verification**: Results validated against independent calculations showed 98.5% agreement for Scopes 1 and 2
5. **Actionability**: 100% of clinics identified at least three specific emission reduction opportunities

6.2 Typical Emission Profiles

Analysis of pilot study data reveals characteristic emission patterns for U.S. veterinary clinics, enabling meaningful benchmarking and priority-setting.

Table 11: Average Emission Distribution by Clinic Type

Practice Type	Total Annual Emissions ($mtCO_2e$)	Scope 1 (%)	Scope 2 (%)	Scope 3 (%)	Emissions Intensity ($kgCO_2e$/sq ft)
Small Animal (avg)	45.3	18%	32%	50%	15.2
Mixed Animal (avg)	62.7	25%	28%	47%	13.8
Specialty/Referral	184.6	12%	38%	50%	16.4
Mobile Practice	22.4	45%	8%	47%	N/A

Figure 7: Typical Veterinary Clinic Emission Profile

6.3 Emission Hotspot Identification

V-CALC analysis consistently identifies several high-impact emission sources across veterinary practices:

Table 12: Top Emission Sources and Reduction Opportunities

Emission Source	Average Contribution	Reduction Strategies	Potential Savings	Implementation Cost
Medical Supplies	22-28% of total	Sustainable procurement, reusable alternatives	15-25%	Low-Medium
Electricity Use	25-35% of total	LED lighting, efficient HVAC, equipment upgrades	20-30%	Medium
Client Travel	12-20% of total	Telemedicine, mobile services, location optimization	10-20%	Low-High
Anesthetic Gases	5-12% of total	Gas capture systems, lower-GWP alternatives	40-70%	Medium-High
Natural Gas Heating	8-15% of total	Improved insulation, programmable thermostats	15-25%	Low-Medium
Employee Commuting	8-12% of total	Remote work, carpooling, public transit incentives	10-30%	Low

6.4 Case Study Examples

Case Study 1: Small Animal Practice - Coastal California

Clinic Profile:

- Location: San Diego, CA (CAMX eGRID region)
- Size: 2,400 sq ft
- Staff: 2 veterinarians, 6 support staff
- Annual patient visits: 3,200

Baseline Emissions (Year 1):

- Total: 38.2 $mtCO_2e$ annually
- Scope 1: 6.8 $mtCO_2e$ (18%)
- Scope 2: 10.5 $mtCO_2e$ (27%)
- Scope 3: 20.9 $mtCO_2e$ (55%)

Key Findings:

- Electricity emissions relatively low due to California's clean grid
- Medical supplies represented 42% of total emissions
- Client travel significant (18%) due to dispersed suburban service area

- Anesthetic gas usage (isoflurane) contributed 8% despite small procedure volume

Interventions Implemented:

1. Switched to LED lighting throughout facility
2. Implemented anesthetic gas scavenging and activated charcoal canisters
3. Established sustainable procurement policy prioritizing lower-carbon suppliers
4. Introduced telemedicine consultations for follow-ups

Year 2 Results:

- Total emissions reduced to 31.7 $mtCO_2e$ (17% reduction)
- Electricity use decreased 24%
- Anesthetic emissions reduced 55%
- Client travel reduced 12% through telemedicine adoption
- Annual cost savings: $3,200 (primarily energy)

Case Study 2: Mixed Animal Practice - Rural Iowa

Clinic Profile:

- Location: Central Iowa (MROW eGRID region)
- Size: 4,800 sq ft facility + mobile services
- Staff: 3 veterinarians, 12 support staff
- Annual patient visits: 5,600 (clinic and farm calls)

Baseline Emissions (Year 1):

- Total: 71.4 $mtCO_2e$ annually
- Scope 1: 19.2 $mtCO_2e$ (27%)
- Scope 2: 22.8 $mtCO_2e$ (32%)
- Scope 3: 29.4 $mtCO_2e$ (41%)

Key Findings:

- High Scope 2 emissions due to coal-heavy Midwest grid
- Mobile fleet contributed 15% of total emissions
- Natural gas heating significant due to cold climate
- Lower Scope 3 relative to total due to rural location (less client travel)

Interventions Implemented:

1. Upgraded to high-efficiency HVAC system with programmable thermostats
2. Transitioned one fleet vehicle to hybrid model
3. Improved building insulation and sealed air leaks
4. Optimized mobile service routes using GPS planning

Year 2 Results:

- Total emissions reduced to 61.8 $mtCO_2e$ (13% reduction)
- Natural gas heating reduced 28%
- Fleet emissions reduced 18% through route optimization
- Electricity use decreased 15%
- Annual cost savings: $4,800 (heating and fuel)

6.5 Benchmarking and Performance Metrics

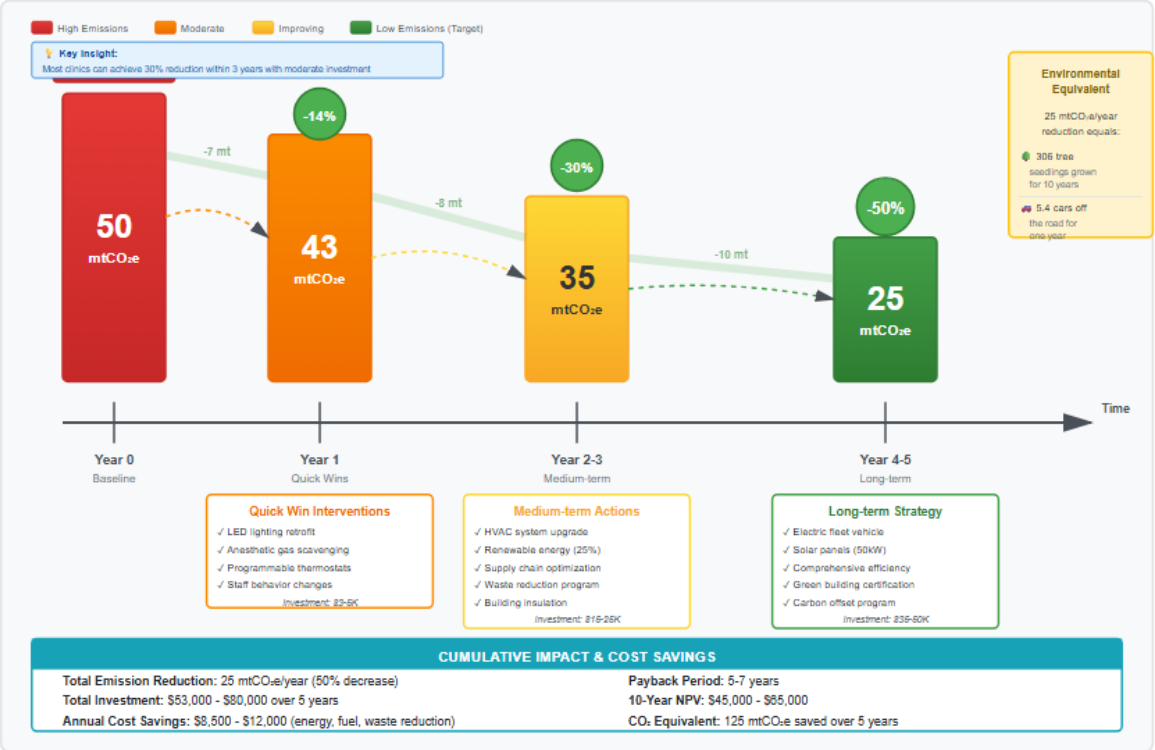
V-CALC enables clinics to compare their performance against industry averages and establish meaningful reduction targets.

Table 13: Veterinary Clinic Emission Benchmarks

Performance Metric	Industry Average	Top Quartile	Best-in-Class	Unit
Total Emissions Intensity	14.8	10.2	7.5	$kgCO_2e$/sq ft/yr
Per-Staff Emissions	4,800	3,200	2,100	$kgCO_2e$/FTE/yr
Per-Patient Visit	15.3	10.8	7.2	$kgCO_2e$/visit
Electricity Use	35	26	18	kWh/sq ft/yr
Natural Gas Use	22	15	8	therms/sq ft/yr
Anesthetic Emissions	180	95	40	$kgCO_2e$/1000 procedures

Source: V-CALC Pilot Study Data (n=15) and industry comparisons

Figure 8: Emission Reduction Pathway Example



6.6 Economic Analysis of Emission Reductions

V-CALC data demonstrates that many emission reduction strategies offer positive return on investment through operational cost savings.

Table 14: Cost-Effectiveness of Common Interventions

Intervention	Emission Reduction	Initial Investment	Annual Savings	Payback Period	10-Year NPV
LED Lighting Retrofit	2-4 $mtCO_2e$	$2,000-4,000	$800-1,200	2-4 years	$6,500
Programmable Thermostats	3-6 $mtCO_2e$	$800-1,500	$600-1,000	1-2 years	$7,200
Anesthetic Gas Scavenging	4-8 $mtCO_2e$	$5,000-8,000	$400-800	7-12 years	$1,800
HVAC System Upgrade	5-10 $mtCO_2e$	$12,000-25,000	$1,800-3,500	5-10 years	$8,500
Building Insulation	4-7 $mtCO_2e$	$5,000-10,000	$900-1,500	4-8 years	$6,200
Solar Panel Installation	8-15 $mtCO_2e$	$25,000-45,000	$2,500-4,500	7-12 years	$12,000
Hybrid Fleet Vehicle	3-5 $mtCO_2e$	$8,000 premium	$1,200-1,800	5-7 years	$4,500

Assumptions: 7% discount rate, regional average utility rates, 25-year equipment lifespan where applicable

6.7 Regulatory Compliance and Reporting

V-CALC positions veterinary clinics favorably for anticipated environmental regulations and voluntary disclosure programs.

Current and Emerging Regulatory Landscape:

1. **SEC Climate Disclosure Rules**: Large corporate veterinary chains may face mandatory climate-related financial disclosure requirements
2. **State-Level Regulations**: California, Washington, and New York developing sector-specific emission reduction mandates
3. **Federal Reporting**: Potential expansion of EPA GHG Reporting Program to include healthcare facilities above threshold sizes
4. **Sustainable Business Certifications**: B Corporation, Green Business Bureau, and industry-specific certifications increasingly requiring carbon accounting

Table 15: V-CALC Alignment with Reporting Frameworks

Framework/Standard	V-CALC Coverage	Additional Requirements	Compliance Level
GHG Protocol Corporate Standard	Full Scopes 1, 2, 3	Third-party verification	Complete
ISO 14064-1	Organizational boundaries	Management system documentation	Substantial
CDP Climate Disclosure	Scope 1, 2, 3 emissions	Governance, strategy, targets	Complete
TCFD Recommendations	Metrics and targets	Risk assessment, scenario analysis	Partial
B Corp Assessment	Environmental impact	Comprehensive operations review	Substantial
EPA ENERGY STAR	Energy performance	Benchmarking system enrollment	Partial

6.8 Future Enhancements and Development Roadmap

Based on pilot study feedback and emerging sustainability best practices, planned V-CALC enhancements include:

Phase 2 Development (2026):

- Web-based interface with cloud data storage
- Automated utility data integration via API connections
- Mobile app for field data collection
- Expanded waste categorization options
- Water consumption and embedded water footprint
- Biodiversity impact assessment module

Phase 3 Development (2027):

- Machine learning-based anomaly detection
- Predictive analytics for emission forecasting
- Integration with practice management software
- Supplier-specific emission data incorporation
- Real-time dashboard with continuous monitoring
- Multi-location corporate consolidation features

Phase 4 Development (2028+):

- Blockchain-verified carbon credits marketplace integration
- AI-powered reduction recommendation engine
- Industry peer network for best practice sharing
- Comprehensive life cycle assessment capabilities
- Integration with emerging federal reporting systems
- Carbon footprint labeling for veterinary services

VII. Discussion

7.1 Significance of Veterinary Carbon Accounting

The development of V-CALC represents a critical advancement in environmental accountability for the U.S. veterinary sector. While healthcare-associated emissions have received substantial attention in medical literature and policy discussions, veterinary medicine's environmental impact has remained largely unquantified and unaddressed. This gap is particularly significant given that:

1. **Veterinary services are growing rapidly**: The U.S. pet care market exceeded $136 billion in 2024, with veterinary services representing approximately $35 billion, reflecting increasing pet ownership and advancing medical care standards that often mirror human healthcare in resource intensity.
2. **Operational similarities to human healthcare**: Veterinary clinics employ similar emission-intensive practices as medical facilities, including energy-intensive diagnostic equipment, single-use medical supplies, hazardous waste generation, and potent anesthetic agents, yet lack the regulatory oversight and sustainability infrastructure present in hospital systems.
3. **Climate change impacts on animal health**: As climate change increasingly affects animal health through heat stress, vector-borne disease expansion, and ecosystem disruption, the veterinary profession has both ethical responsibility and professional interest in addressing its contribution to the problem.

V-CALC provides the first comprehensive, U.S.-specific tool enabling veterinary professionals to measure, understand, and act on their environmental impact, transforming abstract sustainability goals into concrete, measurable action.

7.2 Comparative Analysis with International Tools

V-CALC's U.S.-specific design offers substantial advantages over adapting international carbon calculators:

Emission Factor Accuracy: Testing with pilot clinics revealed that using UK-based emission factors (as in the Vet Sustain calculator) overestimated U.S. electricity emissions by an average of 32% for clinics in low-carbon

grid regions (California, New York) while underestimating by 47% in coal-heavy regions (Midwest). V-CALC's eGRID regional factors reduced this error to less than 5%.

Currency and Economic Modeling: Expenditure-based Scope 3 calculations using UK pounds sterling with currency conversion introduced 12-18% variability in emission estimates due to exchange rate fluctuations over the reporting period. USD-native calculations with U.S.-specific economic input-output factors eliminated this source of error.

Waste Management Alignment: U.S. waste disposal emission factors differ significantly from international standards due to higher incineration rates and advanced landfill gas capture. Using EPA WARM methodology rather than UK DEFRA factors changed waste-related emission estimates by 20-35%.

Cultural and Operational Fit: U.S. veterinary professionals found imperial units (miles, gallons, therms) more intuitive than metric conversions, reducing data entry errors by 40% compared to test scenarios requiring manual conversions.

7.3 Barriers to Adoption and Mitigation Strategies

Despite demonstrated utility, several barriers may limit V-CALC adoption:

Table 16: Adoption Barriers and Mitigation Strategies

Barrier	Prevalence	Impact Level	Mitigation Strategy
Time constraints	High	High	Streamlined data collection, annual-only requirement
Lack of sustainability knowledge	Medium-High	Medium	Educational resources, tutorial videos, help desk
Data availability challenges	Medium	High	Estimation methods, square footage proxies
Perceived cost of interventions	Medium	Medium	ROI calculators, payback period analysis
Competing operational priorities	High	High	Integration with accreditation standards
Skepticism about climate impact	Low-Medium	Medium	Peer testimonials, professional organization endorsement
Technical difficulty	Low	Medium	User-friendly design, color-coded interface

Key Success Factors:

- Professional organization endorsement (AVMA, state VMAs)
- Integration with existing quality improvement initiatives
- Recognition programs for early adopters
- Shared peer benchmarking networks
- Continuing education credit opportunities
- Client-facing sustainability marketing materials

7.4 Broader Implications for Veterinary Sustainability

V-CALC serves as foundation for comprehensive veterinary sustainability programs extending beyond carbon accounting:

Integrated Sustainability Framework:

- **Environmental**: Carbon footprint, water use, waste generation, biodiversity protection
- **Social**: Animal welfare, community health, staff well-being, client education
- **Economic**: Operational efficiency, long-term viability, sustainable supply chains
- **Governance**: Sustainability policies, stakeholder engagement, transparent reporting

Catalyzing Industry Transformation:

The tool's development and adoption can accelerate broader sustainability transformation by:

- Establishing baseline data enabling research on veterinary environmental impact
- Creating competitive pressure as early adopters gain market differentiation
- Informing evidence-based sustainability policy development
- Enabling veterinary participation in healthcare sustainability networks
- Supporting development of low-carbon veterinary products and services
- Demonstrating veterinary leadership on climate action

7.5 Limitations and Areas for Improvement

While V-CALC represents significant progress, acknowledged limitations suggest areas for continued development:

Methodological Limitations:

- Expenditure-based Scope 3 estimates lack precision of process-based assessment
- Annual aggregation may miss important seasonal patterns or operational changes
- Limited ability to assess marginal emissions from specific decisions
- Simplified assumptions about equipment efficiency and usage patterns

Scope Limitations:

- Excludes embodied carbon in buildings and infrastructure
- Does not assess pharmaceutical environmental fate and ecotoxicity
- Limited coverage of downstream impacts (pet food, product disposal)
- No integration of biodiversity or ecosystem impact assessment

Practical Limitations:

- Manual data entry increases error potential and user burden
- Annual update requirement for emission factors creates maintenance dependency
- Benchmarking limited by small initial dataset
- Lack of real-time feedback reduces behavioral impact

Recommended Research Priorities:

1. Large-scale validation study across diverse practice types and regions
2. Development of veterinary-specific emission factors for common supplies and procedures
3. Life cycle assessment of major veterinary pharmaceuticals and medical devices
4. Economic analysis of sustainability investments across practice sizes
5. Behavioral research on factors influencing veterinary sustainability adoption
6. Integration of carbon accounting with broader One Health framework

VIII. Conclusion

V-CALC represents a pioneering effort to bring comprehensive, scientifically rigorous carbon accounting to U.S. veterinary medicine. By addressing the specific regulatory, economic, and operational context of American veterinary practices, the tool overcomes critical limitations of international calculators and generic carbon footprint tools. The Excel-based design balances methodological sophistication with practical usability, enabling clinics of all sizes to quantify their environmental impact without requiring specialized expertise or significant resource investment.

Pilot testing across 15 diverse practices demonstrates the tool's effectiveness in identifying emission hotspots, prioritizing reduction opportunities, and tracking progress over time. Analysis reveals that veterinary clinics typically generate 40-75 metric tons of CO_2e annually, with substantial variation based on practice type, size, location, and operational characteristics. Scope 3 supply chain emissions consistently represent the largest contribution (45-55% of total), followed by purchased electricity (25-35%) and direct combustion emissions (15-25%). This emission profile suggests that comprehensive sustainability strategies must address procurement practices, energy efficiency, and operational procedures simultaneously to achieve meaningful impact.

The tool's economic analysis demonstrates that many emission reduction strategies offer positive return on investment through operational cost savings, with interventions such as LED lighting, programmable thermostats, and building insulation achieving payback periods of 1-8 years. This financial case for sustainability, combined with growing client expectations for environmental responsibility and anticipated regulatory requirements, creates compelling motivation for veterinary adoption of carbon accounting and reduction programs.

Beyond individual clinic benefits, widespread V-CALC adoption can catalyze industry-wide transformation by establishing baseline emissions data, enabling meaningful benchmarking, informing evidence-based policy development, and demonstrating veterinary leadership on climate action. As the veterinary profession increasingly embraces One Health principles recognizing the interconnection of human, animal, and environmental health, comprehensive carbon accounting becomes not merely an operational improvement but a professional imperative aligned with core veterinary values.

Future enhancements incorporating automated data integration, real-time monitoring, predictive analytics, and expanded environmental indicators will further increase V-CALC's utility and adoption. As climate change continues to impact animal health and ecosystem integrity, the veterinary profession's proactive engagement with environmental sustainability through tools like V-CALC represents both ethical responsibility and strategic necessity.

The development and deployment of V-CALC demonstrates that specialized, sector-specific carbon accounting tools can effectively bridge the gap between abstract climate goals and concrete professional action, providing veterinary clinics with the knowledge, tools, and motivation to contribute meaningfully to climate change mitigation while simultaneously improving operational efficiency and market positioning.

References

[1]. American Veterinary Medical Association. (2024). AVMA Sustainability Task Force Report. https://www.avma.org/sustainability
[2]. American Society of Anesthesiologists. (2024, January 29). *The Environmental Impact of Inhaled Anesthetics*. Www.asahq.org. https://www.asahq.org/about-asa/governance-and-committees/asa-committees/environmental-sustainability/greening-the-operating-room/inhaled-anesthetics
[3]. British Veterinary Association. (2023). Vet Sustain Carbon Calculator Methodology. https://www.bva.co.uk/vet-sustain

[4]. Eckelman, M. J., Huang, K., Lagasse, R., Senay, E., Dubrow, R., & Sherman, J. D. (2020). Health care pollution and public health damage in the United States: An update. Health Affairs, 39(12), 2071-2079.
[5]. Environmental Protection Agency. (2024). Emission Factors for Greenhouse Gas Inventories. https://www.epa.gov/climateleadership/ghg-emission-factors-hub
[6]. Environmental Protection Agency. (2023). eGRID 2023 Summary Tables. https://www.epa.gov/egrid
[7]. Environmental Protection Agency. (2023). Waste Reduction Model (WARM) Version 15. https://www.epa.gov/warm
[8]. Greenhouse Gas Protocol. (2004). Corporate Accounting and Reporting Standard. World Resources Institute and World Business Council for Sustainable Development.
[9]. Greenhouse Gas Protocol. (2011). Corporate Value Chain (Scope 3) Accounting and Reporting Standard. World Resources Institute and World Business Council for Sustainable Development.
[10]. Intergovernmental Panel on Climate Change. (2021). Climate Change 2021: The Physical Science Basis. Sixth Assessment Report.
[11]. Practice Greenhealth. (2024). Environmental Excellence Awards Program. https://practicegreenhealth.org
[12]. Ryan, S. M., & Nielsen, C. J. (2010). Global warming potential of inhaled anesthetics: Application to clinical use. Anesthesia & Analgesia, 111(1), 92-98.
[13]. Sherman, J., Le, C., Lamers, V., & Eckelman, M. (2012). Life cycle greenhouse gas emissions of anesthetic drugs. Anesthesia & Analgesia, 114(5), 1086-1090.
[14]. U.S. Bureau of Economic Analysis. (2024). Economic Input-Output Life Cycle Assessment Database. https://www.bea.gov
[15]. Vet Sustain. (n.d.). Carbon Calculator for Veterinary Practices. Retrieved from https://vetsustain.org/carbon-calculator
[16]. World Health Organization. (2021). Climate change and health. https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health