NOVA SCHOOL OF SCIENCE & TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

FRANCISCO PINTO VAN WYNSBERGHE
BSc in Business Engineering

SMALL-SCALE ANAEROBIC DIGESTION PLANTS IN DAIRY FARMS

A MARKET RESEARCH IN PORTUGAL AND EASTERN USA

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Abstract

Anaerobic Digestion (AD) plants have gained a considerable amount of interest in the past decades and are being recognized as a solution to diversify energy sources while enhancing manure management in dairy farms. The biogas produced by AD plants can be used to produce heat and electricity via Combined Heat and Power (CHP) plants, injected in national gas grids to replace natural gas after up-grading or in fuel cells to produce electricity. The economical viability of such installations still lacks overall attention, and companies like Biolectric are therefore willing to further investigate the markets.

This thesis aims to provide a well structured opinion on two markets, Portugal and the East Coast of United States of America (USA). Starting with a literature review to define all the concepts required for the research, the thesis then describes energy markets, required paperwork and applicable investment support. Additionally, two distinct case studies help estimating financial results obtained by the installation of an AD plant in both markets.

In Portugal, a case study was persued at a 879 cows dairy farm called Agro ABA located in Campelos, Torres Vedras. The case study was complemented by the measurement of the power curve at the farm, to understand the energy needs, and help choosing the most suited AD plant for the farm. In the USA, a case study was build from scratch in the state of Vermont. Overall, the Small-Scale Anaerobic Digestion (SSAD) plant by Biolectric would provide farmers with a great 5 to 13 years payback period solution, that is not much affected by neither the discount rate or the inflation rate chosen in the project. Even though both markets widely differ in sizes, Portugal benefits from higher governmental support, with a softer legislation, while the USA is trying to make renewable energy projects interesting at scale but lacks permitting simplification and suffers from much higher maintenance costs. The recommendation is therefore to consider growing in Portugal, and, for the USA, further investigate the potential of partnering up with local companies to sell Biolectric plants.

Keywords: Anaerobic Digestion, Biogas, Agro-Livestock Transition, Renewable Energy, Dairy Farms

Resumo

Instalações de Digestão Anaeróbia (DA) têm ganhado um interesse considerável nas últimas décadas, vindo a ser reconhecidas como uma solução na diversificação das fontes energéticas ao passo que valoriza a gestão de estrume em explorações leiteiras. O biogás obtido a partir da DA pode ser utilizado na produção de calor e eletricidade através de centrais de cogeração, nas células de combustìvel para a produção de eletricidade ou injetado na rede de gás nacional, substituindo o gás natural. A viabilidade económica destas instalações ainda carece de atenção global, e empresas como a Biolectric estão dispostas a investigar melhor estes mercados.

Essa tese tem o objetivo de fornecer um estudo estruturado do potêncial dessas instalações em dois mercados: Portugal e a Costa Leste dos USA. Iniciando com uma revisão da literatura para definir os conceitos utilizados, o estudo descreve os mercados de energia, a documentação necessária e apoio a investimentos aplicáveis para cada uma das regiões estudadas. Além disso, dois casos de estudo foram realizados de forma a serem obtidos valores reais de resultados financeiros para potenciais instalações.

Em Portugal, um caso de estudo foi conduzido na Agro ABA, uma vacaria leiteira com 879 vacas, localizada nos Campelos, Torres Vedras. Mediu-se, ainda, a curva de potência da vacaria, de forma a caracterizar as necessidades energéticas e ajudar na escolha da instalação mais adequada. Nos USA, um caso de estudo fictício foi desenvolvido para o estado de Vermont. Em geral, a instalação SSAD da Biolectric proporcionaria aos agricultores um período de retorno de investimento de 5 a 13 anos, o qual não é fortemente afetado pela taxa de desconto ou pela taxa de inflação escolhida. Apesar da diferença de dimensão dos mercados, Portugal beneficia de um maior apoio governamental, com uma legislação mais flexível, enquanto os USA estão a tornar os projetos de energia renovável interessantes em escala, mas carecem de simplificação no licenciamento e sofrem com custos de manutenção mais elevados. A recomendação, portanto, é considerar a expansão para Portugal e, nos USA, deve ser investigado cuidadosamente a possibilidade de crescimento de parcerias entre empresas locais e a Biolectric.

Palavras-chave: Biogás, Digestão Anaeróbia, Transição agro-pecuária, Vacarias leiteiras

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Acronyms

AD	Anaerobic Digestion *(pp. iv, vi, x, 2–14, 16, 17, 21, 25–27, 31–33, 40, 42–44, 46–52, 54, 56–59)*
APA	Agência Portuguesa do Ambiente *(pp. 25, 26)*
BMP	Biochemical Methane Potential *(p. 9)*
CARB	California Air Resources Board *(p. 47)*
CHP	Combined Heat and Power *(pp. iv, 2, 13, 48, 52)*
CNMP	Comprehensive Nutrient Management Plan *(p. 43)*
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation *(pp. 46, 48)*
CPI	Consumer Price Index *(pp. 43, 50)*
DGEG	Direção-Geral de Energia e Geologia *(p. 25)*
DRAP	Direção Regional de Agricultura e Pescas *(p. 25)*
EIA	Environmental Impact Assessment *(pp. 25, 26)*
EPA	Environmental Protection Agency *(p. 10)*
ETS	Emission Trading System *(pp. 26, 48)*
EU	European Union *(pp. 2, 22, 23, 26)*
FIT	Feed-In-Tariff *(pp. 31–33, 40, 51, 52, 57, 58)*
GHG	Greenhouse Gas *(pp. 2, 4, 10, 14, 22, 26, 46, 47, 56)*
GPR	Biogas Production Rate *(p. 8)*
HHV	Higher Heating Value *(p. 12)*
HRT	Hydraulic Retention Time *(pp. 6–8)*
IRA	Inflation Reduction Act *(pp. 40, 52, 57)*

IRR Internal Rate of Return *(pp. 18, 32–36, 52–54)*
ITC Investment Tax Credit *(pp. 40, 44, 45, 51, 52, 57)*

LCFS Low Carbon Fuel Standard *(p. 47)*
LCOE Levelized Cost of Energy *(pp. 18, 19, 32–36, 52–54, 57, 58)*

MCP Mera Comunicação Prévia *(p. 25)*
MMt Million Metric Ton *(p. 46)*
Mt Metric Ton *(p. 46)*

NAAQS National Ambient Air Quality Standards *(p. 43)*
NG Natural Gas *(p. 39)*
NLI Nitrate Leaching Index *(p. 11)*
NLV Nominal Liquid Volume *(p. 13)*
NPDES National Pollutant Discharge Elimination System *(p. 43)*
NPV Net Present Value *(pp. 18, 19, 32–36, 52–54, 57)*
NRCS Natural Resources Conservation Service *(p. 10)*
NSR New Source Review *(pp. 42, 43, 50)*

OECD Organization for Economic Cooperation and Development *(p. 20)*
OLR Organic Load Rate *(pp. 7, 8)*

P-Index Phosphorus Runoff Index *(p. 11)*
PDM Plano Diretor Municipal *(p. 25)*
POP Persistent Organic Pollutants *(p. 1)*
PTC Electricity Production Tax Credit *(pp. 44, 51, 52, 57)*

RCRA Resource Conservation and Recovery Act *(p. 44)*
REC Renewable Energy Communities *(pp. 22, 26, 33, 56, 58, 59)*
RECs Renewable Energy Certificates *(pp. 45, 46, 51, 52, 57)*
RED Renewable Energy Directive *(p. 22)*
RGGI Regional Greenhouse Gas Initiative *(pp. 46, 48)*
RPS Renewable Portfolio Standards *(pp. 45, 46)*

SGP Specific Biogas Production *(p. 8)*
SOLR Specific Organic Load Rate *(p. 7)*
SRE Substrate Removal Efficiency *(pp. 7, 8)*
SRT Sludge Retention Time *(p. 7)*
SSAD Small-Scale Anaerobic Digestion *(pp. iv–vi, viii, 2–4, 13–15, 17, 21, 23, 24, 26, 27, 31–36, 38, 42, 43, 48–54, 56)*

SWOT Strength Weaknesses Opportunities Threats *(pp. 2, 37, 55)*

TS Total Solids *(pp. 5, 7)*

UAA Utilized Agricultural Area *(p. 6)*
UPAC Unidade de Produção para Autoconsumo *(pp. 25, 26)*
USA United States of America *(pp. iv–vi, viii, 1–4, 10, 19, 20, 31, 38, 40–42, 44–46, 48–50, 52–59)*

VAT Value Added Tax *(p. 24)*
VDACS Virginia Department of Agriculture and Consumer Services *(pp. 43, 50, 59)*
VFA Volatile Fatty Acids *(p. 5)*
VS Volatile Solids *(pp. 7, 8)*

WACC Weighted Average Cost of Capital *(pp. 19, 53)*

Symbols

C	Carbon *(pp. 6, 9)*
$C_6H_{10}O_5$	Cellulose *(p. 5)*
$C_6H_{12}O_6$	Glucose *(p. 5)*
CF_n	Cash-Flow in Year n *(p. 18)*
CH_3COO^-	Acetate *(p. 5)*
CH_4	Methane *(pp. 5, 14, 40, 46, 47)*
CO	Carbon Monoxyde *(p. 43)*
CO_2	Carbon Dioxide *(pp. 1, 5, 14)*
CO_2e	Carbon Dioxide Equivalents *(pp. 26, 46, 48, 51)*
D_t	Operation
Maintenance Costs *(pp. 18, 19)*	
E_n	Energy Produced in Year n *(pp. 18, 19)*
F	Total Influent Flow to Reactor, in m^3/day *(pp. 7, 8)*
F_{biogas}	Biogas Flow, in m^3/day *(p. 8)*
H_2	Dihydrogen *(p. 5)*
H_2O	Water *(pp. 5, 14)*
H_2S	Hydrogen Sulphide *(pp. 14, 17, 42)*
i	Inflation Rate *(p. 19)*
I_0	Initial Investment *(pp. 18, 19)*
K	Potassium *(pp. 10–12)*
N	Nitrogen *(pp. 6, 9–12)*
n	Year *(pp. xvii, 18, 19)*

NH_3	Ammonia *(pp. 9, 11)*
NO_x	Nitrogen Oxides *(pp. 42, 43)*
N_P	Total Project Duration, in years *(pp. 18, 19)*
O_3	Ozone *(p. 43)*
O_2	Dioxygen *(p. 14)*
P	Phosphorus *(pp. 10–12)*
r	Discount Rate *(pp. 18, 19)*
r_N	Nominal Discount Rate *(p. 19)*
r_R	Real Discount Rate *(p. 19)*
S_{in}	Substrate Concentration in the Influent, in kg/m^3 *(pp. 7, 8)*
S_{out}	Substrate Concentration in the Efluent, in kg/m^3 *(p. 8)*
SO_x	Sulfur Oxides *(pp. 42, 43)*
V	Working Volume, in m^3 *(pp. 7, 8)*
X	Biomass Concentration Inside the Reactor, in kg/m^3 *(p. 7)*
X_{out}	Biomass Concentration in the Effluent, in kg/m^3 *(p. 7)*
Y_{biogas}	Biogas Yield *(p. 8)*

1

Introduction

The following chapter defines the background (Section 1.1) and motivation (Section 1.2) of the thesis through some historical milestones and current challenges. The structure of the thesis is then described through a description of the approach (Section 1.3), goals (Section 1.4), and dissertation organization (Section 1.5).

1.1 Background

Bioenergy provided by plants and their refined products has been widely used by the human kind since pre-recorded history. Biofuels used to produce bioenergy can be found in solid, liquid and gaseous forms. Wood, as solid biofuel, was firstly used to warm shelters, cook meat and produce light, thus, greatly contributing to human kind development (Guo et al., 2015). In the 1760's, with the Industrial Revolution starting in the United Kingdom, the use of coal allowed mass population development and became the most widely used source of energy (Fernihough & O'Rourke, 2014). In the 19th century, internal combustion engines using petrol derivatives were developed, providing more efficiency than steam engines, and were then massively used in the automobile industry (Wang et al., 2020). With the widely spread use of fossil fuels in the 20th century, the first environmental impacts started to be noticed, and rising levels of CO_2 were firstly observed in the 1960's (Carey, 2012). In 1968, scientists, economists and industry leaders held a first reunion named "The Club of Rome", where they exposed the environmental problems caused by consumerism and decreasing non renewable resources in a report called "The limits to growth"(Colombo, 2001). Following the three petrol crisis in 1973, 1979 and 1991, in a period where the concept of "Corporate Social Responsibility"was being developed (Madrakhimova, 2013), cleaner energy supplies were needed to fight climate change and find a sustainable alternative to fossil fuels (Pereira, 2008). With a focus on Persistent Organic Pollutants (POP), and being particularly important in the role of the USA in environmental protection, the Stockholm Convention signed in 2001 is a milestone in ensuring cleaner business activities. In 2015, the Paris Agreement set new European targets to prevent drastic climate changes by defining a well below 2°C temperature rise until 2050 compared to pre-industrialized temperature levels (Savaresi, 2016). More recently, the Russian invasion over Ukraine pushed the European Union (EU) to work on their energetic independence through RePowerEu. The plan aims to build a European framework to enhance energy savings, produce clean energy and diversify production methods (European Commission, 2022).

1.2 Motivation

The increasing need to tackle Greenhouse Gas (GHG) emissions both in the EU and in the USA via respectively the Paris Agreement (Savaresi, 2016) and the IRA (von Loesecke & Chermak, 2023), raises global interest over the most GHG emitting sectors. AD plants constitute a solution to reduce GHG emissions both in the energy production sector, responsible for 24,9% of GHG EU emissions and in the agriculture, responsible for 9,9% of the EU GHG emissions (O'Connor et al., 2021). With the continuous specialisation of farms, and increasing volumes of manure to deal with, AD plants provide farmers with a manure management solution that mitigates previous costs linked to manure disposal and produces energy (Petersen et al., 2013). The biogas produced by AD plants can be used to produce heat and electricity via CHP plants, injected in national gas grids to replace natural gas after up-grading or in fuel cells to produce electricity. All in all, AD plants provide their users with a wide variety of energy applications, powered by a high energy content biogas of circa 22,5 $MJ.m^{-3}$ (Lapa, 2023). In the SSAD plant market, Biolectric positions itself as a young, dynamic and adaptative company seeking to become a major leader in dairy farms SSAD plants and awarded "Most Sustainable Company"by the 2022 Trends Impact Awards (Biolectric, 2022).

1.3 Approach

The thesis is composed of two distinct business cases conducted for a Belgian company called Biolectric: Portugal (Chapter 3) and Eastern USA (Chapter 4). The Portuguese market is the first analyzed market and is complemented by a practical case study in a dairy farm called Agro ABA, located in Campelos (Portugal). The USA market analysis will be complemented by a conceptual case study in the state of Vermont. In both case studies, the markets are described through the study of the energy mix, energy price and renewable energy potential. Furthermore, the researches include strategic information about the number of cows, the number of farms, the number of cows per farm and their geographical distribution in the analyzed country. The researches end with an economical and financial description of the markets, where competitors are identified, milk prices are described, a financial simulation of SSAD plants in each market is conducted and the information is gathered into Strength Weaknesses Opportunities Threats (SWOT) matrixes. The structure of both researches enables the comparison of both markets in size, and provide a perception of their attractiveness for Biolectric.

1.4 Goals

With the production of their first Belgian SSAD plant in 2011 and having already expanded to a wide range of countries both inside and outside European borders, Biolectric seeks to continue growing and expand its horizons. The analyzed markets have been identified as potentially interesting by Biolectric and therefore require further analysis. The aim of this thesis is to draw a description of both Portuguese and Eastern USA markets and understand whether Biolectric should or shouldn't consider to grow in those countries. Furthermore, beyond Biolectric's eagerness to obtain insights over these markets, this thesis aims to provide a well structured opinion on the potential of dairy farms AD plants in both countries.

1.5 Dissertation organization

The dissertation of this thesis is composed of five main chapters. The first chapter (Chapter 1) introduces the thesis by defining the background, the motivation, the approach used in the elaboration of the document, the goals of the thesis and the dissertation organization. The second chapter (Chapter 2) is dedicated to a literature review, to define and explore current AD technologies, digestate management solutions, and the financial rates used to perform the market research. The third chapter (Chapter 3), is dedicated to analyzing the Portuguese market, and understanding its potential for Biolectric. The fourth Chapter (chapter 4) is dedicated to analyzing the USA market and understanding its potential for Biolectric. The fifth and last chapter of the thesis, (Chapter 5), is dedicated to concluding on our business cases, summing up all the key points elaborated throughout the thesis and build an opinion on whether Biolectric should or shouldn't consider to grow in those countries.

2

Literature Review

The literature review aims to provide the reader with all the key knowledge for the further conducted market researches. This chapter defines the principles of AD, current technologies, factors affecting its performance and digestate management solutions. Additionally, thanks to a visit at Biolectric headquarters in Temse (Belgium), a presentation of the SSAD plant by Biolectric will help develop precise business cases in the market researches. To end with, a detailed description of all financial tools required for the market research will help decision makers decide whether the results meet their needs.

2.1 AD Plants: The General Concern

For over 2 000 years, Indian and Chinese populations have been using biogas produced by the AD of sewage, slurry, food wastes and biowastes to produce energy. The first recorded AD plant was build in Bombay (India) in 1859. In 1895, England started using biogas produced by sewage treatment plants to light up streets in Exeter. In the 1950's, China build 3,5 million AD plants to supply biogas for cooking and lighting purposes in rural areas. AD plants started to be used in USA farms in the 1970's thanks to governmental incentives (Guo et al., 2015). Nowadays, with the increasing needs to build an energy independence in Europe through RePowerEU and being considered as key to decrease GHG emissions in the IRA signed by President Joe Biden in the USA (von Loesecke & Chermak, 2023), AD plants have not only gained interest, they are considered a key solution producing waste based energy. AD plants found on the market widely vary in their output power and can therefore be classified as shown in Table 2.1, in terms of electricity output power.

2.1.1 Anaerobic Digestion

AD is the process of organic material degradation by microbial organisms in absence of oxygen. AD provides a solution to reduce environmental impacts of agricultural and industrial wastes, offsetting emissions caused by fossil fuel based activities (Chen et al., 2008). AD has been widely used in wastewater treatment and is gaining popularity

Table 2.1: AD plants classification by output power;
From O'Connor et al., 2021.

Designation	Output Power Range	Units
Micro-scale AD	<15	kW
Small-scale AD	[15-99]	kW
Medium-scale AD	[100-299]	kW
Large-scale AD	>300	kW

in animal manure and agricultural residues processing (Nizami et al., 2013). AD can be conducted at three temperature ranges depending on the feedstock: psychrophilic conditions (<20°C), mesophilic conditions (20°C– 43°C), or thermophilic conditions (50°C–60°C). The AD process is a four step process composed of Hydrolisis, Acidogenesis, Acetogenesis and Methanogenesis (Nie et al., 2021).

- **Hydrolisis**

  Hydrolisis is the first step of the anaerobic digestion process. Depending on the feedstock biodegradability, it can be the most time consuming step of the process. This step, as shown in Equation (2.1), consists in the production of glucose from cellulose (in the case of solid biomass), where water enables the hydrolysis and organic soluble matter is produced (Anukam et al., 2019).

$$(C_6H_{10}O_5)n + n(H_2O) \longrightarrow n(C_6H_{12}O_6) + n(H_2) \tag{2.1}$$

- **Acidogenesis and Acetogenesis**

  The acidogenesis and acetogenesis steps produce, among other products, Volatile Fatty Acids (VFA), H_2 and CO_2. Homoacetogenic bacterias will further use H_2 and CO_2 to produce CH_3COO^- (Feng et al., 2022) while acetogenic bacterias will degrade VFA to produce CH_3COO^- (Franke-Whittle et al., 2014).

- **Methanogenesis**

  During methanogenesis, CH_4 and CO_2 are produced from CH_3COO^- and H_2 in an oxygen sensitive process by methanogens (Anukam et al., 2019). This last step of the anaerobic digestion can be greatly inhibited by the presence of antibiotics, resulting in a poorer methane production (Wu et al., 2022).

2.1.2 AD plants Technologies

AD plants design vary widely depending on the feedstock. Plants can perform wet AD, if the amount of Total Solids (TS) doesn't exceed 16%, semi-dry AD for values between 16% and 22% or dry AD for TS values between 22% and 40%. Dry AD is typically used to process municipal solid waste, whereas wet AD is widely used for manure. AD processes have different optimum conditions, some plants therefore separate the processes to maximize methane yields (Ward et al., 2008).

2.1.2.1 Single Stage Reactors

Single stage reactors, as seen in Figure 2.1, where all four steps of AD take place in the same reactor, can be used in a wide variety of AD applications and are easier to develop (Van et al., 2020). Nevertheless, these can suffer from a "short-circuit"effect where the Hydraulic Retention Time (HRT) time is not optimal and which results in lower methane yields (Ward et al., 2008). In a single stage reactor, conditions should be optimized for methanogens as they are the most sensitive microorganisms of the process. Reactor conditions should therefore present a substrate C/N ratio ranging from 15 to 30, a pH from 6.8 to 7.4, and depending on whether the AD is proceeded at mesophilic, thermophilic, or psychrophilic conditions, a HRT of respectively 30, 20 or 50 days. The use of single stage reactors would be more suited for uniform feedstocks, generally require a smaller capital and less Utilized Agricultural Area (UAA). (Van et al., 2020).

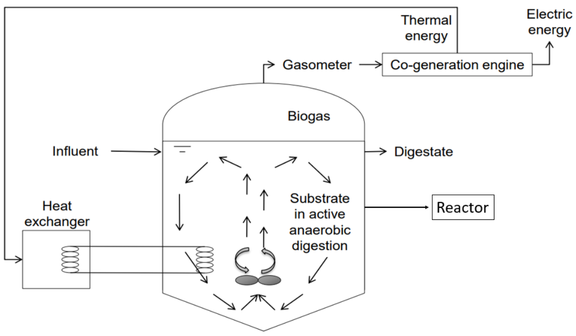

Figure 2.1: Single Stage AD Plant. Adapted from (Lapa, 2023).

2.1.2.2 Multi-stage Reactors

Multi-stage reactors are used to maximize methane yields by separating hydrolisis and acidogenesis from acetogenesis and methanogenesis, because of their different optimal environmental settings. (Ward et al., 2008). Between both reactors, as shown in Figure 2.2, a buffer is typically incoporated to control the pH, remove any material that wouldn't be hydrolyzed, and adjust the C/N ratio. These plants can be used in the AD of all types of feedstocks and have lower HRT ranging from 1 to 12 days. They generally require wider UAA, are more complex to build and more expensive (Van et al., 2020).

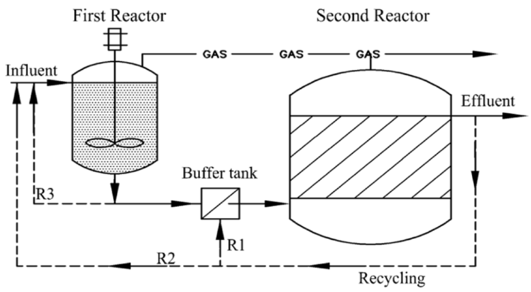

Figure 2.2: Multi-stage AD Plant. Retrieved from (Van et al., 2020).

2.1.3 AD Monitoring

The performance of AD plants can be monitored through some key indicators presented in the following section (Lapa, 2023).

- **HRT**: The HRT measures the medium time the substrate stays in the reactor. As shown in Equation (2.2), HRT is the ratio between the reactor volume V measured in m^3, and the total influent flow F into the reactor measured in m^3/day. A low HRT results in poor methane yields and can be the cause of an unhealthy microorganism decrease. On the opposite, a high HRT will require a bigger reactor volume and therefore affect the financial performance of the plant (Zhang et al., 2006).

$$HRT = \frac{V}{F} \tag{2.2}$$

- **Sludge Retention Time (SRT)**: SRT is a measure of how much time partially digested solid matter stays inside the reactor. This measure is important as an excessive accumulation of sludge could perturb AD and affect methane yields. SRT, as shown in Equation (2.3), is a ratio between HRT in days, times the biomass concentration inside the reactor X in kg/m^3 and X_{out}, the biomass concentration in the effluent measured in kg/m^3. Note that the mass calculation in both X and X_{out} is in terms of TS. TS are what is left of a sampling after evaporation in a bain-marie and posterior drying at circa 104°C (Lapa, 2023).

$$SRT = \frac{V \times X}{F \times X_{out}} = \frac{HRT \times X}{X_{out}} \tag{2.3}$$

- **Organic Load Rate (OLR)**: OLR, described by Equation (2.4), is a measure of the substrate concentration entering in the reactor, S_{in} in kg/m^3, divided by the days of HRT. OLR is an important indicator that gives insights about the reactors kinetics, its stability, and overall efficiency (Nkuna et al., 2022). In this case, S_{in} is defined in terms of Volatile Solids (VS).VS of a sample are the ones that evaporate in a furnace at around 550°C (Lapa, 2023).

$$OLR = \frac{S_{in} \times F}{V} = \frac{S_{in}}{HRT} \tag{2.4}$$

- **Specific Organic Load Rate (SOLR)**: The SOLR is similar to OLR, but represents a specific value, which is calculated in terms of TS inside the reactor and is responsible for the stability of the AD (del Pilar Anzola-Rojas et al., 2015). The SOLR, as shown in Equation (2.5), uses a ratio between VS in the influent (S_{in}) and TS in the reactor (X).

$$SOLR = \frac{S_{in} \times F}{V \times X} = \frac{S_{in}}{HRT \times X} \tag{2.5}$$

- **Substrate Removal Efficiency (SRE)**: The SRE is a dimensionless indicator that evaluates how much of the organic matter is removed from the reactor. Both S_{in}

and S_{out} are in kg/m^3 and defined in terms of VS (Lapa, 2023). This indicator can be calculated using the following equation:

$$SRE = \frac{S_{in} - S_{out}}{S_{in}} \tag{2.6}$$

- **Specific Biogas Production (SGP)**: The SGP, as shown in Equation (2.7), is a ratio of the rate of biogas produced (F_{biogas}) in m^3/day by the daily m^3 of influent (F) at a specific concentration S_{in}. The SGP therefore gives a specific estimative of the biogas produced by each unit of influent used in the AD plant (Lapa, 2023).

$$SGP = \frac{F_{biogas}}{F \times S_{in}} \tag{2.7}$$

- **Biogas Production Rate (GPR)**: The GPR, as shown in Equation (2.8), measures the biogas production rate (F_{biogas}) in m^3/day per unit of reactor working volume V in m^3. The ratio gives an approximation of how big should a AD plant be for a specific biogas daily production (Lapa, 2023).

$$GPR = \frac{F_{biogas}}{V} \tag{2.8}$$

- Y_{biogas}: The Y_{biogas}, as shown in Equation (2.9), is a yield measure of how much volume biogas is produced in m^3 by each kg of substrate removed from the reactor. Note that the substrate removal is defined in terms of VS, as defined in the OLR (Lapa, 2023).

$$Y_{biogas} = \frac{F_{biogas}}{OLR \times SRE \times V} \tag{2.9}$$

2.1.4 Factors affecting AD

AD is a sensitive process that requires a careful operation, the main factors affecting its performance are:

- **Reactor Design**: Optimizing the reactor design can play a key role in reducing HRT, reducing the reactor required volume, and guarantee an optimum organic homogeneity. A squared reactor could be easier to build, but would suffer from limited corner substrate flow and heat losses (Ward et al., 2008).

- **Mixing**: Although it represents a consequent cost, a mixer is often used to enhance the organic homogeneity, allow gas bulbs to easily escape from the substrate and prevent sendimentation at the bottom of the reactor. Mixing needs to be done carefully as excess mixing could have negative impacts on methane yields (Ward et al., 2008).

- **Microbial Biomass**: When pumping the digested out of the reactor, microbial biomass needs to stay in. In some cases, AD plants use a AD filter, where microbial organisms attach themselves, thus preventing them to leave the reactor during pumping. These filters can be either inerts or degradable (Ward et al., 2008).

- **Temperature**: AD can take place at a wide range of temperatures, literature wise, optimums still vary. Nevertheless, three main temperature ranges can be identified as psychrophilic for temperatures under 20°C, mesophilic from 20°C to 43°C and thermophilic from 50°C to 60°C. Eventhough thermophilic conditions may lead to higher methane yields, more energy is required to maintain the reactor at the desired temperature (Nie et al., 2021).

- **Buffering**: The buffer, as referred before, is used to control the pH, remove non hydrolyzed materials and adjust the C/N ratio. pH optimum range is narrow, methanogens are very sensitive to any pH change (Surra et al., 2019). Optimum pH for methanogens is 7.0, whereas optimum pH for hydrolisis and acidogenesis is around 6.0, which is why some plants use a separated hydrolisis reactor (Ward et al., 2008).

- **Short Chain Fatty Acids**: Monitoring short chain fatty acids is important as they can inhibit methanogenesis, as well as demonstrate a high concentration of organic load. Overall, fatty acids can indicate how well a feedstock is being accepted by the microbial biomass (Ward et al., 2008).

- **Feedstock and Co-Digestion**: The performance of different feedstocks can be tricky to analyze as it is greatly influenced by environmental conditions. For comparing feedstock qualities, a laboratory test called Biochemical Methane Potential (BMP) tests the maximum methane yield possible (Ward et al., 2008). Co-digestion, by adding a different type of feedstock can often enhance AD performance. The new feedstock can increase the nutrient content of the reactor and reduce the risk of excess NH_3. However, co-digestion can also be the source of impurities or uncompatible feedstocks, which could result in a methane inhibition. (Chiu & Lo, 2016).

- **Pre-Treatment**: Pre-Treatment by mechanical, thermal or chemical means can be a way to enhance methane yields. These methods can, for example, reduce particules size in the substrate and facilitate AD, resulting in higher yields. Unfortunetly, these methods often use extra machinery that have important economical and logistic impacts (Hashemi et al., 2021).

2.1.5 AD Plants in Portugal

The yearly Portuguese national production of cattle manure was estimated to be 25,24 million metric tons, 55% of which can be found in the interior center region and Alentejo. Nearly 18% of the cattle manure national production can be found on Azores islands (Fernandes et al., 2023). In 2018, Portugal reported 64 biogas plants in the whole country, working for either agriculture, sewage, landfill, and others (European Biogas Association, 2018). It is difficult to evaluate how much of these are still being used today and whether they are used to process cattle manure or not. All in all it seems like the AD plant market still has a lot of room to grow in the country. Considering a manure[1] density of 1 t/m^3 (University of Vermont Extension, 2018), and that the biggest Biolectric plant can process up to 50 m^3 a day (Biolectric, 2023), there would be room for approximately 1383 AD plants for cattle manure in Portugal.

2.1.6 AD Plants in the USA

According to the Environmental Protection Agency (EPA), the USA had 343 AD plants processing manure across their farms in 2023, a number that has recently been increasing. The complete mix digesters, similar to Biolectric AD plants, represented 26% of total plants with 89 installations. With over 30 000 dairy farms across the USA in 2021, there should be a lot of room for new AD plants in the country (Nepveux, 2021).

2.2 Digestate Management

Digestate is the output of the reactor after microbial digestion. It is a nutrient rich substance, more liquid than manure with around 6% of total solids for dairy slurry (Lukehurst et al., 2010), that can be used in a wide range of applications. The basic nutrients N, P, and K found in digestate can also be found in traditional fertilizers (Sogn et al., 2018). The digestate composition varies widely based on feedstocks and can therefore have different applications in function of its quality. Cow manure used in AD results in a great reduction of total solids and in the formation of a nutritious organic fertilizer when cows benefit from a rich diet like corn and soybeans. Due to pathogens content, and possible rests of antibiotics, digestate from cow manure should be handled carefully and may require post-treatment (Lamolinara et al., 2022). Digestate management can be considered as the last step in forming a complete waste management cycle after AD and therefore is a crucial aspect in the sustainable transition of the agro-livestock sector (Fuchs & Drosg, 2013).

2.2.1 Regulations

It is important to understand that land application of digestate at a time where plants are not growing can result in nutrient leaching and runoff into surrounding water sources (Lukehurst et al., 2010). Digestate processing is covered by European Directives that specify an annual limit of 170 kg/ha of N spread on fields (animal manure specific). Additionally, in vulnerable zones where N land applications could be prohibited over a given period, farms must be able to store and cover[2] the quantity manure or digestate they would produce over that period (European Council, 1991). In the USA, the Natural Resources

[1]Manure is defined as animal feces and urine, but may contain residual bedding, spilled feed, water and soil (State of Vermont, 2023).

[2]Covering manure and digestate is required to avoid GHG emissions.

Conservation Service (NRCS) elaborated a nutrient management directive where digestate spreading is regulated. Soils nutrients should be tested every 2 years, and tests should be analyzed in accordance with Cornell University guidance. After testing, the Nitrate Leaching Index (NLI) and Phosphorus Runoff Index (P-Index) help assessing the optimal amount of nutrients to be spread on a specific land (NRCS, 2020).

2.2.2 Solid-Liquid Separation

Digestate is a solid-liquid material in which the solid fraction is rich in K and where P and N can be found in both solid and liquid fractions. The separation of the solid and liquid fractions enables the further treatment of digestate while reducing operating costs, transportation costs and storage capacity requirements. The solid-liquid separation starts by densifying sludge, removing water, and obtaining a thicker 15% to 30% solids content material after dewatering. This first step can be performed statically, by gravity settling, or dynamically, via filtration, air flotation and centrifugation. The dewatering process can be performed mechanically (e.g. belt filter press, chamber filter press, vacuum filtration or centrifugation), by electrocoagulation, or by chemical coagulation (Monfet et al., 2018).

2.2.2.1 Post-Treatment of Liquid and Solid Fractions

Different processing methods can be used for further treatment of the liquid and solid fractions. The liquid fraction can typically be further processed by wastewater treatment plants to recover N and P before being rejected in bigger waterways. The nutrient and fiber rich solid fraction post-treatment is attractive for agricultural purposes, energy valorization or chemical byproducts. The first steps in the post-treatment of the solid fraction is chemical or thermal stabilization (see Section 2.2.2.2). Chemical stabilization is performed by adding acid to reduce NH_3 rejection for storage and field spreading activities, or lime to increase the pH, kill pathogens and reduce odors (Monfet et al., 2018).

2.2.2.2 Thermal Drying

A thermal drying process can be used to vaporize remaining water in the thicker solid content, and obtain around 99% of dry solids. The dried digestate will then be pasteurized[3] to eliminate odors and NH_3 which will simplify handling and further utilization. The process of thermal drying requires a lot of energy, therefore, it is usually advised to optimize dewatering to minimize the water content before performing thermal drying. AD plants can use the heat produced to perform thermal drying (Monfet et al., 2018), thus, providing farmers that usually wouldn't have interest in direct heat with a great added value solution.

[3]Pasteurization is a thermal heating process at around 70°C (Nordell et al., 2022).

2.2.3 Cow Bedding

Bedding materials are an important factor in the production performance of dairy cows, they should therefore be thoroughly chosen. Dried digestate, as described in Section 2.2.2.2, has been previously recognized as one of the most valuable bedding for dairy cows regarding comfort (Jaďuďová et al., 2023). The importance in choosing the right bedding reflects itself on the overall comfort of cows, may be key in controlling diseases and maintaining animal hygiene. Farm dried digestate should be carefully used and monitored due to risks related to mastisis[4] (Blowey et al., 2013), and should be avoided in calves bedding (Leach et al., 2015). The comfort of cows may be increased when choosing an adapted thermally comfortable material, that is not too slippery, and that offers a soft and dry bedding. Two main types of materials are typically used for cow bedding, organic or mineral. Organic bedding refers to materials such as straw, composted manure, wood shavings and sawdust while mineral bedding refers to materials such as sand, rubber mattresses, cement or gypsum.

2.2.4 Pellets

Dried digestate can be transformed into pellets, that will serve in combustion for heating purposes. The pellets produced from AD can benefit from a Higher Heating Value (HHV) of circa 14 MJ/kg (Leach et al., 2015), comparable to HHV found in wood pellets (Telmo & Lousada, 2011). The production of pellets usually involves a three steps process composed of drying, grinding and pressing. For optimum pellet formation, the substrate used should present a moisture content between 8% and 20%. Values over 20% reduce the overall process efficiency, water can't be compressed, while values under 8% compromise the pellet formation and result in a material that desintegrates easily (Czekała, 2021). The separated thickened solid fraction defined in Section 2.2.2 would therefore require less drying than the dried digestate defined in Section 2.2.2.2 if it was to be used for pellets production.

2.2.5 Organic Fertilizers

Digestate can be processed to provide organic fertilizers, and organic pesticides (Kaur et al., 2020). Previous researches have demonstrated that 55% to 95% of N found in animals nutrition was excreted and could be recovered in the feaces and urine together with high levels of K and P (Lukehurst et al., 2010). Traditional fertilizers can cause problems linked with biodiversity, soil erosion, water contamination and pesticide poisoning. Organic fertilizers have the capacity to work better with soil microorganisms, enhance nutrient uptake and be less harmful to the soil's natural fertility (Suhag, 2016).

[4]Mastisis refers to an inflammation of the breast tissues.

2.3 The SSAD Plant by Biolectric

The following section describes the SSAD plant (find datasheet in Annex I) developed by Biolectric, a Belgian, Temse based company. All the information has been gathered during a visit at the Temse Biolectric fabric in February of 2023. The visit was organized by Mr. Klaas Vanhee, Comercial Director at Biolectric and Mrs. Michelle Spiessens, Human Resource Officer. The visit was split in three parts, starting by a tour of the fabric where all AD plants are build, continuing with the visit of a functional AD plant at a client close to the company, and ending with a question and answer session with Mr. Klaas Vanhee at Biolectric.

2.3.1 Models

The eleven models of Biolectric SSAD plants, shown in Table 2.2, range from 9,7 to 74 kW of electrical power output. These plants are all prepared to work as CHP, and can respectively generate a heat power that ranges from 33,6 to 143,6 kW. The plants are composed of a reactor, with a Nominal Liquid Volume (NLV) ranging from 89 to 1 260 m^3, and a shipping container where engines and technical components are stored.

Table 2.2: Biolectric SSAD plants (From *Manuel d'utilisation et d'entretien Installation biogaz Biolectric*, 2020).

												Units
Engine Type	10	11	20-2	22-1	22-2	33	33-2	40	44	60	74	
N° of Engines	1	1	2	1	2	2	2	2	2	2	2	
Electric Power	9,7	11	9,7	22	11	11 or 22	16,5	20	22	30	37	kW
Electric Power	10	11,3	10	22,6	11,3	11,3 or 22,6	17	20,6	22,6	30,9	38,1	kVA
Heat Power	33,6	25,9	33,6	45	25,9	25,9 or 45	33,8	40,9	45	58,2	71,8	kW
Reactor Type	S1	S1-H	S2	S2-H	S3	S3-H	S4	S4-H	S6-H	S8-H		
NLV	89	145	176	287	261	425	362	590	924	1260		m^3
Total Height	5,71	6,93	7	8,22	7,47	8,69	7,47	8,69	9,80	10,70		m

In Figure 2.3, the reactor on the right, composed of a heating system and a mixer, is where the anaerobic digestion process occurs. The shipping container on the left is where the biogas engine, the digestate pump and auxiliary equipment, are stored.

2.3.2 Technology Description

Depending on how the farm is organized, various types of floors can be found. The type of floor will influence the type of manure collection, its quality, and the type of storage. In a farm with slatted floors and underground manure cellar, the organic matter is pumped from the storage compartment to the reactor by the storage compartment pump. The process of bacterial degradation can then start in the reactor, with an average retention time of 30 days. The biogas produced will then be treated to meet the engines requirements. The plant allows all pumpable liquids as long as they contain less than 10% of dry matter and more than 7% of organic dry matter (Biolectric, 2023). The bacterial fermentation in the reactor occurs under mesophilic conditions which range between 32°C

Figure 2.3: Biolectric SSAD Plant.

and 42°C (*Manuel d'utilisation et d'entretien Installation biogaz Biolectric*, 2020). The process of anaerobic digestion under mesophilic conditions, as described in Section 2.1.1, is a four steps process composed of: hydrolisis, acidogenesis, acetogenesis and methanogenesis (Anukam et al., 2019).

2.3.2.1 Biogas Treatment

In ideal conditions, the biogas produced by the AD process is composed of 60% of CH_4, 39% of CO_2 and 1% of other gases such as H_2S. Before being used for combustion in the engines that produce heat and electricity, the biogas needs to be filtered by active carbon filters to remove H_2S and enhance the lifespan of the engine(s) (Lapa et al., 2017).

2.3.2.2 Biogas Combustion, Engine Cooling and Reactor Heating

The biogas produced and treated can be mixed with flitered air and be used for combustion in the engine(s) of the AD plant. The simplified equation of the methane combustion can be written as follows (Lee & Trimm, 1995):

$$CH_{4(g)} + 2O_{2(g)} \longrightarrow CO_{2(g)} + H_2O_{(l)} \tag{2.10}$$

The combustion of CH_4 oxidizes CH_4, that would traditionally be rejected into the atmosphere in farms that don't use AD plants, into CO_2. Being that the GHG effect of CH_4 is 25 times higher than the one of CO_2 (Brander & Davis, 2012), the combustion of CH_4 not only produces electricity and heat, it also plays a crucial role in turning dairy farms more environment friendly. In the SSAD plant by Biolectric, the engine(s) power(s) a generator to produce electricity, and the heat is used to maintain the reactor at its working temperature via heat exchangers. If required by the client, part of the heat in the cooling system can be used to heat water for his own purposes. For energy counting purposes, an optional heat meter can be installed. If ever the temperature of the reactor was to drop below the optimal working temperature, the client can chose to activate the heating of the reactor via electrical resistors. Due to their considerable consumption (6 kW/resistor) the resistors can only be activated if the engine(s) is(are) not operational (*Manuel d'utilisation et d'entretien Installation biogaz Biolectric*, 2020).

2.3.3 Operation Description

2.3.3.1 Manure Collection

Manure collection techniques can typically be separated into either scraping techniques, or flushing systems. In the case of a Biolectric SSAD plant, in order to ensure a sufficient manure quality, scraping collection methods would be recommended (Wilkie, 2005). Manure produced in dairy farms can be collected by scrapers, automatic or manual (El Mashad et al., 2023).

Scraping can be done by a scraper robot as seen in Figure 2.4 and combined with slatted floors as seen in Figure 2.5, storing the manure in an underground manure cellar.

Figure 2.4: Manure Robot Scraper.

Figure 2.5: Slatted Floor.

This setup, with a manure cellar pump as seen in Figure 2.6 ensures an automated manure collection. In other cases, in absence of a robot scraper, manual scraping can be done with a tractor for instance. In this case, the manure will have to be transported to a storage compartment where it can sit until being used in the AD.

Figure 2.6: Manure Cellar Pump.

2.3.3.2 Manure and Digestate Storage

Depending on how the farm is build, or on the willingness of the farmer to upgrade his farm, manure can be stored in an underground cellar. This manure cellar, as seen in Figure 2.7, can be either entirely used for manure (Figure 2.7-A) or divided in two (Figure 2.7-B) in order to stock both manure and digestate underground. Case B of Figure 2.7 can be a better solution as it reduces the required volume of manure for the manure cellar pump to be able to pump. As a consequence, manure sits for less time in the cellar and therefore the manure quality pumped to the digester is of better quality. In cases without underground cellar on the farm, the manure can be directly pumped to the reactor. In this case, the farmer will need less manure production to run the AD plant as the manure will be fresher. The digestate coming out of the reactor can be pumped back into an underground cellar as seen in Figure 2.7, or into a specific storage as seen in Figure 2.8.

2.3.3.3 Manure Supply Cycles

With an automated manure collection and pumping to the reactor, the AD plant requires a minimum of one feeding cycle a day. A pressure sensor at the bottom of the reactor allows the reactor to quantify the height of manure in the reactor. Based on the height result, the right volume of digestate will automatically be pumped out of the reactor and a complementary volume of manure will be pumped into the reactor. The volume of fresh manure used in a cycle can be determined by the user, taking into account that a big

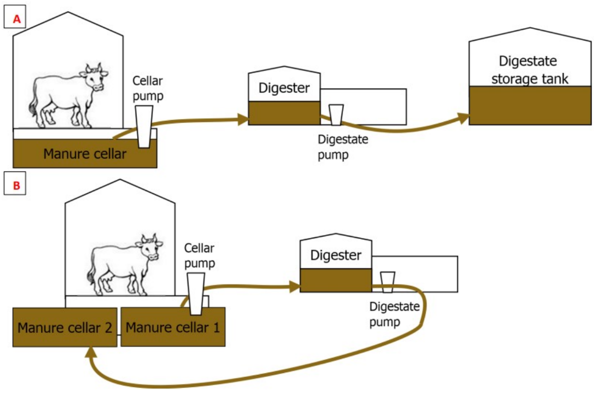

Figure 2.7: Manure and Digestate Cellar (taken from (*Manuel d'utilisation et d'entretien Installation biogaz Biolectric*, 2020)).

Figure 2.8: Digestate Storage.

amount of fresh manure might considerably reduce the temperature inside the reactor and therefore affect the effectiveness of the AD. On a daily basis, 1 to 8 feeding cycles can be executed. In some cases, because of the sensibility of microorganisms consortium, multiple small supply cycles are preferred (*Manuel d'utilisation et d'entretien Installation biogaz Biolectric*, 2020).

2.3.3.4 MyBiolectric Web Page

The operation of the AD plant can be controlled via the "MyBiolectric"tab through the web page: https://biolectric.be/. MyBiolectric lets the user control many types of variable setups such as the quantity of daily manure pumped into the digester or the cycles schedule. The user can be notified of any warnings concerning the AD plant both on "MyBiolectric"or via SMS. MyBiolectric is composed of various tabs that inform the user about the energy production efficiency, the H_2S concentrations, the gas quantities, engine running data and maintenance, the manure supply, and many other critical operating informations (*Manuel d'utilisation et d'entretien Installation biogaz Biolectric*, 2020).

2.4 Financial Tools

2.4.1 Net Present Value

The Net Present Value (NPV) is a financial tool used to evaluate the present value of future cash-flows. The value of stagnant money erodes over time, not only because it could have been used in valuable "no-risk"projects, generating safe returns, but also because of inflation. To be financially convincing, "risky"projects should at least be sufficiently attractive to overcome inflation erosion over time, and also beat the interest rate offered by "no-risk"projects. NPV is computed, as seen in Equation (2.11), by summing the discounted cash-flows of the project from year 0 to year N_P - total project duration.

$$NPV = \sum_{0}^{N_P} \frac{CF_n}{(1+r)^n} \tag{2.11}$$

The discount rate, r, is chosen by the decision maker, and reflects his opinion on what the project should return considering the risks it involves. The higher the discount rate, the lower the NPV, which is less interesting for the decision maker. Once the discount rate has been chosen, all projects with positive NPV are interesting. The ones with negative NPV don't generate enough money to overcome the needs of the decision maker (Gallo, 2014).

2.4.2 Internal Rate of Return

Internal Rate of Return (IRR), as shown in Equation (2.12), is the value of the discount rate that sets the NPV equal to zero. In a wrap, decision makers should see the IRR as an upper limit to their chosen internal rate of return. Beyond the IRR, the project does not generate enough money to compensate the money spent (Hazen, 2003).

$$NPV = \sum_{0}^{N_P} \frac{CF_n}{(1+IRR)^n} = 0 \tag{2.12}$$

2.4.3 Payback Period

The payback period, measured in number of years, gives an idea of the time it takes for the total cumulated income to overcome the total cumulated costs. Decision makers should see payback as the time it takes to get their money back.

2.4.4 Levelized Cost of Energy

The Levelized Cost of Energy (LCOE) defines the cost of the produced energy considering the lifetime of the project, with discounted fluxes. This indicator is measured in €/kWh, and can be computed using Equation (2.13). In this indicator, decision makers will use I_0 and D_t as an estimation of the costs, and E_n as an estimation of the energy produced in year n (Ouyang & Lin, 2014).

$$LCOE = \frac{I_0 + \sum_1^{N_P} \frac{D_t}{(1+r)^n}}{\sum_1^{N_P} \frac{E_n}{(1+r)^n}} \tag{2.13}$$

2.5 Project Financial Rates

The financial rates used to discount or capitalize fluxes throughout the projects lifetime are key in understanding the financial project efficiency. These rates should be carefully chosen, and adapted to the decision makers expectations regarding the project performance.

2.5.1 Discount Rate

Depending on the type of project analysis, discount rates must be calculated differently. In projects where prices are considered constant, with no variations over the project lifetime, a real interest rate should be used to discount the cash-flows. This real interest rate includes an estimation of the opportunity cost of capital, as well as a risk premium. In projects where prices are considered to vary over time, inflation should be taken into account. In this case, the cash-flows are discounted at a nominal interest rate (Santos, 2023). Equation (2.14) shows how the nominal interest rate (r_N) should be computed in function of the real interest rate (r_R) (European Commission, 2014). For European renewable energy projects with a period expectancy ranging from 15 to 25 years, the European Commission suggests to use a real interest rate of 4%. Using the 2% inflation rate defined in Section 2.5.2, the nominal discount rate for the Portuguese market is therefore settled at 6,1%. For the USA market, a 6,19% estimated Weighted Average Cost of Capital (WACC) of USA agricultural industry will be used as a discount rate (Uter, 2023). However, in order to help the decision maker decide whether these estimations are safe or not, a sensitivity analysis is conducted in Section 3.9 for Portugal and Section 4.8 for USA.

$$(1 + r_N) = (1 + r_R) * (1 + i) \tag{2.14}$$

Using WACC as a discount rate to compute the NPV gives the investor an idea about how the investment compares to the opportunity cost of his capital (Santos, 2023). In practical terms, firms can typically use either equity or debt to source the money they need for projects. Equity is money the company owns to its investors with no return guarantee, whereas debt is borrowed money the company needs to reimburse. In both cases, the company is expected to return the money with an extra interest rate. WACC is an estimation of how much interest rate the company pays for money coming from both equity and debt. For this reason, it can be considered as the minimum discount rate a project should return. If the project expects to return less than the firm's WACC, it is usually not profitable for the firm because the money it uses in the project costs more than the project can return (Husmann & Schmidt, 2008).

2.5.2 Inflation Rate

An inflation rate can be used to capitalize costs throughout project lifetime. In this way, the financial simulation will take price rises over time into account. Literature wise, the rate used to estimate inflation over time varies a lot. In some cases, inflation estimations are made custom in function of the specific resources used in the project, which requires a lot of time. In the financial simulations conducted in this thesis, a 2% inflation rate will be used for both the Portuguese and USA market. The choice for this 2% rate is based on a prevision converging towards 2% until 2027 by the *Ministério das Finanças* for Portugal (Ministério das Finanças, 2023) and by the Organization for Economic Cooperation and Development (OECD) for USA (OECD, 2023). However, in order to help the decision maker decide whether this estimation is safe or not, a sensitivity analysis is conducted in Section 3.9 for Portugal and Section 4.8 for USA.

3

Business Case: Portugal

The following chapter is dedicated to evaluating the potential of Portugal for the implementation of SSAD plants by Biolectric in dairy farms. After describing the market, a case study is performed at Agro ABA, to define local dairy farmers needs and choose the most suited AD plant for the farm.

3.1 Portuguese Energy Market

3.1.1 Electrical Energy Mix

The 2022 Portuguese national electrical energy consumption, as shown in Figure 3.1, was composed of 49% of renewable energy, 33% of non renewable energy and 18% of energy balance imports. That same year, the total electrical energy consumption reached 50,4 TWh. The 49% of renewable energy were composed of 5% of solar energy, 25% of wind energy, 13% of hydro energy and 6% of biomass. Natural gas accounted for the 33% of total non renewable energy consumption. Portugal has been eliminating coal from its national energy supplies since 2017, which results in a significant increase in electrical energy import balance from 2020 to 2022 (REN, 2022).

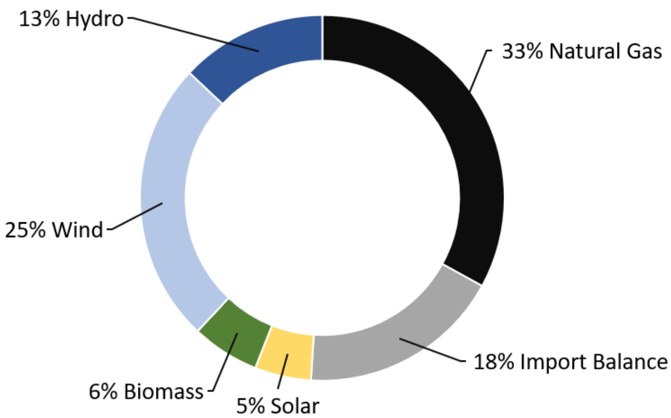

Figure 3.1: Portuguese 2022 Electrical Energy Mix. Adapted from (REN, 2022).

3.1.2 Renewable Energy Potential

With the adoption of Renewable Energy Directive (RED) II in 2018 and its following revision in the "Fit for 55"plan under the European Green Deal, renewable energy has gained a lot of interest in the EU. The plan aims to develop new energy entities on the renewable energy market, to promote the use of renewable energy sources at scale. Renewable Energy Communities (REC), as defined in Section 3.1.2.1, have been recognized to increase energy efficiency, attract private investment in the clean energy sector, increase public acceptance of renewable energy projects and lower electricity bills (Parliament, 2023). In Portugal, as described in Section 3.1.2.2, based on Decreto-Lei n.º 76/2019, 2019, electricity produced by renewable sources can be sold at a fixed tariff, defined by the guaranteed remuneration, or at a general tariff fixed by the market.

3.1.2.1 Renewable Energy Communities

REC can be defined as a group of investors, consumers and producers of renewable energy that organize themselves for the sale, distribution and consumption of that same energy. These communities not only help reducing GHG emissions by producing renewable energy, they also play a key role in diversifying energy sources (Soeiro & Dias, 2020). REC are described in the EU Directive 2019/944, 2019 as a legal entity based on the social participation of private individuals, local authorities, municipalities and small firms. The main purpose of the REC is defined as creating environmental, economical and social benefit to community members. Additionally, the guideline defines authorized activities as distribution, selling, consuming, aggregation, storage, providing energy efficiency services, providing charging stations for electric cars, or other energy related services to community members (DGEG, 2019).

3.1.2.2 Price Valuation of Renewable Electricity

Renewable energy projects, such as the creation of a REC, have the potential to create value in different ways. These projects can mitigate the risk of an electricity interruption, reduce electricity bills, improve environmental quality, help reducing the dependence to fossil fuels, etc (Soeiro & Dias, 2020). However, the eagerness of private investors to develop such projects, will, most often, be driven by the financial performance of these projects. In that sense, the price, payed by the consumers, for every kWh of renewable energy produced is very important. In Portugal, with regard to Decreto-Lei n.º 90/2006, 2006, the guaranteed purchasing price of renewable electricity per type of energy source, as found in Table 3.1, is quite interesting. In the case of biogas, the electricity produced can be sold at a guaranteed 0,1217 €/kWh.

Table 3.1: Portuguese Renewable Electricity Guaranteed Purchasing Price (ERSE, 2023).

Energy Source	Wind	Hydro	Biogas	Biomass	Photovoltaic	Offshore Wind	Waves	Municipal Solid Waste
Price (€/kWh)	0,087	0,1014	0,1217	0,1258	0,2885	0,1506	0,0	0,1705

3.2 Biolectric Market Description & Sizing

3.2.1 Number of Dairy Cows

The dairy sector in Portugal was composed of 221 540 dairy cows in 2022, which represented half of Belgium's dairy cow population and one seventh of Holland's cow population. The population of dairy cows in Portugal decreased 9% from 2015 to 2022. A significant part of the dairy cow population in Portugal is on Azores Islands, they represented 39% of the total Portuguese cow population in 2019. Additionally, in 2019, 83 330 cows could be found in farms that had more than 100 cows on the Portuguese mainland, and 24 234 in Azores. In 2019, as seen in Table 3.2, farms ranging from 50 to 99 cows accounted for 55 279 cows on the mainland and 53 169 in Azores. On a EU scale, Portuguese dairy cows represent 1,1% of the total EU dairy cows population. According to Figure 3.2, Portugal is the 17th country in terms of EU dairy cows population (Eurostat, 2022a). The total cow population in Portugal mainland in farms with more than 50 cows is of 122 626.

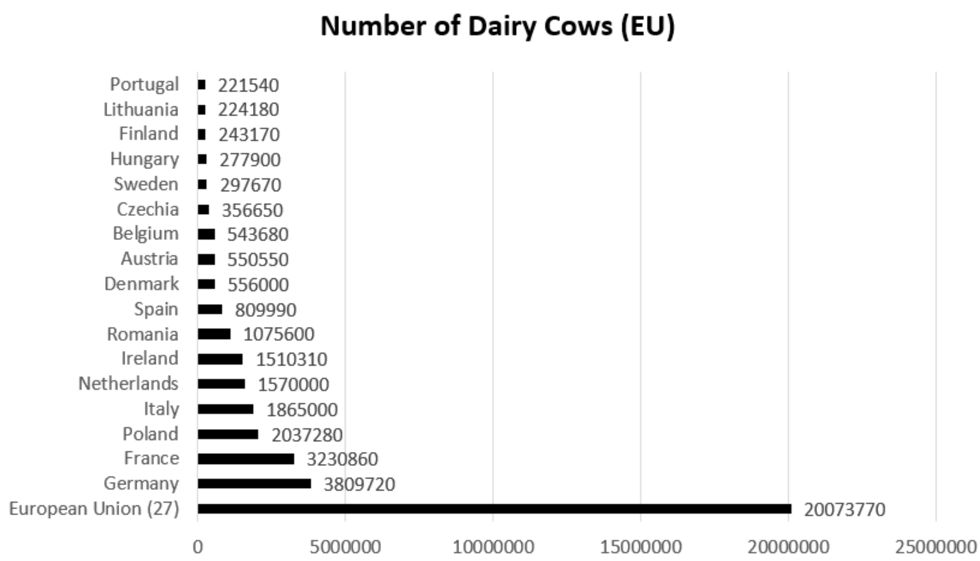

Figure 3.2: Number of Dairy Cows (EU) (Eurostat, 2022a).

3.2.2 Number of Dairy Farms

As shown in Table 3.2, in 2019, most dairy farms in Portugal were composed of 60 to 99 cows, and most cows could be found in the 100 to 199 cows category. On the mainland, 72% of exploitations were found in the North, and they accounted for 55% of the mainland dairy cow population. All in all, the Portuguese dairy sector was composed of 1 587 dairy farms in 2019, from which 40% were on Azores Islands.[1] Portugal mainland is home to 959 dairy farms composed of 50 cows or more, 43% of which in the 60 to 99 cows range.

[1]The only dairy farms considered in these statistics are the ones with a minimum of 50 cows, the minimum required amount of cows to run a SSAD plant by Biolectric.

Table 3.2: Size Distribution of Dairy Farms in Portugal (INE, 2019)

Size Categories		Portugal	Mainland	North	Center	Lisbon	Alentejo	Algarve	Azores	Madeira
50 to 59	N° Exploitations	324	164	128	27	2	7	0	159	1
	N° Cows	17 167	8 619	6 744	1 407	109	359	0	8 498	50
60 to 99	N° Exploitations	712	416	328	77	3	8	0	296	0
	N° Cows	52 605	30 677	23 897	5 961	218	601	0	21 928	0
100 to 199	N° Exploitations	413	263	201	42	7	13	0	150	0
	N° Cows	53 227	34 374	26 015	5 692	913	1 754	0	18 853	0
200 to 299	N° Exploitations	75	58	28	14	2	14	0	17	0
	N° Cows	17 203	13 556	6 518	3 317	458	3 263	0	3 647	0
≥300	N° Exploitations	63	58	9	6	12	31	0	5	0
	N° Cows	37 134	35 400	4 177	2 912	10 070	18 241	0	1 734	0
Totals	N° Exploitations	1 587	959	694	166	26	73	0	627	1
	N° Cows	177 336	122 626	67 351	19 289	11 768	24 218	0	54 660	50

3.2.3 Milk Prices and Milk Yields

Medium prices (Net of Value Added Tax (VAT)) paid to the farmer per 100 kg of milk in Portugal have been lower than the European medium from 2009 to 2019 (GPP AG, 2021). However, in 2022, the average milk price in Portugal increased 36% in comparison to the national 10 year price average before that. The average milk price has become 31% more expensive than the one in Belgium in 2022 although milk prices had been similar in Belgium and in Portugal for the last 10 years. (Eurostat, 2022b) This tremendous 2022 increase in milk prices is related to a sudden increase in the price of production factors such as energy, cows alimentation and fertilizers (CONFAGRI, 2023). The average price paid to individual farmers in Portugal mainland in 2023 was 0,516 €/kg (GPP, 2023). With a dairy milk production of 1 935 544 l in 2021 (INE, 2023), and a cow population at the time of 230 020 (Eurostat, 2022a), the 2021 Portuguese milk yield was 8,4 t/cow, which is higher than the European 2020 average of 7,3 t/cow (European Commission, 2023).

3.3 Predicted Evolution of the Dairy Sector

The current tendency of the Portuguese dairy sector is to decrease in the number of dairy farms, and increase the number of heads per dairy farm. From 2009 to 2019, the number of dairy farms decreased 51%, and the total amount of cows decreased 12%. Over the same period, the amount of dairy cows in farms with less than 30 cows decreased 56% and the number of cows in farms with more than 100 cows increased 46%. (GPP AG, 2021) Interestingly, the total amount of milk production in Portugal only decreased 1% from 2009 to 2019 (INE, 2023), and milk prices have stayed stable from 2011 to 2019 (Eurostat, 2022b). The Portuguese dairy sector is therefore evolving towards dairy farms with high efficiency, which reflects in high milk yields. In the future, we therefore expect to find highly specialized dairy farms, with increasing needs to reduce costs to stay competitive. SSAD plants by Biolectric might therefore play a key role in the future of Portuguese dairy farms, providing them with new manure related revenue streams and enhancing farms management.

3.4 Required Paperwork

3.4.1 Licensing of the Livestock Effluent Management Plan

The production of biogas through effluents is covered by the licensing of the livestock effluent management plan, as described in the Law Decree n.º 631/2009 of 9th June of 2009. The first step in the implementation of an AD plant is to send a request to the regional Direção Regional de Agricultura e Pescas (DRAP).

3.4.2 Municipal Licensing

The Municipal Licensing starts with a localisation feasibility request to the Municipality. The licensing of renewable energy producing units is evaluated by each Municipality. In this evaluation, the Municipality makes sure the energy producing unit is compatible with local territorial plans described in the Plano Diretor Municipal (PDM). In the specific case of the Municipality of Torres Vedras PDM, the installation of renewable energy producing units is permitted on rural lands.

3.4.3 Production Unit Registration & Environmental Impact Assessment (EIA)

Once the Municipal Licensing has been requested, the promoter will have to present a request for a production unit registration to the Direção-Geral de Energia e Geologia (DGEG) and, eventually, a Environmental Impact Assessment (EIA) to the Agência Portuguesa do Ambiente (APA).

3.4.3.1 Energy Production Unit Registration

The DGEG regulates energy production units and requires them to be registered. Energy production units under 350 W don't need any type of control or registration. For units between 350 W and 30 kW, producers should only notify the DGEG of their existence through their portal, indicating "Nova Mera Comunicação Prévia (MCP)". Units with installed power above 30 kW and under 1 MW should firstly be registered on the DGEG portal indicating "Nova Unidade de Produção para Autoconsumo (UPAC)"and receive an operating license as described in Law Decree n.º 172/2006 of 23^{rd} of August of 2006. Following the Ordonnance n.º 15/2020 of the 23^{rd} of January of 2020, the fees related to the production of electricity from renewable sources are described in Table II of the Law Decree n.º 172/2006 of the 23^{rd} of August of 2006 (Portaria n.º 15/2020, 2020). Applicable fees for installed powers up to 250 kW include a pre-production registration cost of 400 €, an issuing of operating certificate cost of 80 € and a DGEG inspection cost of 480 € (Decreto-Lei n.º 162/2019, 2019).

3.4.3.2 EIA

The need to establish an EIA is referred to in Annex II of the Law Decree n.º 152-B/2017 and concerns all industrial energy producing units, not refered in Annex I, above 20 MW. AD plants are not referred to in Annex I of the Law Decree n.º 152-B/2017. SSAD plants maximum electrical power output is 99 kW. Therefore, SSAD plants don't require EIA in Portugal, provided they are not built on sensitive areas (Decreto-Lei n.º 152-B/2017, 2017).

3.4.4 Licensing of Private Works

Once all the previous licensing and registration is complete, a license of private works should be introduced to the Municipality. The costs linked to the following license vary from one Municipality to another. In the specific case of the Municipality of Torres Vedras, following Notice n.º 714/2016, a fee of 400 € is due for the assessment of the request (Table 8 - Point 1), another fee of 100 € is due for issuing the installation permit (Table 14 - Point 9) and 3,5 €/m^2 are due for all associated buildings (Table 13 - Point 2) (Aviso n.º 9961/2016, 2016).

3.5 Investment Support

3.5.1 Environmental Fund

The Environmental Fund is trying to promote the creation of REC and self-consumption through financing long-term projects. Project promoters can benefit up to 200 000 € per UPAC, with a maximum of 500 000 € of benefit. Residential user installations can benefit up to 70% of co-funding whereas business and services user installations can benefit up to 50% of co-funding. Projects can include selling excess electricity with a maximum excedent of 20%. The Environmental Fund accepts applications for UPAC co-funding projects until 2025 (Fundo Ambiental, 2023).

3.5.2 Voluntary Carbon Market in Portugal

Carbon credits are meant to certify a specific installation reduces GHG emissions, and can be traded. The voluntary carbon market in Portugal is regulated by the APA, who defines the market players, the products, the eligibility of projects and their traceability (PLMJ, 2023). Carbon credits can be emitted for projects aiming for reducing or sequestration of carbon emissions, after validation by an independent third-party. The certificates can be attributed before or after the emissions reduction or sequestration (APA, 2023). The Portuguese voluntary carbon market is framed by Law Decree n.º 12401/2020 in Diário da República, 2020 and its creation was approved in November of 2023 by the Council of Ministers (Jornal de Negócios, 2023) after its presentation in March of 2023 (República Portuguesa, 2023). On the EU Emission Trading System (ETS), carbon credits have broken a price record of 100 €/tCO_2e in 2023 (Financial Times, 2023).

3.6 Competitors & Strategic Partners

3.6.1 Sotecnisol

Sotecnisol is a 50 year old Portuguese company specialized in roofing & facades, energy, water treatment, engineering and coatings. They operate in Portugal, Brasil, Angola, Moçambique, Italy and Spain. Sotecnisol has conducted various renewable energy projects which includes 20 projects in energy valorization of biogas. Their website mentions they are able to install AD plants in dairy farms, however, in the conducted projects section they only mention biogas plants in water treatment plants. At the moment, Sotecnisol might not be a direct competitor to Biolectric, however, in the future, given the scope of their activity and provided AD plants gain market in Portuguese dairy farms, Sotecnisol could quickly become a major player in AD plants in the country. Sotecnisol could therefore be considered as a potential strategic partner to install Biolectric plants in Portugal (Sotecnisol, 2023).

3.6.2 Genia Global Energy

Genia Global Energy is a Spanish energy company that focuses on delivering energy solutions and energy management solutions. Genia Bioenergy, a division of Genia Global Energy, sells, among other products, SSAD plants suited for swine farms, dairy farms, poultry farms and others. Genia is able to develop a SSAD plant and provide support in the construction, paperwork, and management of the plant in Spain. With a strategic position over the Portuguese market, being a Spain based company, Genia is a direct competitor to Biolectric. (Genia Bioenergy, 2023)

3.6.3 Equiporave

Equiporave is a poultry, pig and cow equipment installer operating in Portugal since 1976. Equiporave delivers turnkey housing projects and has a set of workforce and engineers that could install SSAD plants in Portuguese farms. Additionally, Equiporave also operates in some Spanish regions as well as in Angola. After a formal conversation with the CEO at Equiporave, M. Asdrubal Neves, would be interested in presenting the SSAD plant by Biolectric to some of his clients and add the SSAD plant to his product portfolio. Equiporave can therefore be considered as a potential strategic partner for the Portuguese market.

3.7 Practical Case Study: Sociedade Agro-Pecuária Agro ABA

This section is dedicated to the study of a business case in Portugal to understand how a SSAD plant by Biolectric could adapt itslelf to local needs. The case study took place at a dairy farm called Agro ABA, located in Campelos (39°10’59.640"N; 9°13’51.155"W), in the municipality of Torres Vedras. Agro ABA is a 15 employee, 879 cows, unipessoal company owned by Mr. Telmo Rodrigo. Agro ABA owns 120 ha of ryegrass lands and 35 ha of corn lands. The farm uses tractors to scrape stables and manually inserted pumps to milk cows, as shown in Figure 3.3. Agro ABA uses slurry[2] to fertilize fields and also gives some of the slurry to neighbors. The yearly temperature in the region ranges from 0°C to 30°C (IPMA, 2023).

Figure 3.3: Manual Milking

3.7.1 Cows

The farm owns 879 Holstein Frísia cows, with stables made out of cement floors and beds of either sand or straw as shown in Figure 3.4-A. The cows feed is a mix, as shown in Figure 3.4-B, composed of corn silage, corn, wheat, soya, beer batter, straw and minerals. Dry cows and youngsters, who are not producing milk, eat ryegrass silage and cereals. The farm monitors the cows through a program called "Dairy Plan"that provides real-time information over herd, reproduction, milking, and individual information over the cows. Adult cows at Agro ABA weigh circa 650 kg and have an average production of 32 l/day, which represents a very high milk yield of 11,7 t/cow.

Figure 3.4: A) Stables at Agro ABA; B) Cows mixed nutrition

[2]Slurry refers to a liquid mix of manure and water.

3.7.2 Electricity Bills

Agro ABA has an average electricity consumption of 450 kWh/day, and currently pays an average of 2 500 €/month, which represents an average of 0,185 €/kWh. The contracted power at Agro ABA is 40 kW, to be increased in the future, and their contract is based on a tri-hours-price contract (0,10;0,17;0,25) €/kWh. The farm has 37,8 kW of photovoltaic panels installed, 108 panels of 350 W, which provides them with a 30% autonomy. The most energy consuming activities at the farm are milking and milk cooling processes. The farm currently uses 700 l/day of hot water, which is heated via heat exchangers that cool down the milk. Mr. Telmo, owner of Agro ABA, insisted on the fact that the farm has more cooling necessities than heating necessities. In the future, Agro ABA expects to pay more for each kWh bought, they are therefore looking for renewable energy projects, to decrease their electricity bills, with paybacks lower than 10 years.

3.7.3 Electricity Measurements

In order to characterize the electricity consumption at Agro ABA, a power supply curve was measured at the farm. On the 17th of October 2023 at 13h00, as shown in Figure 3.5-A and Figure 3.5-B, a Chauvin Arnoux C.A 8334B three phase power quality analyzer was connected on Agro ABA's electrical panel, measuring the grid energy supply. The device measured the current and voltage supplies over a week of time, until the 23rd of October 2023 at 13h00.

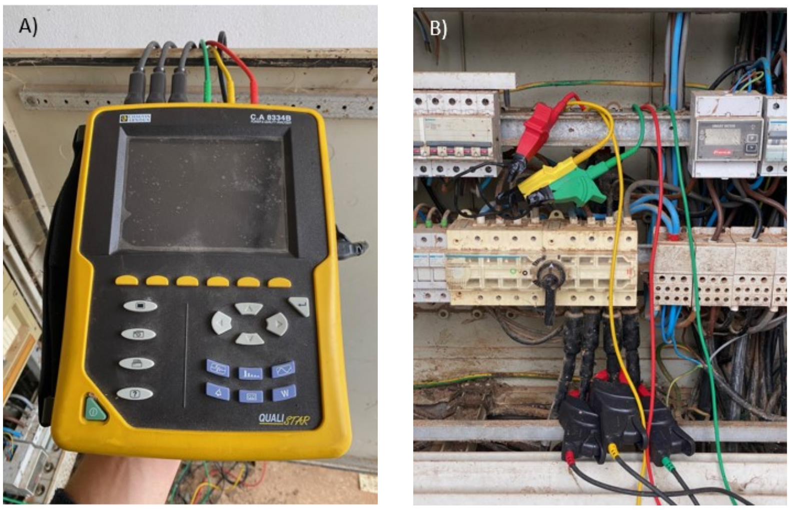

Figure 3.5: A) Three Phase Power Quality Analyzer; B) Current and Voltage Connectors

Power curves were then extracted, via an Excel file, and can be seen in Figure 3.6 and Figure 3.7. As seen in both Figure 3.6 and Figure 3.7, the power curve sometimes drops to negative values, the reason being Agro ABA produces electricity with photovoltaic panels. The peak power registered at Agro ABA is 31,5 kW, and most often occurs between 18h00 and 00h00, when photovoltaic panels don't produce energy.

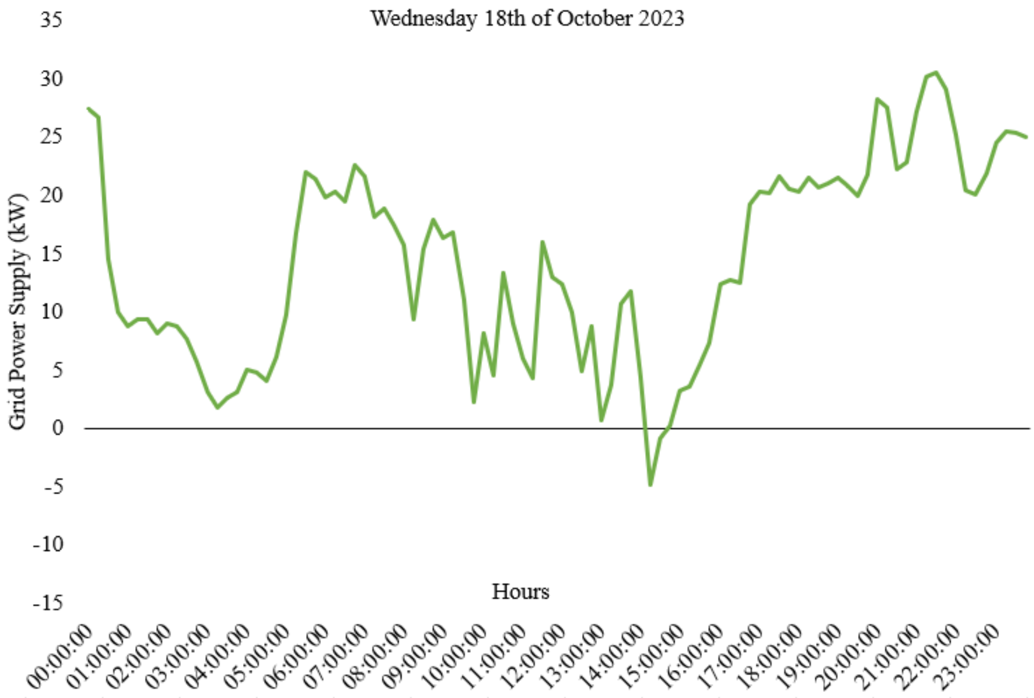

Figure 3.6: Daily Power Curve

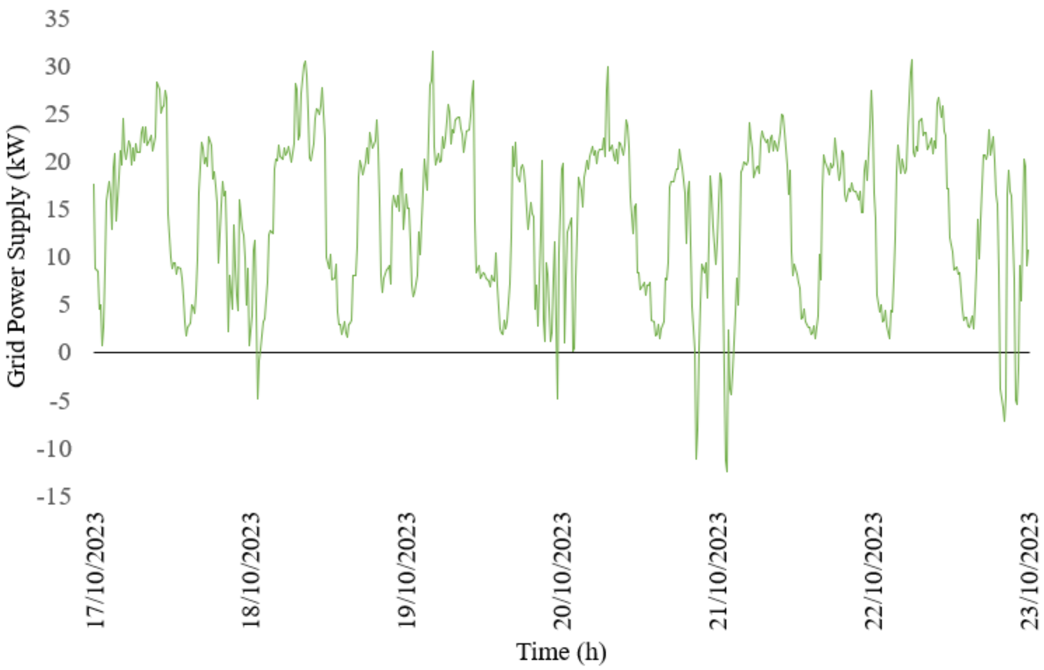

Figure 3.7: Weekly Power Curve

3.7.4 Water

Water on the farm comes from a water hole, is not treated, contains limestone but is still drinkable. In all activities, including the cleaning of the milking parlor, Agro ABA uses an average of 2 000 l/day.

3.7.5 Necessary Barn Adaptations

Inspired of his previous experiences in the USA, Mr. Telmo started developing a flushing system to collect his manure. Eventhough the SSAD plant by Biolectric could work with such a system under some water quantity restrictions, the performance of the SSAD plant would be at risk. With high water quantities, the SSAD plant will be harder to set at the desired 42°C and a larger amount of manure will have to be fed for the same energy production. Additionally, special care will be required with sand beds given their incompatibility with SSAD plants. After a formal conversation with Mr. Telmo, the cow bedding at the farm could be modified and enhanced to meet the AD plant requirements. In his opinion, cows at Agro ABA are not feeling comfortable in sand beds and they might consider other types of bedding. An extra 10% of installation costs was added to the simulations to ensure Agro ABA can modify his flushing system and adapt cow bedding.

3.8 Financial Simulations: Case Study at Agro ABA

3.8.1 Project Costs

The costs considered in the business case, as shown in Table 3.3 include the price of the AD plant, its installation, maintenance, active charcoal, insurance, grid connecting and measuring devices, permitting and barn adaptations. The AD plant cost includes the price of the AD plant and its installation, the transportation costs, the project management and the first year of maintenance. The maintenance and active charcoal prices are capitalized throughout the project at a 2% inflation rate found in Section 2.5.2. The grid connectors and measuring devices are considered to cost around 2 000 €/year. Permitting fees were estimated using the information in Section 3.4. After the three first years of maintenance by Biolectric, the maintenance costs are predicted to decrease to half their original cost, being that Agro ABA has the know-how and maintenance team required.

Table 3.3: SSAD Installation Costs in Portugal.

							Units
SSAD Type	11	22	33	44	60	74	kW
N° of cows	60	120	180	240	325	400	
AD Plant	177 931	240 206	311 379	373 655	459 061	515 999	€
Maintenance	10 000	14 000	18 000	22 000	24 000	25 000	€/year
Active Charcoal	1 000	2 000	2 000	2 500	2 800	3 000	€/year
Insurance (% of AD Plant Price)	0,5%	0,5%	0,5%	0,5%	0,5%	0,5%	€/year
Grid Conncection & Measurement	2 000	2 000	2 000	2 000	2 000	2 000	€/year
Permitting	5 000	5 000	5 000	5 000	5 000	5 000	€
Barn Adaptation	35 000	35 000	40 000	40 000	45 000	50 000	€

3.8.2 Investment Support

The investment support used in the business case includes a Feed-In-Tariff (FIT) and a capital co-funding by the Environmental Fund as described in Section 3.5.1. The simulations performed in Section 3.8.3 and Section 3.8.4 show two distinct results depending on whether the Environmental Fund co-funds the project or not. The model without co-funding is called "raw model"and the other one is called "co-funded model".

- **FIT**: The FIT used in the business case is the 0,1217 €/kWh one defined in Section 3.1.2.2. The farm will make use of all the possible electricity generated by the AD plant, and sell the excess at the FIT tariff. The current buying electricity price at the farm is considered to be 0,185 €/kWh as described in Section 3.7.2.

- **Environmental Fund**: In the co-funded model, a 200 000 € co-funding was used as described in Section 3.5.1. Given the 50% limit on qualified investment instored by the Environmental Fund, the smaller plants actually benefited from less than 200 000 €.

3.8.3 SSAD Raw Model

The following comparison between SSAD plants considers them as projects and compares them as shown in Table 3.4, using NPV, IRR, payback period and LCOE indicators. All project indicators were computed raw, using no type of investment support nor financing solutions. The aim is to provide the decision maker with a conservative financial simulation, that doesn't depend on the eagerness of the Environmental Fund to co-fund the project or on the fluctuations of the interest rates.

The project simulations are conducted over a period of 20 years, the discount rate used to compute the NPV, as defined in Section 2.5.1, is settled at 6,1% and the annual inflation rate of 2% is used to capitalize some costs and electricity prices, as defined in Section 2.5.2. The SSAD engines are considered to work 8 000 h/year. Mr. Telmo showed no interest in taking advantage of heat exchangers to heat water. Agro ABA is already self-sufficient in hot water and would rather have more interest in cooling systems. The full project simulations can be found in Annex II.

Table 3.4: SSAD Raw Financial Simulation at Agro ABA.

							Units
SSAD Type	11	22	33	44	60	74	kW
N° of cows	60	120	180	240	325	400	
Produced Gross Electricity	88 000	176 000	264 000	352 000	480 000	592 000	kWh/Year
Initial Investment	221 821	285 407	361 936	425 023	516 156	578 579	€
NPV	-110 169	-15 585	19 213	60 759	206 104	255 833	€
IRR	-1%	5%	7%	8%	11%	11%	
Payback	>20	13	12	11	10	8	Years
LCOE	0,337	0,223	0,185	0,164	0,141	0,125	€/kWh

As shown in Table 3.4, the 74 kW installation appears to be the best raw model financial choice for Agro ABA, providing them with a 100% self-sufficiency, an interesting 8 year payback with a 255 833 € NPV, a 11% IRR and an interesting 0,125 €/kWh LCOE. With 879 cows at the farm, Agro ABA will produce more than enough fresh manure to feed the 74 kW SSAD plant, and will still have margin to add electrically ran cooling systems in the future.

3.8.4 SSAD Co-Funded Model

The co-funded model seen in Table 3.5 shows attractive simulations in all AD size categories above 11 kW. Overall, the 74 kW plant remains the best option for Agro ABA, with a payback period of 6 years, a NPV of 444 335 €, an IRR of 18% and a very attractive LCOE of 0,096 €/kWh, well under the 0,1217 €/kWh FIT used.

Table 3.5: SSAD Co-Funded Financial Simulation at Agro ABA.

							Units
SSAD Type	11	22	33	44	60	74	kW
Max. Excess Energy	20%	20%	20%	20%	20%	20%	
Initial Investment	221 821	285 407	361 936	425 023	516 156	578 579	€
Co-Funded Amount	110 910	142 704	180 968	200 000	200 000	200 000	€
NPV	-5 635	118 914	189 777	249 261	341 043	444 335	€
IRR	5%	15%	17%	17%	17%	18%	
Payback	13	7	7	7	7	6	Years
LCOE	0,227	0,152	0,124	0,114	0,104	0,096	€/kWh

3.8.5 SSAD Size Choice

The SSAD size choice bases itself on the complexity of paperwork, the applicable investment support, the power curve adaptation, and the attractiveness of both raw and co-funded financial simulations. As referred by Mr. Telmo, interesting projects should present a payback under 10 years. The plants available to choose are therefore the 60 kW and the 74 kW for raw financial simulations, as shown in Table 3.4, and from 22 kW to 74 kW in the co-funded simulations found in Table 3.5. The 74 kW plant is the best choice in all categories. Paperwork might be more complex for plants above 22 kW, but the overall financial and operational advantages of bigger plants makes them worth the additional paperwork.

The 74 kW plant would turn Agro ABA self-sufficient by largely covering the 31,5 kW peak measured in Section 3.7.3. Given the high output power compared to the peak power measured at the farm, the plant would have to be integrated in a REC, to make sure the 20% maximum excess energy imposed by the Environmental Fund is respected.

Table 3.6: SSAD Sizing Choice Matrix.

SSAD Type (kW)	11	22	33	44	60	74
Required Paperwork Complexity	Simple	Simple	Complex	Complex	Complex	Complex
Applicable Investment Support	50%	50%	50%	Dependent	Dependent	Dependent
Power Curve Adaptation	No	No	Self-Sufficient	Self-Sufficient	Self-Sufficient	Self-Sufficient
Attractive Raw Financial Simulation	No	No	No	No	Good	Best Option
Attractive Co- Funded Financial Simulation	No	Good	Good	Good	Good	Best Option

3.9 Sensitivity Analysis of Financial Simulations

3.9.1 Inflation Rate Previsions

The inflation rate suggested in Section 2.5.2 and used in Section 3.8.3 might not be an accurate estimation of what the future inflation will be. In order to make sure the financial simulations stay as conservative as possible, we hereby measured the sensitivity of the financial simulations to the inflation rate. Given the fact that we chose the 74 kW plant in Section 3.8.5, this analysis will focus on the 74 kW plant. Note that the recent economical conjuncture has been tricky and characterized by highly volatile markets. In 2021, inflation forecasters made errors up to nearly 3% in estimating inflation for the year (European Central Bank, 2022). This being said, for the sake of this simulation, a 1% error is considered acceptable given the 20 years of project life.

3.9.1.1 Raw Financial Simulation at 1% Inflation Rate

At 1% of inflation, as shown in Table 3.7, the raw simulation stays attractive, with a 178 420 € NPV, a payback in 8 years and a LCOE of 0,124 €/kWh. Unfortunately, the IRR is quite low at 8%, and is therefore nearly compromising the error accepted on the discount rate.

Table 3.7: Raw Financial Simulation at 1% Inflation Rate.

							Units
SSAD Type	11	22	33	44	60	74	kW
NPV	-123 211	-42 873	-18 304	13 559	138 404	178 420	€
IRR	-2%	4%	5%	6%	10%	8%	
Payback	>20	14	13	12	11	8	Years
LCOE	0,332	0,219	0,182	0,161	0,139	0,124	€/kWh

3.9.1.2 Co-Funded Financial Simulation at 1% Inflation Rate

At 1% of inflation, as shown in Table 3.8, the co-funded simulation is very attractive, with a 366 921 € NPV, a payback in 7 years, an IRR of 16% and a LCOE of 0,094 €/kWh.

Table 3.8: Co-Funded Financial Simulation at 1% Inflation Rate.

							Units
SSAD Type	11	22	33	44	60	74	kW
NPV	-18 677	91 626	152 260	202 060	277 909	366 921	€
IRR	4%	13%	15%	16%	16%	16%	
Payback	15	8	7	7	7	7	Years
LCOE	0,222	0,148	0,121	0,111	0,102	0,094	€/kWh

3.9.1.3 Raw Financial Simulation at 3% Inflation Rate

At 3% of inflation, as shown in Table 3.9, the raw simulation is very attractive, with a 342 973 € NPV, a payback in 8 years, an IRR of 12% and a LCOE of 0,128 €/kWh.

Table 3.9: Raw Financial Simulation at 3% Inflation Rate.

							Units
SSAD Type	11	22	33	44	60	74	kW
NPV	-95 416	15 195	61 517	113 975	282 336	342 973	€
IRR	0%	7%	8%	9%	13%	12%	
Payback	>20	12	11	11	9	8	Years
LCOE	0,343	0,227	0,188	0,167	0,143	0,128	€/kWh

3.9.1.4 Co-Funded Financial Simulation at 3% Inflation Rate

At 3% of inflation, as shown in Table 3.10, the co-funded simulation is very attractive, with a 531 474 € NPV, a payback in 6 years, an IRR of 19% and a LCOE of 0,098 €/kWh.

Table 3.10: Co-Funded Financial Simulation at 3% Inflation Rate.

							Units
SSAD Type	11	22	33	44	60	74	kW
NPV	9 118	149 695	232 081	302 476	412 153	531 474	€
IRR	7%	16%	18%	18%	18%	19%	
Payback	12	7	7	6	6	6	Years
LCOE	0,232	0,156	0,128	0,117	0,107	0,098	€/kWh

3.9.2 Discount Rate Previsions

The discount rate suggested in Section 2.5.1 and used in Section 3.8.3 might not be an accurate estimation of risks and capital opportunity cost. In order to make sure the financial simulations stay as conservative as possible, we hereby measured the sensitivity of the financial simulations to the discount rate. Given the fact that we chose the 74 kW plant in Section 3.8.5, this analysis will focus on the 74 kW plant. For the sake of this simulation, a 1% error in the discount rate is considered acceptable. We will therefore use 5,1% and 7,1% to characterize the sensitivity of the simulations.

3.9.2.1 Raw Financial Simulation at 5,1% Discount Rate

At 5,1% of discount rate, as shown in Table 3.11, the raw simulation is very attractive, with a 334 170 € NPV, a payback in 8 years, an IRR of 11% and a LCOE of 0,119 €/kWh.

Table 3.11: Raw Financial Simulation at 5,1% Discount Rate.

							Units
SSAD Type	11	22	33	44	60	74	kW
NPV	-101 503	8 557	53 817	105 331	264 082	334 170	€
IRR	-1%	5%	7%	8%	11%	11%	
Payback	>20	13	12	11	10	8	Years
LCOE	0,320	0,212	0,175	0,155	0,134	0,119	€/kWh

3.9.2.2 Co-Funded Financial Simulation at 5,1% Discount Rate

At 5,1% of discount rate, as shown in Table 3.12, the co-funded simulation is very attractive, with a 524 465 € NPV, a payback in 6 years, an IRR of 18% and a LCOE of 0,091 €/kWh.

Table 3.12: Co-Funded Financial Simulation at 5,1% Discount Rate.

							Units
SSAD Type	11	22	33	44	60	74	kW
NPV	4 025	144 336	226 003	295 626	404 981	524 465	€
IRR	5%	15%	17%	17%	17%	18%	
Payback	13	7	7	7	7	6	Years
LCOE	0,218	0,146	0,120	0,110	0,100	0,091	€/kWh

3.9.2.3 Raw Financial Simulation at 7,1% Discount Rate

At 7,1% of discount rate, as shown in Table 3.13, the raw simulation is still attractive, with a 188 042 € NPV, a payback in 8 years, an IRR of 11% and a LCOE of 0,132 €/kWh.

Table 3.13: Raw Financial Simulation at 7,1% Discount Rate.

							Units
SSAD Type	11	22	33	44	60	74	kW
NPV	-117 491	-36 335	10 610	22 300	155 561	188 042	€
IRR	-1%	5%	7%	8%	11%	11%	
Payback	>20	13	12	11	10	8	Years
LCOE	0,355	0,234	0,194	0,172	0,149	0,132	€/kWh

3.9.2.4 Co-Funded Financial Simulation at 7,1% Discount Rate

At 7,1% of discount rate, as shown in Table 3.14, the co-funded simulation is very attractive, with a 374 784 € NPV, a payback in 6 years, an IRR of 18% and a LCOE of 0,100 €/kWh.

Table 3.14: Co-Funded Financial Simulation at 7,1% Discount Rate.

							Units
SSAD Type	11	22	33	44	60	74	kW
NPV	-13 933	96 888	158 361	209 041	285 570	374 784	€
IRR	5%	15%	17%	17%	17%	18%	
Payback	13	7	7	7	7	6	Years
LCOE	0,235	0,157	0,129	0,118	0,109	0,100	€/kWh

3.9.2.5 Combining a 1% Inflation Rate and a 7,1% Discount Rate in a Raw model

At 1% inflation rate and 7,1% of discount rate, as shown in Table 3.15, the raw simulation is still attractive, with a 119 786 € NPV, a payback in 8 years, an IRR of 10% and a LCOE of 0,131 €/kWh. This last simulation could be considered as the most pessimistic one.

Table 3.15: Raw Financial Simulation at 1% Inflation Rate and 7,1% Discount Rate.

							Units
SSAD Type	11	22	33	44	60	74	kW
NPV	-128 997	-60 421	-43 696	-19 325	95 207	119 786	€
IRR	-2%	4%	5%	6%	10%	10%	
Payback	>20	14	13	12	11	8	Years
LCOE	0,351	0,231	0,191	0,170	0,146	0,131	€/kWh

3.9.3 Sensitivity Summary

Overall, considering the 74 kW plant, the lowest values found for the sensitivity simulations are a NPV of 119 786 €, an IRR of 8%, a payback period of 8 years and a LCOE of 0,132 €/kWh. The key takeaway of all these simulations is that the 74 kW installation wouldn't be very sensitive to a 1% change in either inflation or discount rate. The 74 kW project can therefore be considered as a safe investment for Agro ABA.

3.10 Market Overview: SWOT Matrix

The following SWOT matrix encompasses all the key aspects developed in the Portuguese market reasearch.

	Strengths Political motivation to create renewable energy communities; Simplified and Accessible Paperwork. Attractive 8 years payback without funding;	**Weaknesses** Voluntary Carbon Market still under development; Farmers need cooling solutions rather than heat.
Opportunities Small number of competitors; Environmental fund support up to 200 000 €; Guaranteed 0,1217 €/kWh FIT; Electricity price at Agro ABA (0,185 €/kWh) well over LCOE (0,096 €/kWh); 959 Dairy Farms on the Mainland (50 to 300+ cows); Low milk prices and farms getting bigger (100+ cows per farm); Local company interested in presenting the SSAD plant by Biolectric to local clients (Equiporave).	**S/O Strategy Analysis** With a strong interest of Municipalities to develop energy communities and simplified paperwork, Biolectric could easily take over the Portuguese market and become the major player in the country. 959 farmers are looking for opportunities to diversify revenue streams, and Equiporave is able to provide turnkey projects with its own workforce and engineers.	**W/O Strategy Analysis** The Environmental Fund provides farmers with a very interesting 200 000 € support for the creation of renewable energy communities, which compensates the fact that they can't yet sell carbon credits on the voluntary market. The attractive FIT and LCOE coupled with high electricity price of 0,185 €/kWh at the farm turn the project attractive even without taking advantage of the heat.
Threats Financial simulation highly dependent on FIT; Some potential competitors already well deployed (Genia Global Energy & Sotecnisol).	**S/T Strategy Analysis** The strong motivation of the EU to turn Europe resilient energy-wise should drive FIT levels up. Competitors are not yet involved in SSAD plants for dairy farms in Portugal, the 8 years payback should be enough to stay competitive.	**W/T Strategy Analysis** AD plants provide farmers with a great solution to reduce manure volumes while producing electricity with an interesting 8 years minimum payback. Equiporave can help Biolectric take over the market, and FIT might not be as important if AD plants are part of energy communities.

4 Business Case: East Coast USA

The following chapter is dedicated to evaluating the potential of the USA market for the implementation of SSAD plants by Biolectric in dairy farms. Given the size of this market, and the fact that dairy farms in the USA are generally much larger than European ones, Biolectric suggested to select five states. These five states must be located on the East Coast of the USA, where dairy farms sizes are comparable to European ones, and, if possible, the states should be as close as possible from one another. The following business case will therefore cover the states of Vermont, New York, Pennsylvania, Virginia and Ohio, as shown in green in Figure 4.1. The choice of these states was based on the number of dairy cows per state, as found in Table 4.1, this being the combination of neighboring states with the most dairy cows on the East Coast (USDA, 2022).

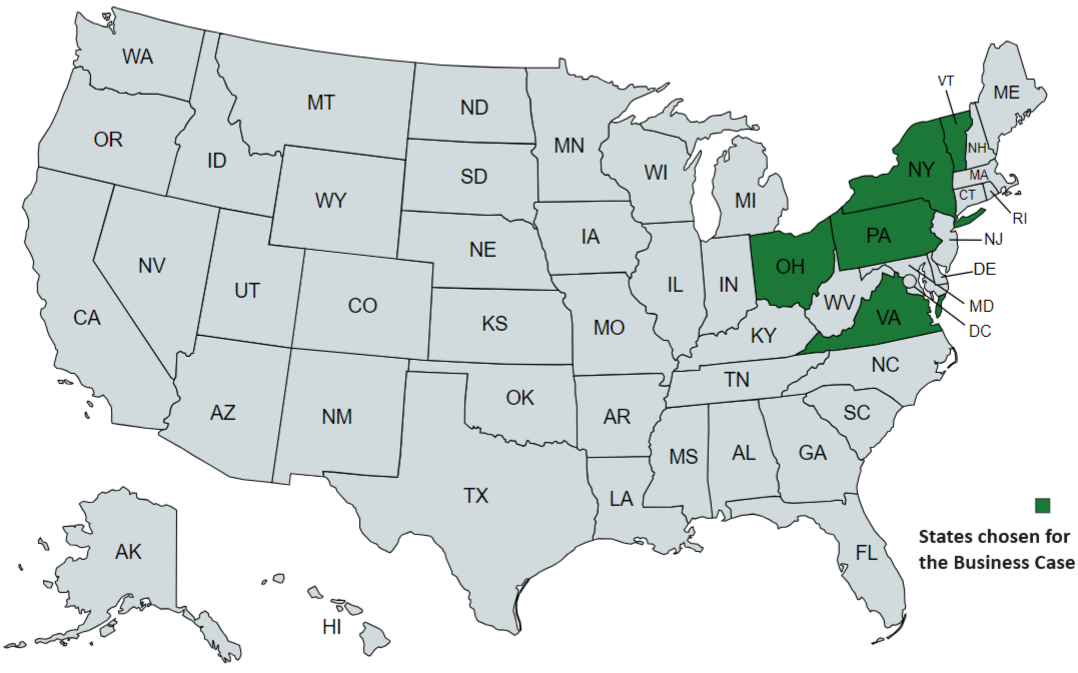

Figure 4.1: USA Business Case Map. Adapted from ("MapChart - USA", 2023).

Table 4.1: Number of Dairy Cows per State (USDA, 2022)

East Coast States	Number of Dairy Cows
New York	630 000
Pennsylvania	465 000
Ohio	250 000
Vermont	118 000
Georgia	92 000
Florida	92 000
Virginia	67 000
Kentucky	45 000
Maryland	40 000
North Carolina	39 000
Maine	25 000
Connecticut	18 500
New Hampshire	13 118
Massachussets	9 000
South Carolina	9 000
West Virginia	5 000
New Jersey	4 100
Delaware	2 600
Rhode Island	500
Total	1 924 818

4.1 USA Energy Market

4.1.1 Energy Mix

The 2022 USA energy mix, as shown in Figure 4.2, was composed of 36% of petroleum, 33% of Natural Gas (NG), 10% of coal, 8% of nuclear, and 13% of renewable energy. In total, fossil fuels therefore accounted for 79% of USA's energy mix. Renewable energy is mainly composed of biomass, 5% and wind, 4%. Solar and hydroelectric only represent 2% each, and geothermal is negligible.

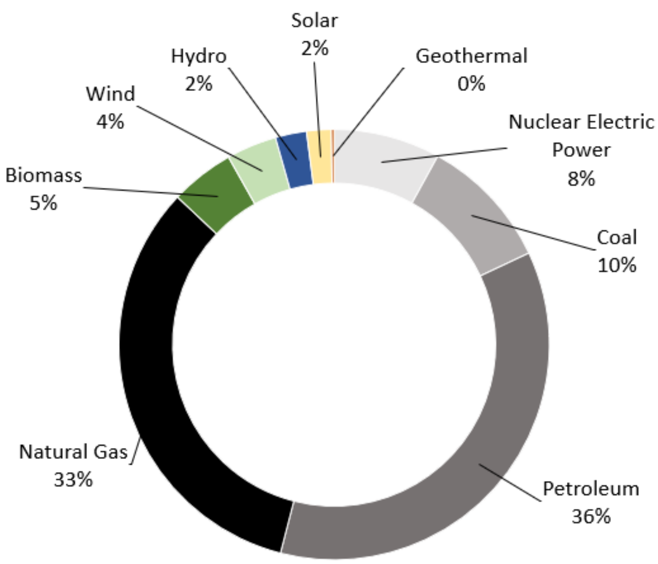

Figure 4.2: USA 2022 Energy Mix. Adapted from (U.S. EIA, 2022b).

4.1.2 Renewable Energy Potential

The Inflation Reduction Act (IRA) of 2022 signed by President Biden has the ambition to promote clean energy, enhance household energy production and address global warming (Roy et al., 2022). In practice, the USA government will fund, between others, renewable energy projects, including AD plants. In total, the amount funded by the IRA is 1 721 632 500 $ and funds up to 50% of the projects cost share. The IRA also proposes a tax credit for clean electricity production, and allows monetization of that credit to sell it (Bistline et al., 2023).

4.1.2.1 Qualified Biogas Property

Section 48 (A)(3) of the IRA mentions biogas plants as qualifying for Investment Tax Credit (ITC). Eligible biogas plants defined under this section should convert biomass into a gas containing a minimum of 52% CH_4 in volume[1], and use this gas for sale or productive use. Additionally, Section 48 suggests that these biogas plants are eligible as "Qualified Biogas Property"until 31 of December of 2024. After that date, new biogas constructions will not qualify for ITC under that amendment (U.S. Congress, 2023b).

4.1.3 Electricity Prices

The electricity prices of both buying and selling activities play a major role in the attractiveness of the business cases. These prices not only vary from one state to another, they fluctuate through the year and are dependent of the type of sector (residential, commercial, industrial). Table 4.2 shows a 2022 per state electricity average buying price. All studied states have defined a net metering tariff, where prosumers pay for the difference between produced and consumed electricity. The net metering mechanism is enabled by an energy meter that spins in both directions and therefore counts energy fluxes both from the grid and to the grid (Poullikkas et al., 2013). In the state of Vermont, farmers who install an AD plant can opt for either a net metering mechanism or a FIT at 0,145 $/kWh secured for 20 years.

Table 4.2: Average Electricity Buying Prices (U.S. EIA, 2022a)

States	Prices ($/kWh)
New York	0,1833
Vermont	0,1699
Pennsylvania	0,1186
Virginia	0,1075
Ohio	0,1064

[1] In ideal conditions, the Biolectric plant would produce a biogas containing 60% of CH_4 in volume, as referred to in Section 2.3.2.1.

4.2 Biolectric Market Description & Sizing

4.2.1 Number of Dairy Cows and Farms

In total, as shown in Table 4.1, the East Coast of the USA is composed of 1 924 818 dairy cows. The five states selected for the analysis account for 79% of the total East Coast dairy cows with 1 530 000 cows. Farms from 50 to 1 000+ cows own a total of 1 362 511 cows in the five states, divided into 8 587 farms, as shown in Table 4.3. All in all, New York is the state with the most dairy farms with a total of 2 309 farms, and the most dairy cows with a total of 504 412 heads. The most represented size category in the five states is the 50 to 99 cows category with a total of 5 078 farms and 340 867 dairy cows. On an international point view, as shown in Figure 4.3, the cow population on the five selected states is 13% lower than the one of the Netherlands, 150% higher than the one in Belgium and 690% higher than the one in Portugal[2].

Table 4.3: Size Distribution of Dairy Farms on the East Coast of USA (USDA, 2017)

Size Categories		New York	Vermont	Pennsylvania	Virginia	Ohio	Totals
50 to 99	N° Exploitations	1 295	255	2 674	189	665	5 078
	N° Cows	85 167	17 953	178 982	13 652	45 113	340 867
100 to 199	N° Exploitations	453	124	956	222	356	2 111
	N° Cows	60 673	16 861	122 162	29 385	47 870	276 951
200 to 499	N° Exploitations	278	86	255	77	179	875
	N° Cows	84 429	26 551	72 645	21 802	49 757	255 184
500 to 999	N° Exploitations	141	38	62	15	41	297
	N° Cows	97 715	26 723	41 622	10 078	25 961	202 099
≥1 000	N° Exploitations	142	21	24	5	34	226
	N° Cows	176 428	34 381	39 470	-	37 131	287 410
Totals	N° Exploitations	2 309	524	3 971	508	1 275	8 587
	N° Cows	504 412	122 469	454 881	74 917	205 832	1 362 511

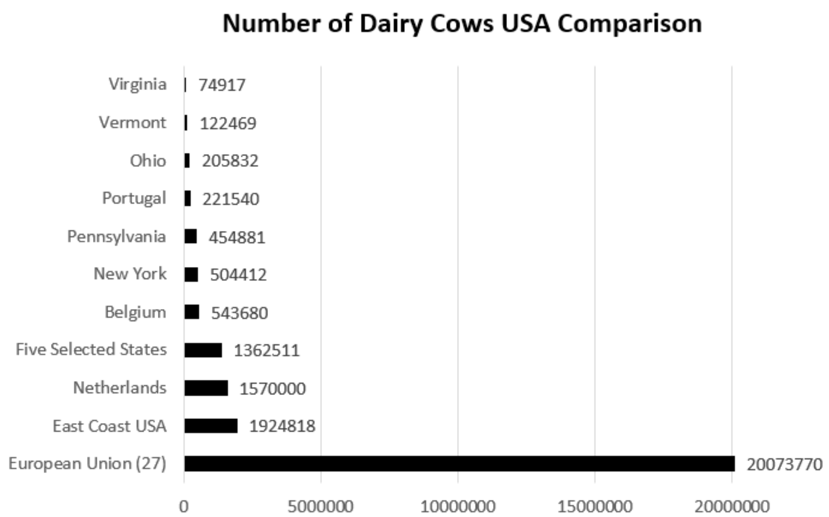

Figure 4.3: Number of Dairy Cows in the East Coast USA International Comparison.

[2]Note that in Figure 4.3 the cow populations considered for USA states only referred to farms with more than 50 cows, whereas the cow populations in all other countries represent the total population.

4.2.2 Milk Prices and Milk Yields

In the past decade, milk prices have fluctuated between 13,6 \$/cwt and 27,2 \$/cwt, which represents a milk price between 0,27 and 0,54 €/kg [3]. Similarly to European markets, milk prices in the USA rose significantly in 2022 with a 53% increase compared to 2021, and broke the decade record at 0,54 €/kg (USDA, 2024b). Milk yields observed in the USA are much higher than the ones found in Europe. In 2023, milk yields fluctuated between 10,3 and 11,6 t/year (USDA, 2024a).

4.3 Predicted Evolution of the Dairy Sector

The USA dairy sector has been evolving towards increasing milk yields and increasing levels of automation in the past 50 years. In the future, smaller farms are expected to incorporate greater levels of lateral integration to stay competitive (University of Minnesota Extension, 2019). Overall, the dairy sector tendency is similar to the one in Europe, with increasing average farm sizes, and decreasing number of farms (USDA, 2023). From 2007 to 2017, the number of dairy farms from 50 to 1 000+ cows decreased nearly 22%. In the same time frame, the national percentage of farms from 50 to 500 cows decreased 15% and the percentage of farms above 500 cows increased 2% (USDA, 2020). Overall, the USA dairy sector is evolving towards more specialized farms, with high milk yields, high automation requirements and increasing needs of farm management performance. The SSAD plant by Biolectric could therefore find its path on the USA market by providing small-scale farmers with new revenue streams based on cattle manure while optimizing manure management on the farm.

4.4 Required Paperwork

Permits and licenses are most often issued on a state to state level. Requirements may therefore vary from state to state. On an AD plant project point of view, it is advised to elect a team that will be responsible for gathering all permits, and make sure they are handed in on time. In some cases, a specialized third-party can be hired to make sure the process is smooth. The project managers should consider a time frame between 6 to 18 month to assess all permits (U.S. Environmental Protection Agency, 2020).

4.4.1 Air Quality

Air quality permit is due to ensure the biogas used in engines for combustion emits a limited quantity of NO_x, H_2S and SO_x. Choosing an engine that minimizes NO_x emissions might eliminate some permit requirements. Air quality permitting scheme is composed of a preconstruction permitting program called New Source Review (NSR) and an operating

[3] An exchange rate of 0,8897€/\$ computed on the 17/07/2023 was considered.

permits program called Title V (U.S. Environmental Protection Agency, 2020). After a formal conversation with Virginia Department of Agriculture and Consumer Services (VDACS) Commissioner Joseph W. Guthrie, the SSAD plant by Biolectric would fall into synthetic minor air permitting requirements in the state of Virginia, which includes a minor NSR permit with a fixed first fee of 4 018 $ in 2024, and an annual Consumer Price Index (CPI) adjusted maintenance fee of 669 $ (VDEQ, 2023).

4.4.1.1 New Source Review

The NSR program is a permit usually required for large industrial installations. In some states, AD plants might require to present a NSR permit to ensure pollutants regulated by the National Ambient Air Quality Standards (NAAQS) are monitored. The main pollutants targeted by the NAAQS are O_3, CO, NO_x, SO_x, particulate matter and lead (U.S. Environmental Protection Agency, 2020).

4.4.1.2 Title V

Title V is a permit usually issued by the state. The permit is required to installations that may emit one or more of the pollutants defined by the NAAQS at a level superior or equal to 100 tonnes per year. Project managers should apply for Title V air pollutant permit in the 12 first month of the installation operation (U.S. Environmental Protection Agency, 2020).

4.4.2 Water Quality

Project constructions that impact more than 1 acre (4 047 m^2) of land may require a stormwater discharge permit from the National Pollutant Discharge Elimination System (NPDES) during the construction phase. On a national point of view, no specific water-related permits are needed for AD plants. However, the addition of an AD plant to an industrial installation might require the modification of the NPDES of that installation. Each state is responsible for regulating its own water quality, therefore water-related permits for AD plants may be required in some states. In some cases, special water-related permits are required for co-digestion of manure and other feedstocks. AD plants require to update the farm's Comprehensive Nutrient Management Plan (CNMP) (U.S. Environmental Protection Agency, 2020).

4.4.3 Water Supply

Some locations may need to add water to the feedstock to dilute it and make it pumpable. In that case, water from groundsource may be needed. Some permits may be necessary in the case of drilling a well, or even just for water use. For surface water use, permits may also be required on a state to state basis (U.S. Environmental Protection Agency, 2020).

4.4.4 Solid Waste

Solid waste permits must align with Resource Conservation and Recovery Act (RCRA) regulations. In many states, AD plants operating with manure only feedstock don't require any solid waste permit. However, many states require solid waste permits in the case of co-digested feedstocks and off-site waste (U.S. Environmental Protection Agency, 2020).

4.4.5 Land Use

Land use is defined in community land use regulations and is essential in understanding whether the AD plant can or can't be installed in the studied area. Usually, farms are located on zoning and land areas where the development of AD plants is authorized (U.S. Environmental Protection Agency, 2020).

4.4.6 Co-Digestion Feedstock

The co-digestion feedstock related permits vary from one state to another and are updated over time. Some states allow a certain quantity of off-farm feedstock to be co-digested without the need of a solid waste permit, others don't (U.S. Environmental Protection Agency, 2020).

4.4.7 Additional Permitting

In some cases, additional permitting could be required. Location specific permits could include noise level control, environmental impact study, wetland delineation study and others (U.S. Environmental Protection Agency, 2020).

4.5 Investment Support

4.5.1 Electricity Production Tax Credit

The Electricity Production Tax Credit (PTC) is a tax credit provided to specific renewable electricity producers under the section 45 of USA tax code (U.S. Congress, 2022). The PTC can be sold over a period of 10 years after installation of the equipment, and currently stands at price of 0,026 $/kWh for AD plants (U.S. Environmental Protection Agency, 2023b).

4.5.2 Investment Tax Credit

ITC is a tax credit incentive covered in Section 48 of USA tax code that can cover up to 50% of the qualified investment in the case of AD plants. The base value of the tax credit is actually 6%, and provided the project doesn't exceed 1 MW of electrical or thermal output power, it can be raised up to 30%. The project can also benefit from a 10% bonus if it uses domestic content produced in the USA and another 10% if it incorporates the installation in an energy community, as defined in Sections 4.5.2.1 and 4.5.2.2 (DSIRE, 2023d) respectively.

4.5.2.1 Domestic Product

Qualified facilities that can certify any steel, iron or manufactured product were produced in the USA and used as components of the facility may qualify for an extra 10% in ITC (U.S. Congress, 2023a). All the above products should align with general requirements defined in title 49 of the Code of Federal Regulations (U.S. Government Publishing Office, 2023).

4.5.2.2 Energy Community

An energy community is defined as a brownfield site, a metropolitan or non-metropolitan statistical area, that from 2009, has or has had a minimum of 0,17% direct employment or a minimum of 25% local tax revenues in activities of transport or storage of coal, oil or natural gas. Additionally, the location should have a unemployment rate above national averages. To end with, a coal mine should have been closed in the location since December 1999, or a coal-fired electrical unit closed after December 2009 (U.S. Congress, 2023a).

4.5.3 Renewable Energy Certificates

Renewable Energy Certificates (RECs) are certificates that serve as economic instruments to characterize the social, environmental and other non financial benefits of renewable energy production. These RECs certify each MWh of energy injected on the grid comes from a renewable energy source (U.S. Environmental Protection Agency, 2023c). The certificates can be traded on both voluntary and compliance markets, in terms of turnover, the compliance market represents 95% of the RECs markets (SP Global Market Intelligence, 2022).

4.5.3.1 Voluntary RECs market

Electricity consumers can purchase RECs on the voluntary market and claim their personal input into energy transition and renewable energy development. These certificates are typically valued at a low price, and can change value in function of supply and demand, geography, purchasing volume, and other (U.S. Environmental Protection Agency, 2023a). In 2021, the average cost for voluntary RECs was estimated at 3 $/certificate (SP Global Market Intelligence, 2022).

4.5.3.2 Compliance RECs market

In some cases, states define Renewable Portfolio Standards (RPS) which obligates natural gas, electricity and other utilities providers to either produce renewable energy, or buy RECs. Not all RECs meet the requirements of the compliance market, the ones who do are typically sold at a much higher price than on voluntary markets (U.S. Environmental Protection Agency, 2023a). In 2021, the average cost for compliance RECs was estimated at 33,94 $/certificate (SP Global Market Intelligence, 2022). Qualifying resources complying with RPS vary from state to state, but AD plants used to produce electricity are part of the RPS in New York (NYSDPS, 2023), Vermont (Vermont Legislature, 2019), Pennsylvania (DSIRE, 2023c), Virginia (DSIRE, 2023a) and Ohio (DSIRE, 2023b).

4.5.4 Carbon Offset Credits

Carbon offset credits are meant to certify a specific installation reduces GHG emissions, and can be traded. These credits represent a measurable amount of avoided GHG emissions in terms of Metric Ton (Mt) of CO_2e. After verification, a project that aims to reduce GHG emissions can receive a carbon credit and sell it on carbon markets to individuals, companies, or institutions that want to offset their carbon emissions. Because AD plants assure CH_4 is recovered, they qualify for carbon offset credits. Individuals or organizations can buy these credits as a way to compensate for their environmental impact (U.S. Environmental Protection Agency, 2020). The carbon offset credit market is composed of both compliance and voluntary markets (U.S. Department of Agriculture, 2023).

4.5.4.1 Compliance Carbon Market

The USA compliance carbon market is composed of four specific markets operating in different regions of the country. The compliance market was responsible for issuing 90% of all the carbon credits related to manure digesters which generate between 1 500 and 70 000 Mt of CO_2e per year. In California, carbon credits can be exchanged through the California's Cap-and-Trade Program. In ten years, from 2013 to 2023, the Californian program generated 9 Million Metric Ton (MMt)CO_2e in carbon offsets from livestock digesters among many others.

The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) set a goal to achieve a 2% annual fuel efficiency improvement until 2050 and limited the amount of aviation related GHG emissions to those of 2020. The aviation sector will be able to buy carbon offset credits under the same conditions as the Cap-and-Trade, which includes livestock digesters, and will start in 2024.

The Regional Greenhouse Gas Initiative (RGGI) is a Cap-and-Trade program for the northeast states power sector. The program includes, in theory, carbon offsets from agricultural methane reductions, but, since it started, in 2009, no credits have been related to agricultural methane reductions and there are no intentions to expand the program in the future.

Washington's Cap-and-Invest program was launched in 2021 and defines rules to obligate businesses to offset their GHG emissions. The credits purchased under the Washington program could be manure related, but they should demonstrate a direct benefit to the Washington State in terms of GHG emission reductions. In practice, the projects should be located in the state, or nearby (U.S. Department of Agriculture, 2023).

4.5.4.2 Voluntary Carbon Market

The voluntary carbon market is used to trade carbon credits within specific program protocols, to individuals or businesses that want to mitigate their carbon footprint. The programs can partner with specific agriculture corporations and differentiate themselves through integrity, marketing, trading platforms, and others. The programs may refer to their carbon credits as tokens or certificates. Programs often operate as project developers, where they ensure the installation is being developed in a way compatible with their protocols, and therefore ensure the carbon credits will be emitted. Sometimes, the programs even provide upfront financing (U.S. Department of Agriculture, 2023). Some examples of the latest programs launched are Nutrien in 2022 (Nutrien, 2023), ESMC in 2022 (Ecosystem Services Market, 2023), Bayer Carbon Program in 2022 (Bayer, 2023) and Locus Ag's CarbonNOW in 2021 (Nutrien, 2023).

4.5.4.3 Project Developers

Projects developers initiate and command projects together with project decision makers to ensure third-party verification bodies will issue carbon credits. These developers work both on the compliance and voluntary markets. In total, 150 developers were identified in the fields of agriculture, forestry and land use in the last ten years but only 20 of them originated carbon credits to more than 50% of the projects. Some developers might be specialized in a type of projects, such as manure AD plants (U.S. Department of Agriculture, 2023).

4.5.4.4 Third-Party Verification Bodies

Carbon programs may require third-party verification from an independent body before issuing a carbon credit. In some cases, the program defines specific rules to elect the verification body. In total, 16 third-parties were identified by the California Air Resources Board (CARB) in 2023 and are authorized to verify manure AD plants projects. In 2017, CARB created a dairy cow manure related credit using the same program as Cap-and-Trade, called Low Carbon Fuel Standard (LCFS) credit. The aim was to create incentives for using new types of fuel while capturing CH_4 emitted in dairy cows manure (U.S. Department of Agriculture, 2023).

4.5.4.5 Carbon Credits Prices

Carbon credits prices are difficult to evaluate, they depend on the year the project has been implemented (which is referred to as the carbon credit vintage literature wise), the sector it is affected to, the size of the project, the market it is being traded on and many other factors. In an article published by the World Bank in 2023, the carbon credits prices traded on the California ETS, Washington ETS, RGGI ETS and the Massachusetts ETS are approximated at respectively 25, 20, 10 and 8 $/t$CO_2e$ (World Bank Group, 2023). Note that the CORSIA ETS is not referred to by the World Bank yet, and that the Massachusetts ETS is actually part of the RGGI (Massachusetts Government, 2023).

4.6 Competitors & Strategic Partners

4.6.1 Ben & Jerry's

Ben & Jerry's is an ice-cream producer owned by Unilever that started its journey in Vermont back in 1978. Ben & Jerry's is already an official Biolectric partner. The ice-cream maker developed a series of quality development programs for dairy farms where they support animal well-being and environmental friendly practices. Farms can for instance be part of the caring dairy program where they have to respect a series of operational criteria like milking with dignity, be labeled by the Global Animal Partnership and others. Ben & Jerry's incentives farmers to work close with the University of Vermont and other local Universities to foster development (Ben & Jerry's, 2024). With a strategic implementation in the dairy sector of the state of Vermont, a state with more than 120 000 dairy cows, Ben & Jerry's is a crucial partner for Biolectric.

4.6.2 Martin Energy Group

Martin Energy Group offers a wide variety of energy solutions including CHP systems and AD plant design and construction. The group claims 30 years experience and hundreds of installations worldwide. Martin Energy group provides project backup and can help during the phases of startup, digester operation, troubleshooting, training and warranty support. Martin Energy Group was involved in several biogas projects in the USA, one of them being a complete mix digester at Rockwood dairy (Pennsylvania) in 2018. The Rockwood dairy farm was composed of 600 cows and co-digested manure with landfill food waste to power the 450 kW plant. In their product portfolio, Martin Energy Group proposes a mini digester suited for dairy farms between 50 to 240 dairy cows ranging from 10 to 44 kW (Martin Energy Group, 2024). Additionally, after a formal conversation with Biolectric's Commercial Director Klaas Vanhee, Martin Energy Group already bought one Biolectric SSAD plant in 2018 and installed it in 2020. Martin Energy Group can therefore be considered as a key partner to Biolectric, being that they are interested in the Belgian SSAD plant and they can ensure installation and maintenance.

4.6.3 California Bioenergy

California Bioenergy is a western USA operating company founded in 2006 that develops dairy digesters projects. Their website mentions three main kind of projects where they either inject upgraded biogas into national gas grids for vehicle use, transport the upgraded biogas out of the farm for later vehicle use, or use the biogas on the farm to produce electricity via a fuel-cell or internal combustion engine. California Bioenergy works closely with a company called 4Creeks that provides them with all the permitting support they need to develop their projects. Although California Bioenergy operates in the same sector as Biolectric, they seem to focus on much larger projects for big dairy farms and operate exclusively in the west (CalBioEnergy, 2024).

4.6.4 Vanguard Renewables

Vanguard Renewables was founded in 2014 and provides, between others, farm solutions for manure and digestate management. Vanguard Renewables is part of the Farm Powered Strategic Alliance that aims to reduce food waste, increase recycling solutions, and increase renewable energy production in the USA. Interestingly, Unilever is also part of that alliance. Vanguard Renewables provides AD plants for all dairy farms sizes including small to medium farms. Their solution includes co-digestion of food and beverage waste, and is suitable for farms from 350 to 10 000+ dairy cows. The company operates in the whole country, and has already developed a manure only project on the East Coast (Georgia) that processes up to 150 000 tons of dairy manure a year (Vanguard Renewables, 2024). Vanguard Renewables can therefore be considered as a direct competitor to Biolectric. The company is already well deployed on the market, has been working on a wide variety of project sizes and could therefore easily compete with Biolectric on the SSAD plant market.

4.6.5 CH-Four Biogas

CH-Four is a leader in the North-American biogas market since it launched in 2009. The company designs and provides consulting services for AD plants. Their services include project management, engineering, otpimization, development and construction assistance in the agricultural sector and for Municipalities. The company already designed and build more than 25 AD plants for farm use in Canada, USA, Chile, Argentina and Jamaica (CHFour, 2024). In 2010, CH-Four Biogas was involved in the design of an AD plant at a 390 dairy cows farm called Wagner Farms. The plant had an output power of 100 kW and could process nearly 24 m^3 of manure per day (Jennifer Pronto et al., 2014). CH-Four could be a strategic partner for Biolectric, adding the Belgian SSAD in their product portfolio, as they already operate in the same dairy farm size category and benefit from a market presence in both Canada and USA.

4.7 Practical Case Study: A dairy farm in Vermont

This section is dedicated to simulating a business case in the state of Vermont (USA) and understanding how a SSAD plant by Biolectric would adapt itslelf to the USA market. The complete financial simulations can be found in Annex III.

4.7.1 Permitting Summary

Specific permitting for the implementation of SSAD plants on dairy farms is still quite ambiguous and rather difficult to numerate in all five states of the market research. However, many AD plants projects have been conducted all over the USA in the past, and their development is often described and published through online documents. In the state of Vermont, a 370 kW AD plant was installed in 2014 and required the permitting summarized in Table 4.4. The AD plant installed was used to process manure from a dairy farm and co-digest food waste from the industry. Additionally, a digested solid fraction divider was installed to produce cow bedding for the farm. Overall, the installation is five times as powerful as the 74 kW SSAD plant by Biolectric and performs co-digestion from off-farm products, which should be a reason for extra permitting as seen in Section 4.4. After a formal conversation with VDACS Commissioner Joseph W. Guthrie, in the state of Virginia, the SSAD plant by Biolectric would fall into synthetic minor air permitting and include a NSR permit with a fixed cost of 4 018 $ in 2024 and a CPI yearly adjusted maintenance fee of 669 $ (VDEQ, 2023). With no other price information found, the permitting fees used in the business case in Vermont will base themselves on the information provided by Commissioner Joseph W. Guthrie. In the year of implementation, a 5 000 $ permitting fee is used, and a 1 000 $ yearly fee is used for the next 20 years of the project.

Table 4.4: Vermont Specific Permitting (Vermont Tech, 2016).

State	Permits	Agencies
Vermont	Certificate of Public Good	Vermont Agency of Agriculture Food and Markets
	Nutrient Management Plan	Vermont Agency of Agriculture Food and Markets
	Medium Farm Operation Certification	Vermont Agency of Agriculture Food and Markets
	National Environmental Policy Act	Department of Energy
	Public Safety Permit	Vermont Department of Public Safety
	Construction General Permit	Vermont Agency of Natural Resources
	Air Pollution Control Permit	Vermont Agency of Natural Resources
	Solid Waste Certification	Vermont Agency of Natural Resources
	Effluent Storage Certification	Natural Resource Conservation Service
	Power Interconnection Agreement	e.g Green Mountain Power

4.7.2 Project Costs

The costs considered in the business case, as shown in Table 4.5 include the price of the AD plant, its installation, maintenance, active charcoal, insurance, grid connecting and measuring devices, permitting and barn adaptations. The AD plant cost includes the price of the AD plant and its installation, the transportation costs, the project management and the first year of maintenance. The maintenance and active charcoal prices are capitalized throughout the project at a 2% inflation rate found in Section 2.5.2. The grid connectors and measuring devices are considered to have a year zero cost shown in 4.5 and an annual 2 000 $ extra was added to ensure their maintenance. Permitting fees were estimated as described in Section 4.7.1.

Table 4.5: SSAD Installation Costs in Vermont.

							Units
SSAD **Type**	11	22	33	44	60	74	kW
N° of cows	60	120	180	240	325	400	
AD Plant	200 000	270 000	350 000	420 000	525 000	580 000	$
Maintenance	15 000	20 000	25 000	28 000	32 000	40 000	$/year
Active Charcoal	2 000	2 000	2 000	2 500	3 000	3 500	$/year
Insurance (% of AD Plant Price)	0,5%	0,5%	0,5%	0,5%	0,5%	0,5%	$/year
Grid Connection & Measuring	10 000	10 000	15 000	20 000	30 000	30 000	$
Connectors Maintenance	2 000	2 000	2 000	2 000	2 000	2 000	$/year
Fixed Permitting	5 000	5 000	5 000	5 000	5 000	5 000	$
Annual Permitting	1 000	1 000	1 000	1 000	1 000	1 000	$/year
Barn Adaptation	75 000	75 000	80 000	80 000	85 000	85 000	$

4.7.3 Investment Support

The investment support used in the business case includes a FIT, a voluntary GMP, a PTC, an ITC, selling RECs and selling carbon credits.

- **FIT**: The state of Vermont defined a 2022 price cap of 0,208 $/kWh for food waste AD (DSIRE, 2024). Unfortunetly, it is most likely the Biolectric AD plant won't fit the category. For the business case, a 0,145 $/kWh FIT by the Vermont Standard Offer program is used and capitalized throughout the project at a 2% inflation rate found in Section 2.5.2 (VDEC, 2024).

- **Cow Power Program**: Green Mountain Power provides an extra FIT of 0,04 $/kWh for electricity produced by cow powered AD (VDEC, 2024). As referred to in Section 4.1.3, farmers in Vermont can choose between a FIT or a net-metering count. The cow power program is not applicable in farms with net-metering, and therefore FIT at 0,145 $/kWh is more interesting than the 0,1699 $/kWh net-metering tariff presented in Table 4.2. The extra FIT is also capitalized throughout the project at a 2% inflation rate found in Section 2.5.2.

- **PTC**: The PTC of 0,026 $/kWh found in Section 4.5.1 is used during the ten first years of the project.

- **ITC**: An ITC of 30% of the qualified investment is used in the year of implementation of the project as defined in Section 4.5.2.

- **RECs**: RECs are considered to be sold on the compliance market at a conservative value of 30 $/MWh, as defined in Section 4.5.3.

- **Carbon Credits**: Carbon Credits are considered to be sold on the compliance market at a conservative price of 10 $/t$CO_2e$. The annual tonnes CO_2e were computed using a yearly 2,4 tCO_2e/cow emission approximation. On average, milk cows with a milk yield of 7 t/year will emit 2,4 tCO_2e a year (FAO, 1996). The milk yield of 7 t/year is lower than the 7,2 t/year European average defined in Section 3.2.3, which could be considered conservative.

4.7.4 Financial Simulation: A typical Vermont dairy farm

The following comparison between SSAD plants considers them as projects and compares them as shown in Table 4.6, using NPV, IRR, payback period and LCOE indicators. The project simulations are conducted over a period of 20 years, the discount rate used to compute the NPV, as defined in Section 2.5.1, is settled at 6,19% and the annual inflation rate of 2% is used to capitalize some costs and electricity prices, as defined in Section 2.5.2. The SSAD engines are considered to work 8 000 h/year. The full project simulations can be found in Annex III.

Table 4.6: SSAD Financial Simulation in Vermont.

							Units
SSAD Type	11	22	33	44	60	74	kW
N° of cows	60	120	180	240	325	400	
Produced Gross Electricity	88 000	176 000	264 000	352 000	480 000	592 000	kWh/Year
Initial Investment	293 000	363 350	453 750	529 600	650 625	706 400	$
NPV	-193 380	-29 774	117 079	292 711	545 250	751 995	$
IRR	0%	5%	10%	14%	18%	21%	
Payback	>20	13	9	7	6	5	Years
LCOE	0,556	0,347	0,284	0,244	0,213	0,197	$/kWh

The final simulations in Table 4.6 show similar results to the ones in Section 3.8 of the Portuguese market. The 74 kW plant is the best option with a 5 years payback, a NPV of 751 995 $, a 21% IRR and a 0,197 $/kWh LCOE. The 11 kW and 22 kW plants do not show interesting outcomes with negative NPV. The main driver for negative NPV on both these smaller AD plants is the maintenance cost estimation in the USA that is much higher than in Portugal for instance. The simulations in Vermont were computed using all types of investment support. The simulation might not be as conservative as possible, and may be dependent of the carbon credits and RECs prices fluctuations. With the IRA signed by President Biden in 2022, it is most likely that the estimations of the FIT, PTC and ITC can be considered conservative. Additionally, no installation was considered as CHP, meaning no financial benefit was taken from the renewable heat produced. This could have been critical in the financial performance of the AD plants, and could have driven both the 11 kW and 22 kW installations to positive NPV. However, the financial value of the heat generated by the AD is strongly dependent on the farm organization. Using electrical output only was therefore considered more conservative in this market research.

4.8 Sensitivity Analysis of Financial Simulations

4.8.1 Inflation Rate Previsions

The 2% inflation rate suggested in Section 2.5.2 and used in Section 4.7.4 might not be an accurate estimation of what the future inflation will be. In order to make sure the financial simulations stay as conservative as possible, we hereby measured the sensitivity of the financial simulations to the inflation rate. Note that the recent economical conjuncture has been tricky and characterized by highly volatile markets. In 2021, inflation forecasters made errors up to nearly 3% in estimating inflation for the year (European Central Bank, 2022). This being said, for the sake of this simulation, a 1% error is considered acceptable given the 20 years of project life.

4.8.1.1 Financial Simulation at 1% Inflation Rate

At 1% of inflation rate, as shown in Table 4.7, the simulations stay attractive above 22 kW with paybacks under 9 years. The 33 kW plant might be a little tight though with a NPV at 80 128 $ and a LCOE at 0,274 $/kWh. Taking advantage of the heat would make this 33 kW plant interesting if the inflation was to drop at 1%.

Table 4.7: Financial Simulation at 1% Inflation Rate in Vermont.

							Units
SSAD Type	11	22	33	44	60	74	kW
NPV	-197 134	-50 126	80 128	237 564	463 059	651 002	€
IRR	0%	4%	9%	13%	17%	20%	
Payback	>20	14	9	7	6	5	Years
LCOE	0,537	0,334	0,274	0,235	0,206	0,190	€/kWh

4.8.1.2 Financial Simulation at 3% Inflation Rate

At 3% of inflation rate, as shown in Table 3.9, the simulations stay attractive above 22 kW with paybacks under 8 years.

Table 4.8: Financial Simulation at 3% Inflation Rate in Vermont.

							Units
SSAD Type	11	22	33	44	60	74	kW
NPV	-189 186	-6 973	158 487	354 522	637 382	865 202	€
IRR	0%	6%	11%	15%	19%	22%	
Payback	>20	12	8	7	6	5	Years
LCOE	0,578	0,361	0,296	0,254	0,221	0,206	€/kWh

4.8.2 Discount Rate Previsions

The 6,19% discount rate suggested in Section 2.5.1 and used in Section 4.7.4 might not be an accurate estimation of the USA agricultural industry WACC. In order to make sure the financial simulations stay as conservative as possible, we hereby measured the sensitivity of the financial simulations to the discount rate. Given the fact that the 74 kW plant is the best financial choice in Table 4.6, this analysis will focus on the 74 kW plant. For the sake of this simulation, a 1% error in the discount rate is considered acceptable. We will therefore use 5,19% and 7,19% to characterize the sensitivity of the simulations.

4.8.2.1 Financial Simulation at 5,19% Discount Rate

At 5,19% of discount rate, as shown in Table 4.9, the simulations stay attractive above 22 kW with paybacks under 9 years.

Table 4.9: Financial Simulation at 5,19% Discount Rate in Vermont.

SSAD Type	11	22	33	44	60	74	Units kW
NPV	-193 517	-9 542	157 501	355 371	640 852	871 031	€
IRR	0%	5%	10%	14%	18%	21%	
Payback	>20	13	9	7	6	5	Years
LCOE	0,535	0,334	0,273	0,235	0,204	0,190	€/kWh

4.8.2.2 Financial Simulation at 7,19% Discount Rate

At 7,19% of discount rate, as shown in Table 4.10, the simulations stay attractive above 22 kW with paybacks under 9 years. However, the NPV of the 33 kW can be considered low at 81 865 $, which would require giving value to the heat produced to make the simulation more attractive.

Table 4.10: Financial Simulation at 7,19% Discount Rate in Vermont.

SSAD Type	11	22	33	44	60	74	Units kW
NPV	-193 131	-47 342	81 865	238 057	461 807	648 034	€
IRR	0%	5%	10%	14%	18%	21%	
Payback	>20	13	9	7	6	5	Years
LCOE	0,578	0,360	0,295	0,254	0,222	0,205	€/kWh

4.8.2.3 Combining a 1% Inflation Rate and a 7,19% Discount Rate

At 1% inflation rate and 7,19% of discount rate, as shown in Table 4.11, the simulations stay attractive above 22 kW with paybacks under 9 years. However, at 49 266 $ of NPV and 0,285 $/kWh LCOE, the 33 kW requires to take advantage from the heat to make the simulation more attractive.

Table 4.11: Financial Simulation at 1% Inflation Rate and 7,19% Discount Rate in Vermont.

SSAD Type	11	22	33	44	60	74	Units kW
NPV	-196 454	-65 303	49 266	189 412	389 317	558 960	€
IRR	0%	4%	9%	13%	17%	20%	
Payback	>20	14	9	7	6	5	Years
LCOE	0,559	0,348	0,285	0,246	0,215	0,198	€/kWh

4.8.3 Sensitivity Summary

Overall, the lowest values found in plants above 22 kW are a NPV of 49 266 $, an IRR of 9%, a payback in 9 years and a LCOE at 0,296 $/kWh. The financial simulation in Section 4.7.4 is more positive than the worst results found in the sensitivity analysis. However, provided the farm owners use the AD plant heat, all installations above 22 kW can be considered an interesting investment. The less risky plant powers are the 44 kW, 60 kW and 74 kW ones, with simulations staying attractive with all kinds of inflation or discount rates fluctuations.

4.9 Market Overview: SWOT Matrix

The following SWOT matrix encompasses all the key aspects developed in the East Coast USA market reasearch.

	Strengths Market Size: The five states represent a market size comparable to the Netherlands; Most represented farm size category: 8 000+ farms (50 to 500 cows) own 870 000+ cows; Market concentration: New York and Pennsylvania account for nearly 1 000 000 cows (in 50 to 1 000+ heads dairy farms).	**Weaknesses** Electricity prices look quite low compared to minimum LCOE (0,197 $/kWh), therefore net-metering might not be an option. Eventual future plans of co-digestion are hard to set up due to high paperwork supplement.
Opportunities IRA signed by President Biden defines a wide range of investment support for AD plants; Low milk prices and farms getting bigger will require innovation in dairy farms; Some key partners could help quickly increasing market shares (e.g. Ben & Jerries, Martin Energy Group, CH-Four Biogas);	**S/O Strategy Analysis** Market size and market concentration can allow quicker territory deployment, thanks to key partners already well deployed on the studied market. 8 000+ farms in the right size category are looking to enhance their production performance.	**W/O Strategy Analysis** Net metering might not be necessary, with IRA signed, FIT and FIT premiums make the business case more interesting. The high LCOE in the USA is a weakness, but many investment supports are already available and look easy to apply for.
Threats Paperwork and their costs are unclear and may require an externalized team to work on; Vanguard Renewables has already developed SSAD plants and is already well installed on the market; Maintenance costs and overall service costs in the USA might be a LCOE killer; AD plants under 33 kW will struggle financially in cases where the farmer doesn't use heat.	**S/T Strategy Analysis** With a market concentration in New York and Pennsylvania, Biolectric could specialize in the paperwork for those two states first and work from there for other states next. With a market size of +8 000 farms in 5 states, clients requirements might vary a lot. It should be possible to find farmers that need heat.	**W/T Strategy Analysis** Co-digestion isn't Biolectric's focus at the moment, and if it was to be, key partners might be able to help on paperwork. Biolectric has a ready to work solution that needs little adaptation to clients, therefore could grow quicker than Vanguard Renewables. Also Vanguard focuses on co-digestion. With digestate usually used as bedding in the USA, why not study the development of a digestate dryer with AD heat?

5 General Conclusion and Future Works

5.1 General Conclusion

The general need to tackle worldwide GHG emissions, and build resilient energy systems has risen global interest over renewable energy sources. AD plants have the ability to provide dairy farmers with a solution for their manure management, while producing electricity, heat, and a nutrient rich digestate that can serve in a wide range of applications. The main goal of this thesis was to answer to the question: should the Belgian company Biolectric, selling SSAD plants for dairy farmers, consider to grow in Portgual and on the East Coast of the USA?

The answer to the question was divided into three main chapters. Section 2 defined the concept of AD, how to monitor AD, the factors that affect its performance and the number of AD plants across Portugal and USA. Additionally, Section 2 focused on defining how to add value to digestate, and provide farmers with a complete waste management solution from their manure. The Portuguese and the East Coast USA markets were then described in Sections 3 and 4 respectively, using key indicators such as the amount of dairy farms and dairy cows on each market, the paperwork required on each territory, energy mix and energy prices description, the milk prices and milk yields found on each market and their predicted evolution. Each one of the business cases was complemented by a practical case study where a financial adaptability test was conducted. In Portugal, the case study was performed at a dairy farm called Agro ABA, located in Torres Vedras. In the USA a case study was build from scratch in the state of Vermont.

Portugal has been betting on the development of renewable energy in the past decades and has reached an electrical energy mix composed of 49% of renewable electricity. Local municipalities are interested in developing REC and considerable incentives from the Environmental Fund push the market to invest in renewable energy solutions. A total of 64 AD plants have been reported in Portgual and have been used in applications such as agriculture, sewage and landfills. Although not very active in the SSAD market yet, competitors exist and companies like Genia Global Energy and Sotecnisol might benefit from being already well established on the market. With 122 626 dairy cows on the mainland, distributed in 959 farms with a predominant size category of 100 to 199 heads, Portugal is a small market. Nevertheless, paperwork does not seem abundant at first sight, FIT is sensibly equal to the LCOE of the 74 kW plant, using no type of investment support, and without adding value to heat. Payback periods seem interesting, ranging from 8 to 13 years for the raw model, and from 6 to 7 years in the co-funded model. Additionally, the plant by Biolectric seems to fit the requirements of Agro ABA, a local 879 dairy cows farm. Being that Lisbon and Temse (Biolectric headquarters) are only separated by 2056 km, two countries, France already being a market where the company is well established, and Spain being a market with 800 000+ dairy cows, the recommendation would be to consider growing in Portgual. Once the first installation is sold, provided the customer requirements are met, and being that competitors are not yet active on the market, other farmers are expected to be willing to invest in a Biolectric plant.

Though traditionally relying on fossil fuels, USA has recently been betting on renewable energy too, with President Biden signing the IRA and defining a broad range of investment support for renewable energy projects. In some cases, projects can benefit from funding up to 50%. The East Coast of the USA is a big market, with 1 362 511 dairy cows distributed in 8 587 farms with a predominant size category of 50 to 99 cows. AD plants in the USA can benefit from a wide range of financial incentives, including PTC, ITC, RECs and Carbon Offset Credits. On a competitors point of view, some companies like Vanguard Renewables and CH-Four Biogas offer similar products, but the overall local partners already established should help growing quickly on the market. Unfortunately, electricity prices are not attractive in all states and usually lower than LCOE, with a maximum price found in New York at 0,1866 $/kWh. Maintenance and paperwork predicted costs result in high LCOE for all installations. Paperwork is expected to be heavy and might require an external team to work on. Overall, payback periods are interesting for installations above 22 kW ranging from 5 to 13 years, but the NPV of the 22 kW installation in the case study of Vermont is not positive. Taking advantage of heat could make the smaller installation interesting, but these calculations were not performed in this thesis. The USA market is certainly moving towards making renewable energy sources interesting at scale, and has a sufficient amount of dairy cows, nevertheless, the decision to grow in the USA is complex. With higher paperwork and maintenance costs, and being that the five states territory is wide, Biolectric should further investigate workforce and paperwork costs. The market certainly has potential, and Biolectric would be able to provide farmers with an attractive financial and waste management solution, but being on the other side of the Atlantic, the recommendation would be to work with a partner abroad. Companies like CH-Four, Ben & Jerries, and Martin Energy Group already have a glimpse of how paperwork works in the USA, are already spread on the market and are interested in joining forces with Biolectric.

Portugal and USA are two very different markets, they differ in size, in financial incentives, in the amount of paperwork, and represent different levels of difficulty to enter in. The market sizing matrix found in Figure 5.1 characterizes these differences [1]. The Portuguese market benefits from high government support, because paperwork has been simplified over the years, a legal framework for REC has been developed, and farmers can expect a significant financial support from the Environmental Fund. Additionally, the business case for the farmer is highly attractive, with LCOE values similar to FIT, resulting in payback periods between 6 to 13 years. Unfortunetly, the size of the market is small, as shown by the size of the Portuguese flag in Figure 5.1, it is estimated to represent half of Belgium's market. On the other hand, the five american states chosen, represented by the USA flag in Figure 5.1, benefit from an attractive business case for the farmer, with payback periods between 5 to 13 years, but suffer from higher paperwork. The government support in the USA is clearly positive, but the overall ambiguity around permitting and permitting fees are to be carefully analyzed. Nonetheless, the USA is a big market, with the five states chosen in the analysis representing a market size similar to the Netherlands.

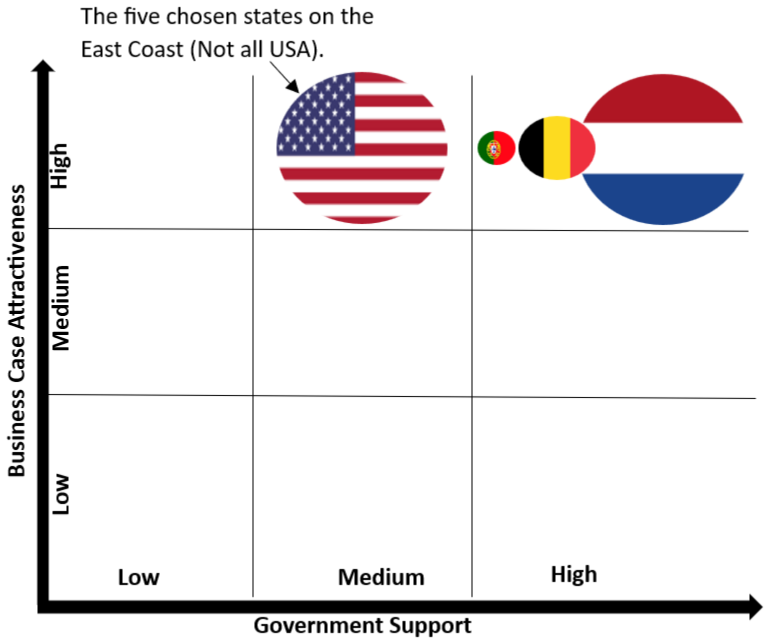

Figure 5.1: Biolectric Market Sizing Matrix.

5.2 Future Works

AD plants technology has benefited from a significant amount of interest on a literature point of view, which significantly reduced the amount of research required in this thesis.

[1]Belgium and Netherlands were added to Figure 5.1 to enable a size comparison, the business case attractiveness and government support in those countries wasn't studied in this thesis and were assumed high given that Biolectric already entered the markets.

Nevertheless, the results found in this thesis could be improved by the following future works:

- **Study the practical creation of a REC in Portugal**

  Further reasearch for the creation of a REC with an AD plant in Portugal could enhance the business case. During the thesis, Municipal authorities showed a real interest in developing REC. On a Municipal point of view, accepting various types or sources of feed stock in the AD could be a way to diversify revenue streams for the farmer and enhance circular economy.

- **Study diverse ways to use heat produced by AD**

  The engines used to burn biogas have an average electric efficiency of 30 %. Adding value to the heat produced makes sense not only on an environmental point of view, but also financially. In the litterature review of this thesis, we suggested the heat could be used for digestate drying. Finding a practical solution for the heat produced in cases where the farmer has no needs to heat water would turn smaller AD plants much more attractive financially and make AD plants much more interesting on a sustainability point of view.

- **Further investigate permitting and permitting fees in the USA**

  It has been difficult to estimate permitting fees in the USA. Overall, after a formal conversation with VDACS Commissioner Joseph W. Guthrie, paperwork seems accessible in the state of Virginia. Unfortunetly, the information provided doesn't fully align with a project description in Vermont (see Vermont Business Case in Section 4.7), which suggests there might be significant changes from one state to another. Carefully studying states one by one would help evaluating the potential of each state independently and provide Biolectric with a more conservative opinion of the USA market.

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I

Data Sheet

Manuel d'utilisation et d'entretien des installations biogaz Biolectric v4.0

Tableau 1 : Fiche technique des différentes installations biogaz Biolectric

Biolectric

Biolectric NV
Jan De Malschelaan 2
B-9140 Temse
+32(0)3 68 92 92 8
info@biolectric.be
www.biolectric.be

Specification Sheet
Types: 10, 11, 20-2, 22-1, 22-2, 33, 33-2, 40, 44, 60, 74 kW

Type	10	11	20-2	22-1	22-2	33		33-2	40	44	60	74
Engine												
Fuel						Biogas						
Number of engines	1	1	2	1	2	2		2	2	2	2	2
Engine type	DF972	DF972	DF972	WG1605	DF972	DF972	WG1605	WG1605	WG1605	WG1605	WG3800	WG3800
Number of cylinders		3		4	3			4			4	
Displacement (l)		0.962		1.537	0.962			1.537			3.769	
Rotation Speed (rpm)		2400		2700	2400		2700	2300	2700		1650	2000
Cycle						Otto						
Electric Power (kW)	**9.7**	**11**	**9.7**	**22**	**11**	**11**	**22**	**16.5**	**20**	**22**	**30**	**37**
Electric Power (kVA)	10	11.3	10	22.6	11.3	11.3	22.6	17.0	20.6	22.6	30.9	38.1
Consumption (kW)	46.1	39.3	46.1	68.8	39.3	39.3	68.8	51.6	62.5	68.8	90,9	112,1
Consumption (m3/h)	7.7	6.6	7.7	11.5	6.6	6.6	11.5	8.6	10.4	11.5	15,2	18,7
Electric Efficiency (%)	21	28	21	32	28			32			33	
Total Efficiency (%)		94		97	94				97			
Heat power (kW)	**33.6**	**25.9**	**33.6**	**45.0**	**25.9**	**25.9**	**45.0**	**33.8**	**40.9**	**45.0**	**58,2**	**71,8**
Max Flue gas temperature (°C)		90		110	90				110			
Max Coolant temperature (°C)						85						
Voltage (V)						400						
Current (A)	14	16	14	32	16	16	32	24	29	32	44	54
Cos phi						0.97						
Generator												
Type						4P/IE2 Asynchronous Generator						
Rotation Speed						1500 rpm						
Frequency						50Hz						
Voltage						3 x 400V						
Mode						Triangle						

Mechanical construction
Engine and generator on rigid chassis, with belt drive. The set is placed on vibration dampers inside a sea container of 20ft.

Fuel
Biogas (= 60% CH4 + 40% CO2; 6,0 kWh/m3) though airlock, gas filter, solenoid valve and carbon filter.

Exhaust
Exhaust system with water cooled exhaust collector, two stage silencer and flue gas heat exchanger, optional biogas flare.

Cooling system
Cooling system under pressure with electric circulation pump. Heat is generated at the engine, the water cooled exhaust collector and the flue gas heat exchanger. Heat delivery to reactor by stainless steel pipes and to hot water.

Engine start
12V battery with electric charger, optional petrol pilot start

Electric cabinet
PCB control board with microcontroller
Interface:
Buttons
Engine start/stop, Pump Manual/Auto
LCD screen
Date/Time, Reactor Temperature, Water Temperature, Electric
Web Interface
Electric Power, kWh counter, Hours run - maintenance interval, Errors, Diagnostics

Temperature measurements
Reactor, Water, Container, Exhaust, Engine
Pressure Measurements
Reactor, Engine oil, Coolant
Flow Measurements
Biogas, Manure
Relay
Pump, Mixer, Valves, Engine start, Generator start, Solenoid Biogas Valve

The values in this sheet have been obtained according to ISO 3046.1.2002. Test conditions 20°C, sea level, relative humidity 50%.
Biolectric NV reserves the right to change the technical specifications without prior notice.

Figure I.1: Biolectric Data Sheet

II

Financial Simulations: Agro ABA

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost (€)	177931																				
Maintenance (€)			10404	10612	5152	5255	5360	5467	5576	5688	5801	5917	6036	6157	6280	6405	6533	6664	6797	6933	7072
Active Charcoal (€)	1000	1020	1040	1061	1082	1104	1126	1149	1172	1195	1219	1243	1268	1294	1319	1346	1373	1400	1428	1457	1486
Insurance (€)	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890
Grid Connection & Measur. (€)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits (€)	5000																				
Barn Adapatation (€)	35000																				
Total Costs (€)	221821	3910	14334	14563	9124	9248	9375	9505	9637	9772	9910	10050	10194	10340	10489	10641	10796	10954	11115	11280	11448
Total Cumulated Costs (€)	221821	225730	240064	254627	263751	272999	282375	291880	301517	311290	321200	331250	341444	351784	362272	372913	383709	394663	405778	417058	428505

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000
Annual Saved Electricity (€)		16606	16938	17276	17622	17974	18334	18701	19075	19456	19845	20242	20647	21060	21481	21911	22349	22796	23252	23717	24191
Annual Sold Electricity to grid (€)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Income (€)		16606	16938	17276	17622	17974	18334	18701	19075	19456	19845	20242	20647	21060	21481	21911	22349	22796	23252	23717	24191
Total Cumulated Income (€)	0	16606	33543	50820	68442	86416	104750	123451	142525	161981	181827	202069	222716	243776	265257	287168	309517	332312	355564	379281	403472

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash-Flows	-221821	12696	2604	2714	8498	8726	8958	9195	9437	9684	9935	10192	10453	10720	10992	11270	11553	11842	12137	12437	12744
NPV (20 YRS)	-110.169 €																				
IRR	-1%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI
Discounted Costs (€)	221821	3685	12733	12193	7200	6878	6572	6280	6001	5735	5482	5240	5009	4789	4578	4378	4186	4003	3829	3662	3503
Discounted Energy Production (kWh)	0	82941	78172	73678	69442	65449	61687	58140	54797	51647	48678	45879	43241	40755	38412	36204	34122	32160	30311	28569	26926
LCoE (€/kWh)	0,3373																				

Figure II.1: 11 kW Raw

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost (€)	177931																				
Maintenance (€)			10404	10612	5152	5255	5360	5467	5576	5688	5801	5917	6036	6157	6280	6405	6533	6664	6797	6933	7072
Active Charcoal (€)	1000	1020	1040	1061	1082	1104	1126	1149	1172	1195	1219	1243	1268	1294	1319	1346	1373	1400	1428	1457	1486
Insurance (€)	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890	890
Grid Connection & Measur. (€)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits (€)	5000																				
Barn Adapatation (€)	35000																				
Total Costs (€)	221821	3910	14334	14563	9124	9248	9375	9505	9637	9772	9910	10050	10194	10340	10489	10641	10796	10954	11115	11280	11448
Total Cumulated Costs (€)	221821	225730	240064	254627	263751	272999	282375	291880	301517	311290	321200	331250	341444	351784	362272	372913	383709	394663	405778	417058	428505

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000
Co-Fund (Fundo Ambiental) (€)	110910																				
Annual Saved Electricity (€)		16606	16938	17276	17622	17974	18334	18701	19075	19456	19845	20242	20647	21060	21481	21911	22349	22796	23252	23717	24191
Annual Sold Electricity to grid (€)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Income (€)	110910	16606	16938	17276	17622	17974	18334	18701	19075	19456	19845	20242	20647	21060	21481	21911	22349	22796	23252	23717	24191
Total Cumulated Income (€)	110910	127516	144454	161730	179352	197327	215660	234361	253436	272892	292737	312979	333626	354686	376167	398078	420427	443223	466475	490192	514383

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash-Flows	-110910	12696	2604	2714	8498	8726	8958	9195	9437	9684	9935	10192	10453	10720	10992	11270	11553	11842	12137	12437	12744
NPV (20 YRS)	-5.635 €																				
IRR	5%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs (€)	110910	3685	12733	12193	7200	6878	6572	6280	6001	5735	5482	5240	5009	4789	4578	4378	4186	4003	3829	3662	3503
Discounted Energy Production (kWh)	0	82941	78172	73678	69442	65449	61687	58140	54797	51647	48678	45879	43241	40755	38412	36204	34122	32160	30311	28569	26926
LCoE (€/kWh)	0,2266																				

Figure II.2: 11 kW Co-Funded

	Costs																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost (€)	240206																				
Maintenance (€)			14566	14857	7212	7356	7503	7653	7807	7963	8122	8284	8450	8619	8791	8967	9147	9329	9516	9706	9901
Active Charcoal (€)	2000	2040	2081	2122	2165	2208	2252	2297	2343	2390	2438	2487	2536	2587	2639	2692	2746	2800	2856	2914	2972
Insurance (€)	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201
Grid Connection & Measur. (€)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits (€)	5000																				
Barn Adapatation (€)	35000																				
Total Costs (€)	285407	5241	19847	20180	12578	12765	12957	13152	13351	13554	13761	13972	14188	14407	14631	14860	15093	15331	15574	15821	16073
Total Cumulated Costs (€)	285407	290648	310495	330676	343254	356019	368976	382128	395479	409032	422793	436765	450953	465360	479992	494852	509945	525276	540849	556670	572744

	Income																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000
Annual Saved Electricity (€)		30569	31181	31804	32440	33089	33751	34426	35115	35817	36533	37264	38009	38769	39545	40336	41142	41965	42805	43661	44534
Annual Sold to Grid Electricity (€)		1738	1773	1808	1844	1881	1919	1957	1996	2036	2077	2118	2161	2204	2248	2293	2339	2386	2433	2482	2532
Total Income (€)	0	32307	32953	33612	34285	34970	35670	36383	37111	37853	38610	39382	40170	40973	41793	42629	43481	44351	45238	46143	47066
Total Cumulated Income (€)	0	32307	65261	98873	133158	168128	203798	240181	277292	315145	353756	393138	433308	474282	516074	558703	602185	646535	691773	737916	784982

Cash-Flows (€)	-285407	27066	13106	13432	21707	22205	22713	23231	23760	24299	24849	25410	25983	26566	27162	27769	28388	29020	29664	30322	30992
NPV (20 YRS) (€)	-15.585 €																				
IRR	5%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs (€)	285407	4940	17631	16896	9925	9494	9082	8689	8314	7955	7612	7284	6971	6672	6387	6113	5852	5603	5364	5136	4918
Discounted Energy Production (kWh)	0	165881	156344	147356	138884	130899	123373	116280	109595	103294	97355	91758	86482	81510	76824	72407	68244	64321	60623	57137	53852
LCoE (€/kWh)	0,2229																				

Figure II.3: 22 kW Raw

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost (€)	240206																				
Maintenance (€)			14566	14857	7212	7356	7503	7653	7807	7963	8122	8284	8450	8619	8791	8967	9147	9329	9516	9706	9901
Active Charcoal (€)	2000	2040	2081	2122	2165	2208	2252	2297	2343	2390	2438	2487	2536	2587	2639	2692	2746	2800	2856	2914	2972
Insurance (€)	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201	1201
Grid Connection & Measur. (€)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits (€)	5000																				
Barn Adapatation (€)	35000																				
Total Costs (€)	285407	5241	19847	20180	12578	12765	12957	13152	13351	13554	13761	13972	14188	14407	14631	14860	15093	15331	15574	15821	16073
Total Cumulated Costs (€)	285407	290648	310495	330676	343254	356019	368976	382128	395479	409032	422793	436765	450953	465360	479992	494852	509945	525276	540849	556670	572744

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000
Co-Fund (Fundo Ambiental)	142704																				
Annual Saved Electricity (€)		30569	31181	31804	32440	33089	33751	34426	35115	35817	36533	37264	38009	38769	39545	40336	41142	41965	42805	43661	44534
Annual Sold to Grid Electricity (€)		1738	1773	1808	1844	1881	1919	1957	1996	2036	2077	2118	2161	2204	2248	2293	2339	2386	2433	2482	2532
Total Income (€)	142704	32307	32953	33612	34285	34970	35670	36383	37111	37853	38610	39382	40170	40973	41793	42629	43481	44351	45238	46143	47066
Total Cumulated Income (€)	142704	175011	207964	241577	275861	310832	346502	382885	419996	457849	496459	535842	576012	616985	658778	701407	744888	789239	834477	880620	927685

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash-Flows (€)	-142704	27066	13106	13432	21707	22205	22713	23231	23760	24299	24849	25410	25983	26566	27162	27769	28388	29020	29664	30322	30992
NPV (20 YRS) (€)	118.914 €																				
IRR	15%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs (€)	142704	4940	17631	16896	9925	9494	9082	8689	8314	7955	7612	7284	6971	6672	6387	6113	5852	5603	5364	5136	4918
Discounted Energy Production (kWh)	0	165881	156344	147356	138884	130899	123373	116280	109595	103294	97355	91758	86482	81510	76824	72407	68244	64321	60623	57137	53852
LCoE (€/kWh)	0,1516																				

Figure II.4: 22 kW Co-Funded

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost (€)	311379																				
Maintenance (€)			18727	19102	9273	9458	9647	9840	10037	10238	10442	10651	10864	11081	11303	11529	11760	11995	12235	12480	12729
Active Charcoal (€)	2000	2040	2081	2122	2165	2208	2252	2297	2343	2390	2438	2487	2536	2587	2639	2692	2746	2800	2856	2914	2972
Insurance (€)	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557
Grid Connection & Measur. (€)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits (€)	5000																				
Barn Adapatation (€)	40000																				
Total Costs (€)	361936	5597	24365	24781	14994	15223	15456	15694	15937	16185	16437	16695	16958	17226	17499	17778	18062	18352	18648	18950	19258
Total Cumulated Costs (€)	361936	367533	391898	416679	431673	446896	462352	478047	493984	510168	526606	543300	560258	577484	594983	612760	630823	649175	667823	686773	706031

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000
Annual Saved Electricity (€)		30569	31181	31804	32440	33089	33751	34426	35115	35817	36533	37264	38009	38769	39545	40336	41142	41965	42805	43661	44534
Annual Sold Electricity to grid (€)		12662	12915	13173	13437	13705	13980	14259	14544	14835	15132	15435	15743	16058	16379	16707	17041	17382	17729	18084	18446
Total Income (€)	0	43231	44096	44978	45877	46795	47731	48685	49659	50652	51665	52698	53752	54827	55924	57042	58183	59347	60534	61745	62980
Total Cumulated Income (€)	0	43231	87327	132304	178182	224976	272707	321392	371051	421703	473368	526067	579819	634646	690570	747613	805796	865143	925677	987422	1050401

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash-Flows	-361936	37634	19731	20197	30883	31572	32274	32991	33722	34467	35228	36004	36795	37602	38425	39265	40121	40995	41886	42795	43722
NPV (20 YRS)	19.213 €																				
IRR	7%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs (€)	361936	5275	21644	20748	11832	11322	10835	10369	9924	9499	9092	8704	8333	7978	7638	7314	7004	6707	6423	6152	5893
Discounted Energy Production (kWh)	0	248822	234516	221033	208325	196348	185060	174420	164392	154941	146033	137637	129724	122266	115236	108611	102366	96481	90934	85706	80779
LCoE (€/kWh)	0,184650037																				

Figure II.5: 33 kW Raw

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost (€)	311379																				
Maintenance (€)			18727	19102	9273	9458	9647	9840	10037	10238	10442	10651	10864	11081	11303	11529	11760	11995	12235	12480	12729
Active Charcoal (€)	2000	2040	2081	2122	2165	2208	2252	2297	2343	2390	2438	2487	2536	2587	2639	2692	2746	2800	2856	2914	2972
Insurance (€)	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557
Grid Connection & Measur. (€)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits (€)	5000																				
Barn Adapatation (€)	40000																				
Total Costs (€)	361936	5597	24365	24781	14994	15223	15456	15694	15937	16185	16437	16695	16958	17226	17499	17778	18062	18352	18648	18950	19258
Total Cumulated Costs (€)	361936	367533	391898	416679	431673	446896	462352	478047	493984	510168	526606	543300	560258	577484	594983	612760	630823	649175	667823	686773	706031

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000
Co-Fund (Fundo Ambiental) (€)	180968																				
Annual Saved Electricity		30569	31181	31804	32440	33089	33751	34426	35115	35817	36533	37264	38009	38769	39545	40336	41142	41965	42805	43661	44534
Annual Sold Electricity to grid (€)		12662	12915	13173	13437	13705	13980	14259	14544	14835	15132	15435	15743	16058	16379	16707	17041	17382	17729	18084	18446
Total Income (€)	180968	43231	44096	44978	45877	46795	47731	48685	49659	50652	51665	52698	53752	54827	55924	57042	58183	59347	60534	61745	62980
Total Cumulated Income (€)	180968	224199	268295	313272	359149	405944	453675	502360	552019	602671	654336	707035	760787	815614	871538	928581	986764	1046111	1106645	1168390	1231369

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash-Flows	-180968	37634	19731	20197	30883	31572	32274	32991	33722	34467	35228	36004	36795	37602	38425	39265	40121	40995	41886	42795	43722
NPV (20 YRS)	189.777 €																				
IRR	17%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs (€)	180968	5275	21644	20748	11832	11322	10835	10369	9924	9499	9092	8704	8333	7978	7638	7314	7004	6707	6423	6152	5893
Discounted Energy Production (kWh)	0	248822	234516	221033	208325	196348	185060	174420	164392	154941	146033	137637	129724	122266	115236	108611	102366	96481	90934	85706	80779
LCoE (€/kWh)	0,1244																				

Figure II.6: 33 kW Co-Funded

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost (€)	373655																				
Maintenance (€)			22889	23347	11334	11560	11791	12027	12268	12513	12763	13019	13279	13545	13815	14092	14374	14661	14954	15253	15558
Active Charcoal (€)	2500	2550	2601	2653	2706	2760	2815	2872	2929	2988	3047	3108	3171	3234	3299	3365	3432	3501	3571	3642	3715
Insurance (€)	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868
Grid Connection & Measur. (€)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits (€)	5000																				
Barn Adapatation (€)	40000																				
Total Costs (€)	425023	6418	29358	29868	17908	18189	18475	18767	19065	19369	19679	19995	20318	20647	20982	21325	21674	22030	22393	22764	23142
Total Cumulated Costs (€)	425023	431442	460800	490667	508575	526764	545239	564006	583071	602441	622120	642115	662433	683080	704062	725387	747061	769091	791484	814248	837389

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000
Annual Saved Electricity		30569	31181	31804	32440	33089	33751	34426	35115	35817	36533	37264	38009	38769	39545	40336	41142	41965	42805	43661	44534
Annual Sold Electricity to grid (€)		23585	24057	24538	25029	25530	26040	26561	27092	27634	28187	28751	29326	29912	30510	31121	31743	32378	33025	33686	34360
Total Income (€)	0	54155	55238	56343	57470	58619	59791	60987	62207	63451	64720	66014	67335	68681	70055	71456	72885	74343	75830	77346	78893
Total Cumulated Income (€)	0	54155	109393	165736	223205	281824	341615	402603	464809	528261	592981	658995	726330	795011	865066	936523	1009408	1083751	1159581	1236927	1315821

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash-Flows	-425023	47737	25880	26475	39562	40430	41316	42220	43142	44082	45041	46019	47017	48035	49073	50131	51211	52313	53437	54583	55752
NPV (20 YRS)	60.759 €																				
IRR	8%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs (€)	425023	6049	26079	25007	14131	13528	12951	12399	11872	11368	10886	10425	9984	9562	9159	8773	8404	8051	7713	7390	7081
Discounted Energy Production (kWh)	0	331762	312688	294711	277767	261798	246746	232560	219189	206588	194710	183516	172965	163021	153648	144814	136489	128642	121246	114275	107705
LCoE (€/kWh)	0,1638																				

Figure II.7: 44 kW Raw

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost (€)	373655																				
Maintenance (€)			22889	23347	11334	11560	11791	12027	12268	12513	12763	13019	13279	13545	13815	14092	14374	14661	14954	15253	15558
Active Charcoal (€)	2500	2550	2601	2653	2706	2760	2815	2872	2929	2988	3047	3108	3171	3234	3299	3365	3432	3501	3571	3642	3715
Insurance (€)	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868	1868
Grid Connection & Measur. (€)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits (€)	5000																				
Barn Adapatation (€)	40000																				
Total Costs (€)	425023	6418	29358	29868	17908	18189	18475	18767	19065	19369	19679	19995	20318	20647	20982	21325	21674	22030	22393	22764	23142
Total Cumulated Costs (€)	425023	431442	460800	490667	508575	526764	545239	564006	583071	602441	622120	642115	662433	683080	704062	725387	747061	769091	791484	814248	837389

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000
Co-Fund (Fundo Ambiental) (€)	200000																				
Annual Saved Electricity (€)		30569	31181	31804	32440	33089	33751	34426	35115	35817	36533	37264	38009	38769	39545	40336	41142	41965	42805	43661	44534
Annual Sold Electricity to grid (€)		23585	24057	24538	25029	25530	26040	26561	27092	27634	28187	28751	29326	29912	30510	31121	31743	32378	33025	33686	34360
Total Income (€)	200000	54155	55238	56343	57470	58619	59791	60987	62207	63451	64720	66014	67335	68681	70055	71456	72885	74343	75830	77346	78893
Total Cumulated Income (€)	200000	254155	309393	365736	423205	481824	541615	602603	664809	728261	792981	858995	926330	995011	1065066	1136523	1209408	1283751	1359581	1436927	1515821

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash-Flows	-225023	47737	25880	26475	39562	40430	41316	42220	43142	44082	45041	46019	47017	48035	49073	50131	51211	52313	53437	54583	55752
NPV (20 YRS)	249.261 €																				
IRR	17%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs (€)	225023	6049	26079	25007	14131	13528	12951	12399	11872	11368	10886	10425	9984	9562	9159	8773	8404	8051	7713	7390	7081
Discounted Energy Production (kWh)	0	331762	312688	294711	277767	261798	246746	232560	219189	206588	194710	183516	172965	163021	153648	144814	136489	128642	121246	114275	107705
LCoE (€/kWh)	0,1138																				

Figure II.8: 44 kW Co-Funded

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost (€)	459061																				
Maintenance (€)			24970	25469	12364	12611	12863	13120	13383	13650	13923	14202	14486	14776	15071	15372	15680	15994	16313	16640	16972
Active Charcoal (€)	2800	2856	2913	2971	3031	3091	3153	3216	3281	3346	3413	3481	3551	3622	3695	3768	3844	3921	3999	4079	4161
Insurance (€)	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295
Grid Connection & Measur. (€)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits (€)	5000																				
Barn Adapatation (€)	45000																				
Total Costs (€)	516156	7151	32178	32736	19690	19998	20312	20632	20959	21292	21632	21979	22332	22693	23061	23436	23819	24209	24608	25014	25428
Total Cumulated Costs (€)	516156	523308	555486	588221	607911	627908	648220	668852	689810	711102	732734	754713	777045	799738	822799	846235	870054	894263	918871	943885	969314

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000
Annual Saved Electricity (€)		30569	31181	31804	32440	33089	33751	34426	35115	35817	36533	37264	38009	38769	39545	40336	41142	41965	42805	43661	44534
Annual Sold Electricity to grid (€)		39475	40264	41069	41891	42729	43583	44455	45344	46251	47176	48119	49082	50063	51065	52086	53128	54190	55274	56379	57507
Total Income (€)		70044	71445	72874	74331	75818	77334	78881	80459	82068	83709	85383	87091	88833	90609	92422	94270	96155	98079	100040	102041
Total Cumulated Income (€)	0	70044	141489	214363	288694	364512	441846	520727	601186	683253	766962	852346	939437	1028269	1118879	1211300	1305570	1401726	1499804	1599844	1701885

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash-Flows	-446112	64294	40696	41596	56128	57337	58569	59827	61109	62417	63751	65112	66501	67916	69361	70834	72336	73869	75432	77027	-25428
NPV (20 YRS)	206.104 €																				
IRR	11%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs (€)	516156	6740	28584	27408	15537	14873	14238	13631	13051	12496	11966	11459	10974	10510	10066	9642	9236	8848	8476	8121	7781
Discounted Energy Production (kWh)	0	452403	426393	401879	378774	356997	336472	317127	298895	281710	265514	250249	235861	222301	209520	197474	186121	175420	165335	155829	146870
LCoE (€/kWh)	0,1410																				

Figure II.9: 60 kW Raw

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost (€)	459061																				
Maintenance (€)			24970	25469	12364	12611	12863	13120	13383	13650	13923	14202	14486	14776	15071	15372	15680	15994	16313	16640	16972
Active Charcoal (€)	2800	2856	2913	2971	3031	3091	3153	3216	3281	3346	3413	3481	3551	3622	3695	3768	3844	3921	3999	4079	4161
Insurance (€)	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295	2295
Grid Connection & Measur. (€)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits (€)	5000																				
Barn Adapatation (€)	45000																				
Total Costs (€)	516156	7151	32178	32736	19690	19998	20312	20632	20959	21292	21632	21979	22332	22693	23061	23436	23819	24209	24608	25014	25428
Total Cumulated Costs (€)	516156	523308	555486	588221	607911	627908	648220	668852	689810	711102	732734	754713	777045	799738	822799	846235	870054	894263	918871	943885	969314

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000
Co-Fund (Fundo Ambiental) (€)	200000																				
Annual Saved Electricity (€)		30569	31181	31804	32440	33089	33751	34426	35115	35817	36533	37264	38009	38769	39545	40336	41142	41965	42805	43661	44534
Annual Sold Electricity to grid (€)		39475	40264	41069	41891	42729	43583	44455	45344	46251	47176	48119	49082	50063	51065	52086	53128	54190	55274	56379	57507
Total Income (€)	200000	70044	71445	72874	74331	75818	77334	78881	80459	82068	83709	85383	87091	88833	90609	92422	94270	96155	98079	100040	102041
Total Cumulated Income (€)	200000	270044	341489	414363	488694	564512	641846	720727	801186	883253	966962	1052346	1139437	1228269	1318879	1411300	1505570	1601726	1699804	1799844	1901885
Cash-Flows	-316156	62893	39267	40138	54642	55820	57023	58249	59500	60776	62077	63405	64759	66140	67549	68985	70451	71946	73471	75026	76613
NPV (20 YRS)	341.043 €																				
IRR	17%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs (€)	316156	6740	28584	27408	15537	14873	14238	13631	13051	12496	11966	11459	10974	10510	10066	9642	9236	8848	8476	8121	7781
Discounted Energy Production (kWh)	0	452403	426393	401879	378774	356997	336472	317127	298895	281710	265514	250249	235861	222301	209520	197474	186121	175420	165335	155829	146870
LCoE (€/kWh)	0,1043																				

Figure II.10: 60 kW Co-Funded

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost (€)	515999																				
Maintenance (€)			26010	26530	12879	13137	13399	13667	13941	14219	14504	14794	15090	15392	15699	16013	16334	16660	16994	17333	17680
Active Charcoal (€)	3000	3060	3121	3184	3247	3312	3378	3446	3515	3585	3657	3730	3805	3881	3958	4038	4118	4201	4285	4370	4458
Insurance (€)	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580
Grid Connection & Measur. (€)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits (€)	5000																				
Barn Adapatation (€)	50000																				
Total Costs(€)	578579	7640	33711	34294	20706	21029	21358	21693	22036	22385	22741	23104	23475	23852	24238	24631	25032	25441	25858	26284	26718
Total Cumulated Costs (€)	578579	586219	619930	654224	674930	695959	717317	739010	761046	783431	806171	829275	852750	876602	900840	925471	950503	975944	1001803	1028087	1054805

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000
Annual Saved Electricity (€)		30569	31181	31804	32440	33089	33751	34426	35115	35817	36533	37264	38009	38769	39545	40336	41142	41965	42805	43661	44534
Annual Sold to Grid Electricity (€)		53378	54445	55534	56645	57778	58933	60112	61314	62540	63791	65067	66368	67696	69050	70431	71839	73276	74742	76236	77761
Total Income (€)		83947	85626	87338	89085	90867	92684	94538	96429	98357	100324	102331	104378	106465	108594	110766	112982	115241	117546	119897	122295
Total Cumulated Income (€)	83947	167894	253520	340858	429944	520811	613495	708033	804462	902819	1003143	1105474	1209852	1316317	1424912	1535678	1648659	1763901	1881447	2001344	2123639

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash-Flows (€)	-578579	76307	51915	53045	68379	69838	71326	72845	74393	75973	77584	79227	80903	82613	84357	86135	87950	89800	91688	93613	95577
NPV (20 YRS) (€)	255.833 €																				
IRR	11%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs (€)	578579	7201	29946	28712	16340	15640	14971	14332	13722	13138	12579	12045	11535	11047	10580	10133	9706	9298	8907	8533	8175
Discounted Energy Production (kWh)	0	557964	525885	495651	467154	440296	414982	391124	368637	347443	327467	308640	290896	274171	258408	243552	229549	216352	203913	192189	181140
LCoE (€/kWh)	0,1255																				

Figure II.11: 74 kW Raw

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost (€)	515999																				
Maintenance (€)			26010	26530	12879	13137	13399	13667	13941	14219	14504	14794	15090	15392	15699	16013	16334	16660	16994	17333	17680
Active Charcoal (€)	3000	3060	3121	3184	3247	3312	3378	3446	3515	3585	3657	3730	3805	3881	3958	4038	4118	4201	4285	4370	4458
Insurance (€)	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580	2580
Grid Connection & Measur. (€)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits (€)	5000																				
Barn Adapatation (€)	50000																				
Total Costs(€)	578579	7640	33711	34294	20706	21029	21358	21693	22036	22385	22741	23104	23475	23852	24238	24631	25032	25441	25858	26284	26718
Total Cumulated Costs (€)	578579	586219	619930	654224	674930	695959	717317	739010	761046	783431	806171	829275	852750	876602	900840	925471	950503	975944	1001803	1028087	1054805

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000
Co-Fund (Fundo Ambiental)	200000																				
Annual Saved Electricity (€)		30569	31181	31804	32440	33089	33751	34426	35115	35817	36533	37264	38009	38769	39545	40336	41142	41965	42805	43661	44534
Annual Sold to Grid Electricity (€)		53378	54445	55534	56645	57778	58933	60112	61314	62540	63791	65067	66368	67696	69050	70431	71839	73276	74742	76236	77761
Total Income (€)	200000	83947	85626	87338	89085	90867	92684	94538	96429	98357	100324	102331	104378	106465	108594	110766	112982	115241	117546	119897	122295
Total Cumulated Income (€)	200000	283947	369573	456911	545997	636864	729548	824086	920515	1018872	1119196	1221527	1325905	1432370	1540965	1651731	1764712	1879954	1997500	2117397	2239692

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash-Flows (€)	-378579	76307	51915	53045	68379	69838	71326	72845	74393	75973	77584	79227	80903	82613	84357	86135	87950	89800	91688	93613	95577
NPV (20 YRS) (€)	444.335 €																				
IRR	18%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs (€)	378579	7201	29946	28712	16340	15640	14971	14332	13722	13138	12579	12045	11535	11047	10580	10133	9706	9298	8907	8533	8175
Discounted Energy Production (kWh)	0	557964	525885	495651	467154	440296	414982	391124	368637	347443	327467	308640	290896	274171	258408	243552	229549	216352	203913	192189	181140
LCoE (€/kWh)	0,0958																				

Figure II.12: 74 kW Co-Funded

III

Financial Simulations: Vermont

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Costs																					
AD Plant Cost ($)	200000																				
Maintenance ($)			15606	15918	16236	16561	16892	17230	17575	17926	18285	18651	19024	19404	19792	20188	20592	21004	21424	21852	22289
Active Charcoal ($)	2000	2040	2081	2122	2165	2208	2252	2297	2343	2390	2438	2487	2536	2587	2639	2692	2746	2800	2856	2914	2972
Insurance ($)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Grid Connection & Measur. ($)	10000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits ($)	5000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Barn Adapatation ($)	75000																				
Total Costs ($)	293000	6040	21687	22041	22401	22769	23145	23528	23918	24317	24723	25137	25560	25991	26431	26880	27337	27804	28280	28766	29261
Total Cumulated Costs ($)	293000	299040	320727	342767	365169	387938	411083	434610	458529	482845	507568	532706	558266	584257	610688	637568	664905	692709	720989	749755	779016
Income	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000	88000
Feed In Tariff ($)	0	13015	13276	13541	13812	14088	14370	14657	14950	15249	15554	15865	16183	16506	16837	17173	17517	17867	18224	18589	18961
Voluntary GMP ($)	0	3590	3662	3735	3810	3886	3964	4043	4124	4207	4291	4377	4464	4553	4645	4737	4832	4929	5027	5128	5231
Production Tax Credit ($)	0	2288	2288	2288	2288	2288	2288	2288	2288	2288	2288										
Investment Tax Credit ($)		60000																			
RECs ($)		2693	2747	2802	2858	2915	2973	3033	3093	3155	3218	3283	3348	3415	3483	3553	3624	3697	3771	3846	3923
Carbon Credits ($)		1469	1498	1528	1559	1590	1622	1654	1687	1721	1755	1790	1826	1863	1900	1938	1977	2016	2057	2098	2140
Total Income ($)		83055	23471	23894	24326	24767	25217	25675	26143	26620	27107	25315	25821	26338	26865	27402	27950	28509	29079	29661	30254
Total Cumulated Income ($)	0	83055	106526	130420	154746	179513	204730	230405	256548	283168	310275	335590	361412	387749	414614	442016	469966	498475	527554	557214	587468
Cash-Flows	-293000	77015	1784	1854	1925	1998	2072	2148	2225	2304	2384	178	261	347	433	522	613	705	799	895	993
NPV (20 YRS)	-193.380 €																				
IRR																					
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI
Discounted Costs ($)	293000	5688	19232	18407	17617	16863	16142	15452	14793	14163	13560	12984	12433	11905	11401	10919	10457	10016	9594	9189	8803
Discounted Energy Production (kWh)	0	82870	78040	73491	69207	65173	61374	57796	54427	51254	48267	45453	42803	40308	37959	35746	33662	31700	29852	28112	26473
LCoE ($/kWh)	0,5560																				

Figure III.1: 11 kW Vermont

	Costs																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost ($)	270000																				
Maintenance ($)			20808	21224	21649	22082	22523	22974	23433	23902	24380	24867	25365	25872	26390	26917	27456	28005	28565	29136	29719
Active Charcoal ($)	2000	2040	2081	2122	2165	2208	2252	2297	2343	2390	2438	2487	2536	2587	2639	2692	2746	2800	2856	2914	2972
Insurance ($)	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350
Grid Connection & Measur. ($)	10000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits ($)	5000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Barn Adapatation ($)	75000																				
Total Costs ($)	363350	6390	27239	27697	28164	28640	29126	29621	30127	30642	31168	31704	32251	32809	33379	33959	34551	35155	35771	36400	37041
Total Cumulated Costs ($)	363350	369740	396979	424675	452839	481479	510604	540225	570352	600994	632162	663866	696117	728927	762305	796264	830816	865971	901742	938142	975183
	Income																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000	176000
Feed in Tariff ($)	0	26030	26551	27082	27624	28176	28740	29314	29901	30499	31109	31731	32366	33013	33673	34347	35033	35734	36449	37178	37921
Voluntary GMP ($)	0	7181	7324	7471	7620	7773	7928	8087	8248	8413	8582	8753	8928	9107	9289	9475	9664	9858	10055	10256	10461
Production Tax Credit ($)	0	4576	4576	4576	4576	4576	4576	4576	4576	4576	4576										
Investment Tax Credit ($)		81000																			
RECs ($)		5386	5493	5603	5715	5830	5946	6065	6186	6310	6436	6565	6696	6830	6967	7106	7248	7393	7541	7692	7846
Carbon Credits ($)		2938	2996	3056	3117	3180	3243	3308	3374	3442	3511	3581	3653	3726	3800	3876	3954	4033	4113	4196	4280
Total Income ($)		127110	46941	47788	48653	49534	50433	51350	52286	53240	54213	50630	51643	52676	53729	54804	55900	57018	58158	59321	60508
Total Cumulated Income ($)	0	127110	174051	221840	270493	320027	370460	421810	474096	527337	581550	632180	683823	736499	790228	845032	900932	957949	1016108	1075429	1135937
Cash-Flows	-363350	120720	19702	20092	20489	20894	21308	21729	22159	22598	23046	18926	19391	19866	20351	20845	21349	21863	22387	22922	23467
NPV (20 YRS)	-29.774 €																				
IRR	5%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs ($)	363350	6018	24156	23130	22149	21211	20313	19454	18633	17847	17095	16376	15687	15028	14398	13794	13217	12664	12135	11628	11143
Discounted Energy Production (kWh)	0	165741	156079	146981	138413	130345	122747	115592	108854	102509	96533	90906	85607	80617	75918	71492	67325	63400	59705	56224	52947
LCoE ($/kWh)	0,3468																				

Figure III.2: 22 kW Vermont

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost ($)	350000																				
Maintenance ($)			26010	26530	27061	27602	28154	28717	29291	29877	30475	31084	31706	32340	32987	33647	34320	35006	35706	36420	37149
Active Charcoal ($)	2000	2040	2081	2122	2165	2208	2252	2297	2343	2390	2438	2487	2536	2587	2639	2692	2746	2800	2856	2914	2972
Insurance ($)	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750
Grid Connection & Measur. ($)	15000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits ($)	5000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Barn Adapatation ($)	80000																				
Total Costs ($)	453750	6790	32841	33403	33976	34560	35156	35765	36385	37017	37663	38321	38993	39677	40376	41088	41815	42557	43313	44084	44871
Total Cumulated Costs ($)	453750	460540	493381	526783	560759	595319	630476	666240	702625	739642	777305	815626	854619	894296	934672	975761	1017576	1060132	1103445	1147529	1192400

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000	264000
Feed in Tariff ($)	0	39046	39827	40623	41436	42264	43109	43972	44851	45748	46663	47596	48548	49519	50510	51520	52550	53601	54673	55767	56882
Voluntary GMP ($)	0	10771	10987	11206	11430	11659	11892	12130	12373	12620	12873	13130	13393	13660	13934	14212	14497	14787	15082	15384	15692
Production Tax Credit ($)	0	6864	6864	6864	6864	6864	6864	6864	6864	6864	6864										
Investment Tax Credit ($)		105000																			
RECs ($)		8078	8240	8405	8573	8744	8919	9098	9280	9465	9654	9848	10044	10245	10450	10659	10872	11090	11312	11538	11769
Carbon Credits ($)		4406	4495	4584	4676	4770	4865	4962	5062	5163	5266	5371	5479	5588	5700	5814	5930	6049	6170	6293	6419
Total Income ($)		174166	70412	71683	72979	74301	75650	77026	78429	79860	81320	75945	77464	79013	80594	82206	83850	85527	87237	88982	90762
Total Cumulated Income ($)	0	174166	244577	316260	389239	463540	539190	616216	694645	774505	855825	931770	1009235	1088248	1168842	1251048	1334897	1420424	1507661	1596643	1687405

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash-Flows	-453750	167376	37571	38280	39003	39741	40494	41261	42044	42843	43657	37624	38472	39336	40218	41117	42035	42970	43925	44898	45891
NPV (20 YRS)	117.079 €																				
IRR	10%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs ($)	453750	6394	29124	27895	26720	25595	24519	23489	22504	21560	20657	19793	18966	18174	17416	16690	15995	15330	14693	14083	13499
Discounted Energy Production (kWh)	0	248611	234119	220472	207620	195518	184121	173388	163281	153763	144800	136359	128410	120925	113876	107238	100987	95100	89557	84336	79420
LCoE ($/kWh)	0,2840																				

Figure III.3: 33 kW Vermont

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost ($)	420000																				
Maintenance ($)			29131	29714	30308	30914	31533	32163	32806	33463	34132	34814	35511	36221	36945	37684	38438	39207	39991	40791	41607
Active Charcoal ($)	2500	2550	2601	2653	2706	2760	2815	2872	2929	2988	3047	3108	3171	3234	3299	3365	3432	3501	3571	3642	3715
Insurance ($)	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100
Grid Connection & Measur. ($)	20000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits ($)	5000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Barn Adapatation ($)	80000																				
Total Costs ($)	529600	7650	36832	37467	38114	38774	39448	40135	40836	41550	42279	43023	43781	44555	45344	46149	46970	47807	48662	49533	50421
Total Cumulated Costs ($)	529600	537250	574082	611549	649663	688438	727886	768021	808856	850406	892686	935709	979490	1024045	1069389	1115538	1162508	1210316	1258977	1308510	1358931

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000	352000
Feed in Tariff ($)	0	52061	53102	54164	55247	56352	57479	58629	59801	60998	62217	63462	64731	66026	67346	68693	70067	71468	72898	74356	75843
Voluntary GMP ($)	0	14362	14649	14942	15241	15545	15856	16173	16497	16827	17163	17507	17857	18214	18578	18950	19329	19715	20110	20512	20922
Production Tax Credit ($)	0	9152	9152	9152	9152	9152	9152	9152	9152	9152	9152										
Investment Tax Credit ($)		126000																			
RECs ($)		10771	10987	11206	11430	11659	11892	12130	12373	12620	12873	13130	13393	13660	13934	14212	14497	14787	15082	15384	15692
Carbon Credits ($)		5875	5993	6113	6235	6360	6487	6616	6749	6884	7021	7162	7305	7451	7600	7752	7907	8065	8227	8391	8559
Total Income ($)		218221	93882	95577	97305	99068	100867	102701	104572	106480	108427	101260	103286	105351	107458	109608	111800	114036	116316	118643	121016
Total Cumulated Income ($)	0	218221	312103	407680	504985	604053	704920	807621	912193	1018673	1127100	1228361	1331646	1436998	1544456	1654063	1765863	1879899	1996215	2114858	2235873

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cash-Flows	-529600	210571	57050	58110	59191	60294	61419	62566	63736	64930	66148	58237	59504	60796	62114	63459	64830	66228	67655	69110	70594
NPV (20 YRS)	292.711 €																				
IRR	14%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs ($)	529600	7204	32663	31289	29975	28716	27512	26359	25256	24200	23190	22222	21295	20408	19559	18746	17967	17222	16507	15824	15168
Discounted Energy Production (kWh)	0	331481	312159	293962	276827	260690	245494	231184	217708	205017	193066	181812	171214	161234	151835	142984	134649	126801	119409	112449	105894
LCoE ($/kWh)	0,2442																				

Figure III.4: 44 kW Vermont

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost ($)	525000																				
Maintenance ($)			33293	33959	34638	35331	36037	36758	37493	38243	39008	39788	40584	41395	42223	43068	43929	44808	45704	46618	47550
Active Charcoal ($)	3000	3060	3121	3184	3247	3312	3378	3446	3515	3585	3657	3730	3805	3881	3958	4038	4118	4201	4285	4370	4458
Insurance ($)	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625
Grid Connection & Measur. ($)	30000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits ($)	5000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Barn Adapatation ($)	85000																				
Total Costs ($)	650625	8685	42039	42767	43510	44268	45041	45829	46633	47453	48290	49143	50013	50901	51807	52730	53672	54633	55614	56613	57633
Total Cumulated Costs ($)	650625	659310	701349	744116	787626	831894	876935	922764	969397	1016850	1065140	1114283	1164297	1215198	1267005	1319735	1373407	1428041	1483655	1540268	1597901

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000	480000
Feed in Tariff ($)	0	70992	72412	73860	75337	76844	78381	79949	81547	83178	84842	86539	88270	90035	91836	93672	95546	97457	99406	101394	103422
Voluntary GMP ($)	0	19584	19976	20375	20783	21198	21622	22055	22496	22946	23405	23873	24350	24837	25334	25841	26357	26885	27422	27971	28530
Production Tax Credit ($)	0	12480	12480	12480	12480	12480	12480	12480	12480	12480	12480										
Investment Tax Credit ($)		157500																			
RECs ($)	0	14688	14982	15281	15587	15899	16217	16541	16872	17209	17554	17905	18263	18628	19000	19381	19768	20163	20567	20978	21398
Carbon Credits ($)		7956	8115	8277	8443	8612	8784	8960	9139	9322	9508	9698	9892	10090	10292	10498	10708	10922	11140	11363	11590
Total Income ($)	0	283200	127964	130274	132630	135033	137484	139984	142534	145135	147788	138015	140775	143590	146462	149391	152379	155427	158535	161706	164940
Total Cumulated Income ($)	0	283200	411164	541438	674068	809101	946585	1086570	1229104	1374239	1522027	1660042	1800817	1944407	2090869	2240261	2392640	2548067	2706602	2868308	3033248

Cash-Flows	-650625	274515	85925	87507	89120	90765	92443	94155	95901	97682	99499	88871	90761	92689	94655	96661	98707	100793	102922	105093	107307
NPV (20 YRS)	545.250 €																				
IRR	18%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs ($)	650625	8179	37281	35716	34218	32785	31413	30099	28842	27638	26486	25383	24327	23315	22347	21419	20531	19681	18866	18085	17338
Discounted Energy Production (kWh)	0	452020	425671	400858	377491	355487	334765	315251	296874	279569	263272	247926	233474	219864	207048	194979	183613	172910	162831	153339	144401
LCoE ($/kWh)	0,2130																				

Figure III.5: 60 kW Vermont

Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AD Plant Cost ($)	580000																				
Maintenance ($)			41616	42448	43297	44163	45046	45947	46866	47804	48760	49735	50730	51744	52779	53835	54911	56010	57130	58272	59438
Active Charcoal ($)	3500	3570	3641	3714	3789	3864	3942	4020	4101	4183	4266	4352	4439	4528	4618	4711	4805	4901	4999	5099	5201
Insurance ($)	2900	2900	2900	2900	2900	2900	2900	2900	2900	2900	2900	2900	2900	2900	2900	2900	2900	2900	2900	2900	2900
Grid Connection & Measur. ($)	30000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Permits ($)	5000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Barn Adapatation ($)	85000																				
Total Costs ($)	706400	9470	51157	52063	52986	53928	54888	55868	56867	57887	58926	59987	61069	62172	63297	64445	65616	66811	68029	69271	70539
Total Cumulated Costs ($)	706400	715870	767027	819090	872076	926003	980891	1036759	1093626	1151513	1210439	1270426	1331494	1393666	1456964	1521409	1587025	1653836	1721864	1791136	1861674

Income

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Annual Gross Electricity Produced (kWh)		592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000	592000
Feed in Tariff ($)	0	87557	89308	91094	92916	94774	96670	98603	100575	102587	104638	106731	108866	111043	113264	115529	117840	120197	122601	125053	127554
Voluntary GMP ($)	0	24154	24637	25129	25632	26145	26668	27201	27745	28300	28866	29443	30032	30633	31245	31870	32508	33158	33821	34497	35187
Production Tax Credit ($)	0	15392	15392	15392	15392	15392	15392	15392	15392	15392	15392										
Investment Tax Credit ($)		174000																			
RECs ($)	0	18115	18478	18847	19224	19608	20001	20401	20809	21225	21649	22082	22524	22974	23434	23903	24381	24868	25366	25873	26390
Carbon Credits ($)		9792	9988	10188	10391	10599	10811	11027	11248	11473	11702	11936	12175	12419	12667	12920	13179	13442	13711	13985	14265
Total Income ($)	0	329010	157802	160650	163555	166519	169541	172624	175769	178976	182248	170193	173597	177069	180610	184222	187907	191665	195498	199408	203396
Total Cumulated Income ($)	0	329010	486812	647462	811017	977536	1147077	1319701	1495470	1674446	1856694	2026887	2200484	2377553	2558163	2742385	2930292	3121957	3317456	3516864	3720260

Cash-Flows	-706400	319540	106645	108588	110570	112591	114653	116756	118902	121090	123322	110206	112528	114897	117313	119777	122291	124855	127470	130137	132858
NPV (20 YRS)	751.995 €																				
IRR	21%																				
ROI	NO ROI	NO ROI	NO ROI	NO ROI	NO ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI	ROI
Discounted Costs ($)	706400	8918	45367	43479	41670	39939	38280	36692	35172	33715	32320	30984	29704	28478	27303	26178	25100	24067	23077	22129	21220
Discounted Energy Production (kWh)	0	557491	524994	494391	465572	438433	412876	388809	366145	344801	324702	305775	287951	271166	255359	240474	226456	213255	200824	189118	178094
LCoE ($/kWh)	0,1974																				

Figure III.6: 74 kW Vermont

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