

Article

A Systems Thinking Approach Investigating the Estimated Environmental and Economic Benefits and Limitations of Industrial Hemp Cultivation in Ireland from 2017–2021

Sinéad M. Madden ^{1,*} , Alan Ryan ¹  and Patrick Walsh ² ¹ Faculty of Science and Engineering, University of Limerick, V94 T9PX Limerick, Ireland; Alan.Ryan@ul.ie² Enterprise Research Unit, University of Limerick, V94 T9PX Limerick, Ireland; Patrick.Walsh@ul.ie

* Correspondence: sinead.madden@ul.ie

Abstract: There may be unrecognised environmental and economic benefits in cultivating industrial hemp for CO₂ sequestration in Ireland. By using a Systems Thinking approach, this study aims to answer how industrial hemp, which can sequester between 10 tonnes (t) to 22 t of CO₂ emissions per hectare, has been helpful towards carbon sequestration efforts in Ireland. A mixed-methods design combining qualitative and quantitative secondary material is used to inform Behaviour over Time Graphs (BoTGs) to illustrate the data from 2017 to 2021. In 2019 at its peak of hemp cultivation in Ireland the total CO₂ emissions from agriculture was 21,156.92 kilotonnes, and the total land cultivated with hemp was 547 hectares which represented an estimated 0.0079% of total land use and 0.011% of agricultural land use. Based on a sequestration rate of between 10 t and 22 t of CO₂, industrial hemp had the potential to remove between 5470 t and 24,068 t of CO₂ in 2019. The total amount of estimated CO₂ sequestered between 2017 and 2021 was between 14,660 t and 64,504 t of CO₂. This represents an estimated contribution in carbon tax equivalent of between €348,805 and €1,534,742, respectively.

Keywords: sustainability; agriculture systems; systems thinking; carbon emissions; carbon tax; cannabis sativa; industrial hemp; Ireland



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1. Introduction

Sustainable development is “development which meets the needs of current generations without compromising the ability of future generations to meet their own needs” [1–4]. At the United Nations Sustainable Development Summit 2015, “Transforming our world: the 2030 Agenda for Sustainable Development” [5], the 17 Sustainable Development Goals (SDGs) makes clear the links between climate change and sustainable development. The United Nations Climate Change Conference in Morocco in 2016 acted as the first meeting of the parties to the accord. The European Union (EU) has set a longer-term climate and energy policy goal of reducing CO₂ emissions by 80–95% by 2050 compared to 1990 levels and a target of 55% reduction in CO₂ emissions by 2030 [6]. The EU decarbonisation Road map 2050 [7] incorporates a cap-and-trade system, the EU Emissions Trading System (ETS), which aims at achieving these goals at the lowest possible cost. The overall objective of the EU Adaptation Strategy [8] is to contribute to a more climate-resilient Europe. The EU Adaptation strategy has three objectives, (1) promoting action by the Member States; (2) “climate-proofing” action at the EU level; and (3) promoting better-informed decision making.

Ireland missed its 2020 European Union (EU) climate CO₂ emissions target and is not on the right trajectory towards decarbonisation in the longer 2030 and 2050 challenges [9]. A report on progress toward meeting the EU Effort Sharing Decision (Decision No 406/2009/EU) [10] and (Regulation EU/2018/842) [11] CO₂ emission reduction objectives for 2020 and 2030 is included in an updated prediction of Ireland’s total CO₂

emissions to 2040 [12]. According to recent estimates from the Environmental Protection Agency (EPA) [13], CO₂ emissions will rise in most sectors in Ireland due to economic growth and the expansion of the agricultural dairy sector as a result of the Food Wise programme [14]. The transition of Ireland's environment, society, and economy to a low-carbon, climate-resilient state while reaching national and international targets is a top issue for policymakers. Ag Climatise [15], is a climate and air road map for the agriculture sector. It states that more research and innovation, as well as the establishment of a climate-smart agriculture centre of excellence, agricultural CO₂ emissions balanced by removals, and the extensive adoption of renewable energy on the farm, are all cross-cutting activities. Land management initiatives for re-wetting carbon-rich soils to transform them from carbon sources to carbon sinks are also included in the road map. In addition, it contains an effort to develop a pilot scheme to reward farmers for their farm's carbon benefit.

In the 1990s, hemp cultivation returned to the European Union (EU), and since 2016, Irish farmers can apply for a license to cultivate hemp. Industrial hemp is a strain of *Cannabis Sativa* that contains lower concentrations of tetrahydrocannabinol (THC), the narcotic component of cannabis and can be utilised as a carbon sink [16]. Hemp can sequester between 10 tonnes (t) and 22 t of CO₂ per hectare [17–21], making it more efficient at CO₂ sequestration than agroforestry [17,22]. In Ireland [23] researched industrial hemp as an energy crop by means of Life Cycle Assessment found that hemp production in Ireland might boost net CO₂ abatement by up to 21 t CO₂e annually by replacing 25% of oilseed rape (OSR) and sugar beet production. Hemp does not have to compete with food sources when it is integrated into food crop rotations.

The United Nations Commission on Narcotic Substances' decision in December 2020 to remove medicinal cannabis from a category of harmful drugs (Schedule IV of the Single Convention on Narcotic Drugs, 1961) has reignited interest in cultivating the cannabis plant [24]. However, there is little research on the environmental and economic benefits of industrial hemp for CO₂ sequestration. In Ireland, the current Programme for Government (PFG) commits to exploring the potential for growing fibre crops, including hemp, to see if the crop has a viable market [25]. Based on these policy objectives, this study aims to answer how industrial hemp has been helpful to carbon sequestration efforts in Ireland, which has a problem with rising CO₂ emissions from agriculture and international financial, legal obligations and environmental policies to maintain. If industrial hemp can sequester CO₂ at a rate of up to 22 t [17–21] per hectare and the current carbon tax is at a rate of €33.50 per tonne [26] then there may be unrecognised environmental and economic benefits in cultivating hemp for CO₂ sequestration in Ireland.

The environmental impact in this study is measured by using the number of hectares of land used to cultivate industrial hemp and multiplying it by either 10 tonnes (t), 15 t or 22 t of CO₂ per ha for each year from 2017 to 2021. The economic contribution is calculated by multiplying the total annual amounts of CO₂ sequestered from industrial hemp by the appropriate carbon tax for that year. Behaviour over Time Graphs (BoTGs), also known as time series or trend graphs and are sometimes referred to as reference mode activity, are created to visualise the data. In the business and economics communities, trend analysis implies recognising patterns from many periods and plotting them in a graphical manner to generate actionable information. BoTGs graphs are well-known components in System Dynamics approaches and can be beneficial in a variety of situations. The systems thinking approach can be applied with [27–30]. The BoTGs used to visualise the data in this study can be used as a reference point to understanding this complex system. Although industrial hemp can be cultivated twice annually, it is assumed for this study that one crop of industrial hemp was cultivated in Ireland between 2017–2021.

CO₂ values absorbed by 1 hectare of hemp vary considerably according to the agronomic practices adopted and the biomass produced per hectare. CO₂ sequestration potential is highly dependent on location, climate conditions and farming practices. Carbon storage in soils is hard to measure because it's a slow process and also due to the variation in the use of fertilisers. The different combinations make the calculations complex,

and methodological assumptions may lead to a wide range of results expressed on a per hectare basis [31]. The results are provided as a means of wide ranges which made it possible to draw insights from the historical data to ascertain the environmental and economic benefits and possible emerging implications of cultivating industrial hemp in Ireland. When hemp is grown on a large scale and under certain conditions, it can more than double the Volatile Organic Compounds (VOCs) rate in the atmosphere [32]; these calculations are not within the scope of this study.

2. Material and Methods

The study aims to qualify and quantify the benefits and limitations of outdoor cultivation of industrial hemp in Ireland. The paper aims to extend the breadth and range of inquiry by using mixed methods research design combining both qualitative and quantitative secondary data [33]. First, qualitative data in the form of environmental policy in Ireland is studied, followed by quantitative data analysis in the form of CO₂ emissions and carbon tax. This will bring together a comprehensive account of the economic and environmental benefits and limitations of cultivating industrial hemp as an agricultural crop to sequester CO₂. This is aimed at gaining an in-depth contextual knowledge and exploration of the environmental and economic benefits of hemp cultivated in Ireland. The results are reported in both narrative and quantitative terms. As a result, the contribution to the literature is a case study following [34,35].

An extensive exploration of relevant reports issued by the Government of Ireland were analysed to synthesise the knowledge on the environmental and economic benefits and limitations of cultivating industrial hemp for CO₂ sequestration in Ireland. An electronic search was performed on the University of Limerick online library and Google Scholar. Searches included keywords such as Cannabis Sativa and industrial hemp in Ireland. Suitable papers were chosen throughout the years 2020 and 2022. In addition, reports from the Environmental Protection Agency (EPA) and Teagasc were reviewed to synthesise the critical information.

In 2021, secondary empirical data was obtained from the Health Products Regulatory Authority (HPRA), which issue licenses on behalf of the Department of Health in Ireland. The application process for a hemp license in Ireland commences in January, are issued annually and are valid until 31 October of that year. The data is presented in the form of time series Behaviour over Time Graphs (BoTGs), which are used in the system thinking approach to understanding complex systems. This aims to answer how industrial hemp cultivation in Ireland has contributed to CO₂ sequestering efforts since licensing was introduced in 2016. The study follows a case study protocol that captures the set of procedures involved in the collection of empirical material [36].

Data Collection and Analysis

The Environmental Protection Agency (EPA) monitoring and assessment programs fulfil statutory reporting duties to the European Union and the Government of Ireland. The EPA data used for the study is based on the Greenhouse Gas Emissions final report 2020 [37], which was submitted by the EPA in March 2022. Ireland's overall estimated CO₂ emissions until 2040 are updated in the Greenhouse Gas Emissions projections 2019–2020 [12]. It includes an assessment of progress towards achieving the European Unions (EU) 2020 and 2030 CO₂ emission reduction targets set out in the Effort Sharing Decision (Decision No 406/2009/EU) [10] and the Effort Sharing Regulation (Regulation (EU) 2018/842) [11]. The Teagasc Working Group on CO₂ emissions has examined and prepared a study on the abatement potential of CO₂ emissions in Irish agriculture from 2021 to 2030 [38] accessed on 29th March 2022.

The unit of measurement for carbon emissions is carbon dioxide CO₂. For this study, each carbon unit is equal to one tonne (t) of CO₂. The International System of Units (SI) base unit for mass is kilograms (kg), 1000 kg equals 1 tonne [39]. Globally CO₂ emissions are measured in Gigatonne (Gt), 1 Gt is equal to 1 billion tonnes, 1 Megatonne (Mt) is

equal to 1 million tonnes and 1 kilotonnes (kt) is equal to 1000 tonnes. One tonne of CO₂ that has been removed from the atmosphere equivalent is measured as CO₂e. Other greenhouse gases (GHGs) are quantified in terms of their Global Warming Potential (GWP) over 100 years as equivalents of carbon dioxide CO₂. By definition CO₂ has a GWP of 1 CO₂ emission, CO₂ sequestration is measured in tonnes (t), land use is measured in hectares (ha) while carbon taxes are calculated in euros per tonne. The carbon sequestration rate is calculated at 10 t, 15 t and 22 t per ha annually. The land area of Ireland is 6.9 million hectares, of which 4.9 million hectares or about 69% of total land area is used for agriculture and 773,229 hectares or about 11% of total area for forestry [40].

Plants with large biomass, such as hemp, can sequester more carbon through photosynthesis and then store it in the plant's body and roots through biosequestration. Hemp stems store the most carbon, while roots and leaves store the least. Industrial hemp can sequester between 9 t to 28 t CO₂e [17,31,41]. The carbon storage estimations for this study are as follows. A low scenario conservative estimation, a mid scenario mid estimation and a high scenario overestimation. This is based on hemp capturing between 10 t and 22 t of CO₂ per hectare. The annual carbon sequestration estimations for hemp in this study are based on a single and double crop per year, as hemp can be cultivated twice annually. It is assumed due to the novelty of this crop and licensing timeline that only one crop of industrial hemp was cultivated. The different combinations make the calculations complex, and methodological assumptions may lead to a wide range of results expressed on a per hectare basis [31]. The results are provided as a means of wide ranges which made it possible to draw insights into the potential environmental and economic historical benefits and possible emerging implications of cultivating industrial hemp in Ireland.

- Low scenario conservative estimation: 1 hectare of industrial hemp on average sequesters 10 t of CO₂ per hectare [19,42].
- Mid scenario mid estimation: 1 hectare of industrial hemp on average sequesters 15 t of CO₂ per hectare [43,44].
- High scenario high estimation: 1 hectare of industrial hemp on average sequesters 22 t of CO₂ per hectare [16–19,22].

The unit of analysis is the number of hemp licenses issued annually in Ireland and the number of hectares of land cultivating hemp in Ireland since 2016. Empirical secondary material was collected from the Health Products Regulatory Authority (HPRA), which issue licenses on behalf of the Department of Health. All hemp licenses are issued annually. The application process for 2022 commenced in January 2022 and is valid until 31 October 2022. The data relating to licensing for this study was obtained from the HPRA in early 2021 and again in late 2021 and relates from the years 2016 to 2021. There was no data available for the number of hectares cultivated for 2016. Email correspondence was received from the Health Products Regulatory Authority (HPRA), Wednesday 12 May 2021 with the data for 2016 to 2020 and email correspondence received Wednesday 13 October 2021 regarding data for 2021.

3. Results

3.1. Environmental Policies in Ireland

Like all countries, Ireland is committed to achieving the 17 Sustainable Development Goals by 2030. Ireland ratified an agreement on 4 November 2016 and is legally bound to fulfil the commitments made in Paris. The Climate Action and Low Carbon Development Act 2015 [45] was a turning point for the country. More recently at COP26 'Conference of the Parties' [46] Ireland signed a global pledge for a 30% cut in methane emissions, to cut CO₂ emissions by half by 2030 and attain net-zero CO₂ emissions by 2050 [47]. Following the implementation of the Climate Action Plan [48] into law [49], Ireland has legally binding targets to reduce CO₂ emissions by 51% by the end of the decade. Through its 'National 2050 Climate Objective,' the state commits to accomplishing net-zero CO₂ emissions by 2050 as part of its goal to create a climate-resilient and climate neutral economy. This means implementing changes to reduce CO₂ emissions to the bare minimum and using offsets only

as a last resort. As part of the Climate Action Plan 2017 [50], in terms of mitigation, the Act establishes the legal framework for the national goal of achieving a low-carbon transition by 2050 [51]. This comprises carbon-neutral agriculture and land use strategies, including forestry, that does not jeopardise long term food security. The scale of this challenge for all sectors is significant. As part of the plan, several new projects have been proposed to reduce CO₂ emissions from agriculture [52].

The Programme for Government recognises the distinctive economic and social role agriculture plays in Ireland and commits to implementing initiatives to encourage and incentives farmers to farm in a more ecologically friendly and sustainable manner [52]. This aims to create a sustainable Irish agricultural sector that benefits farmers and rural communities while also protecting the environment and aligning with rising consumer attitudes. Appropriate strategies must be established to maximise soil CO₂ sequestration potential and other ecological benefits [53]. These commitments have been followed with the Government of Ireland's Interim Climate Actions [54] and Ireland's CAP Strategic Plan 2023–2027 [55].

3.2. Environmental Research in Ireland

Ireland's Environmental Protection Agency (EPA) is an independent public regulatory body that aims to protect and improve Ireland's environment. Ireland's overall estimated CO₂ emissions until 2040 are updated in the projections [12]. It includes an assessment of progress toward attaining the EU's 2020 and 2030 CO₂ emission reduction targets set out in the Effort Sharing Decision (Decision No 406/2009/EU) [10] and the Effort Sharing Regulation (Regulation EU/2018/842) [11]. An assessment provided by [38] provides analysis of the possibilities for Irish agriculture in reducing CO₂ emissions from 2021 to 2030.

Using a wide and diverse range of knowledge on CO₂ emissions from across Teagasc and other organisations, the Teagasc Working Group on CO₂ emissions examined and prepared a study on the abatement potential of CO₂ emissions in Irish agriculture from 2021 to 2030. This was in response to the European Union's (EU) Climate and Energy Package and the accompanying Effort Sharing Decision [10]. Teagasc released a report in 2012 following the development of the Food Harvest 2020 output targets. They reported the implications for CO₂ emissions are numerous, and prompt mitigation action was essential, or the agricultural sector's potential to grow in the medium to long term may be hampered.

3.3. Carbon Emission Targets

Ireland missed its European Union 2020 climate emissions target and is not on the right trajectory towards decarbonisation in the longer 2030 and 2050 challenges [12]. For the 2013–2020 period, the Environmental Protection Agency's (EPA) CO₂ emissions inventory and projections [9] shows that Ireland did not meet its commitments under the Effort Sharing Decision (ESD). Ireland's goal is to reduce CO₂ emissions by 20% before 2025 in comparison to 2005 levels. Early projections indicate that CO₂ emissions will be 8% lower than in 2005 (mostly from agriculture, transportation, and residential sectors).

Over the 2021–2030 period, under the With Existing Measures scenario, the amount of CO₂ emissions associated with agriculture are projected to grow by 3.0% and will account for 39.7% of CO₂ emissions by 2030 [50], reaching up to 21.9 million tonne CO₂ emissions. This is predicted to grow steadily with a plan to increase the national herd [14]. Estimates by the Environmental Protection Agency (EPA) [8] project that CO₂ emissions will increase in most sectors especially, in the agriculture sector given the solid economic growth and the expansion of the agricultural industry [12]. The challenge of sustainability for Irish agriculture are discussed by [56].

Under the With Additional Measures scenario, CO₂ emissions are expected to decrease to approximately 19 million tonnes by 2030, which means a 10% reduction. Ireland plans to

mitigate 16.5 million tonnes CO₂ through its Climate Action Plan, Ref. [48] which includes the measures from Teagasc's Marginal Abatement Cost Curve, Ref. [13].

Behaviour over Time Graphs (BoTGs), also known as time series or trend graphs and are sometimes referred to as reference mode activity, were created to visualise the data [37]. Figure 1 shows BoTG illustrating the historical CO₂ emissions from agriculture in Ireland from 1990 to 2020

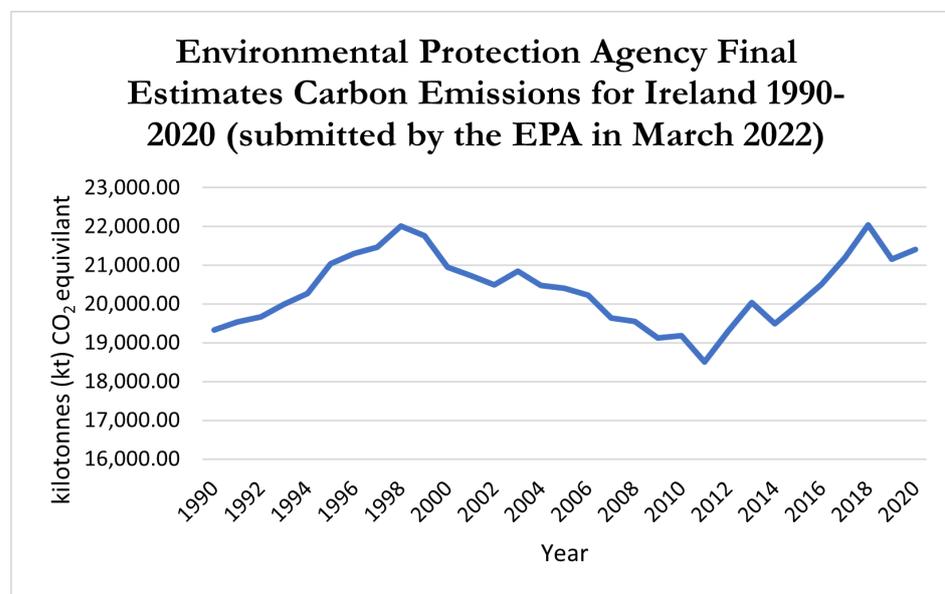


Figure 1. Behaviour over Time Graph (BoTG) historic carbon emissions from agriculture in Ireland 1990–2020 (final submission) 2022 [37].

3.4. Carbon Tax

Ireland implemented a carbon tax in 2010. From 1 May 2013, to 1 May 2014, the carbon tax rate was €10 per tonne of CO₂ emitted. As of 1 May 2014, the levy was raised to €20 per tonne. The Finance Act 2020 has planned increases in a carbon tax of €7.50 per tonne annually through to 2030. Budget 2021 implemented a €7.50 increase in the price per tonne, from €26 to €33.50. The increase for motor fuels took effect in October 2020, while the increase for solid fuels took effect in May 2021. The 2022 budget announced another €7.50 rise in the carbon price from €33.50 to €41.00 per tonne of CO₂ emissions emitted [26]. The Climate Change Advisory Council of Ireland has recommended that carbon taxes be raised in order to minimise CO₂ emissions. The Government's Climate Action Plan [57] intends on implementing a carbon tax rate of at least €80 per tonne by 2030. Figure 2 shows Behaviour over Time Graph (BoTG) historical and projected carbon tax from 2010 through to 2030.

The Programme for Government has pledged to set aside €1.5 billion in estimated carbon tax receipts over the next ten years. An investment of €20 million in projected additional carbon tax receipts to fund pilot environmental programmes has been the first step towards reaching this goal. The €3 million in funding for agricultural programmes provided by carbon tax collections in 2020 was maintained, bringing the overall funding of carbon tax-supported measures in the farming sector to €23 million in 2021 [55]. The money will be used to build and operate the REAP programme, the Results-Based Environment Agri Pilot Program. Farmers participating in the programme will be paid for environmental functions such as biodiversity enhancement, improved water quality, improved soil health, and CO₂ sequestration. Payments will be based on the quality of the environmental outcomes delivered [52].

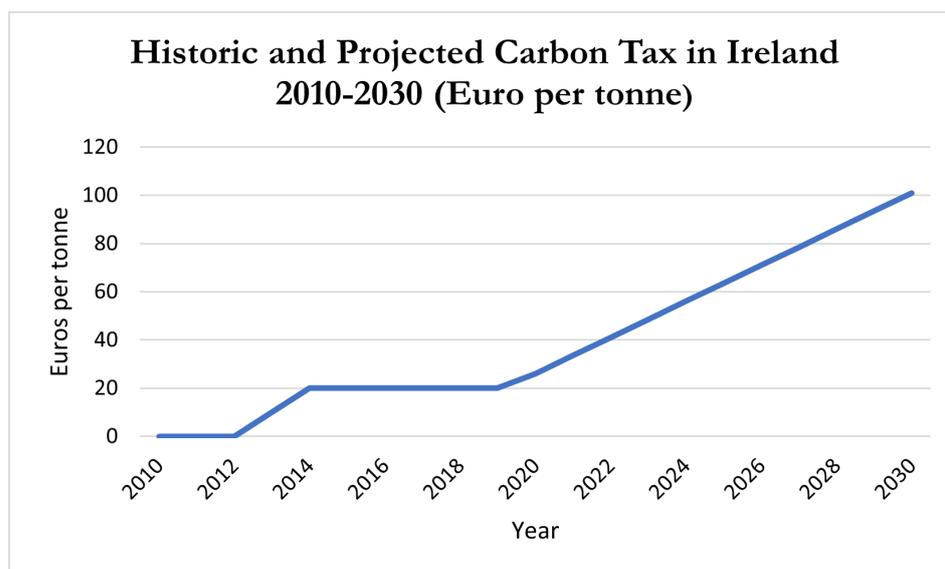


Figure 2. Behaviour over Time Graph (BoTG) historic and projected carbon tax from 2010 through to 2030.

3.5. Carbon Credits

Since 2013, Ireland has benefited from €367 million through the Kyoto protocol Effort Sharing Programme and will have to buy compliance to fulfil the 2020 targets. Ireland pays a lower price because they can offset years when they created less carbon than expected with years when they are producing more. This cost estimate is in addition to the State's past acquisitions and agreements, which have totalled more than €120 million since 2007. According to the Department of Communications, Climate Action, and Environment, more carbon credits under the Kyoto Protocol would cost the State between €2 million and €13 million in 2020 [51]. This will depend on the cost of carbon at that time. The penalty for failing to meet climate commitments will rise dramatically from 2020.

3.6. Hemp Research in Ireland

Hemp research has been undertaken in Ireland by An Foras Taluntais or the Agricultural Institute, the predecessor to Teagasc since the 1960s. In more recent decades research has been carried out by [58–63]. Industrial hemp can be utilised as a carbon sink and can sequester up to 22 t of CO₂ per hectare [17–19,22]. Ref. [61] grew industrial hemp in Ireland successfully over three years. They produced yields averaging 12.5 t/ha of entire stems at 15% m.c., which was very encouraging. Industrial hemp as a sustainable yearly energy crop in Ireland has been studied by [23] which resulted in a life cycle assessment of hemp versus other annual and perennial energy crops. Their research evaluated the CO₂ emissions balance and farm economics of hemp produced for bioenergy. They compared two perennial bioenergy crops, Miscanthus and Willow, and two traditional annual bioenergy crops, sugar beet and oilseed rape (OSR). They found the CO₂ emissions burden of hemp cultivation is intermediate between perennial and yearly conventional energy crops. The mid yield estimate's net fuel chain CO₂ abatement potential of 11t CO₂e ha annually is comparable to perennial crops and 140% and 540% higher than the OSR and sugar beet fuel chains, respectively. By substitution 25% of OSR and sugar beet with industrial hemp, net CO₂ abatement might increase to 21 t CO₂e annually. They found that hemp is a more efficient biofuel feedstock than most annual energy crops and the gross margins were significantly lower than those of OSR and sugar beet [23].

3.7. Hemp Regulations in Ireland

Since 2016, Irish landowners can apply for a license to cultivate industrial hemp, a strain of Cannabis Sativa. Industrial hemp contains lower concentrations of tetrahydro-

cannabinol (THC), the narcotic component of cannabis. To obtain a license to cultivate industrial hemp, an application must be made to the Social Inclusion section of the Department of Health and Children. Before the provision of an application form from the Department of Health and Children to cultivation hemp, the following information must be provided to the Health Products Regulatory Authority (HPRA). Name and address of the potential applicant; company registration documentation; specific identification of the lands or area for cultivation, including Ordnance Survey Maps where relevant; authorisation from the Gardaí to provide a statement to the Department of Health stating that there are no convictions recorded against the applicant; security arrangements for the crop; specific details of the seed variety that the potential applicant wishes to sow; information on the suppliers of the seeds; detailed information on the end-use of the crop, including the names of any customers to whom it will be supplied. As per regulation 5 and Schedule 2 (b) of the Misuse of Drugs (Designation) Order, SI 174 of 2017 [64], only hemp seeds recognised by the European Commission (EU) are allowed to be grown. Approved seed varieties can be obtained from the HPRA. Table 1 shows documentation required by the Health Products Regulatory Authority (HPRA).

Table 1. Documentation required by the Health Products Regulatory Authority (HPRA).

Item No	Documentation
1	Name and address of the potential applicant.
2	Company registration documentation.
3	Specific identification of the lands.
4	Authorisation for the Gardaí no convictions recorded.
5	Security arrangements for the crop.
6	Specific details of the seed variety.
7	Information on the suppliers of the seeds.
8	Information on the end-use of the crop along with names of future customers.

3.8. Legal Instruments

The following are some of the legal instruments pertaining to cultivating industrial hemp in Ireland, source [65].

- EU Regulation 1307/2013—establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy.
- EU Regulation 1308/2013—establishing a common organisation of the markets in agricultural products.
- EU Delegated Regulation 639/2014—establishing the requirement to use certified seed of varieties listed in the ‘Common Catalogue of Varieties of Agricultural Plant Species’
- EU Implementing Regulation 809/2014—establishing specific control measures and methods for determining tetrahydrocannabinol levels in hemp.
- EU Delegated Regulation 2016/1237 and EU Implementing Regulation 2016/1239—establishing the import licenses rules for hemp.
- EU Implementing Regulation 2016/1239—laying down rules for the application of EU Regulation 1308/2013 of the European Parliament and of the Council with regard to the system of import and export licenses.
- Council Directive 2002/53/EC—on the common catalogue of varieties of agricultural plant species.
- Council Directive 2002/57/EC—on the marketing of seed of oil and fibre plants.
- Council Decision 2003/17/EC—on the equivalence of field inspections carried out in third countries on seed-producing crops and on the equivalence of seed produced in third countries.

3.9. Hemp Cultivation in Ireland

The Health Products Regulatory Authority (HPRA) on behalf of the Department of Health process license applications to cultivate industrial hemp in Ireland. Data was

requested from the HPRA, and email correspondence was received on 12 May 2021 relating to the data from 2016 to 2020. A second email correspondence was received on 13 October 2021 regarding data for 2021. The number of licenses issued and area of land used to cultivate industrial hemp in Ireland since licensing was introduced in 2016 is as follows:

- 2021: 76 licenses not more than 251 hectares
- 2020: 94 licenses not more than 362 hectares
- 2019: 74 licenses not more than 547 hectares
- 2018: 24 licenses not more than 230 hectares
- 2017: 16 licenses not more than 76 hectares
- 2016: 7 licenses & no data

CO₂ emissions and removals associated with land use, land use change and forestry (LULUCF), are reported in Ireland's greenhouse gas emissions inventory, including emissions and removals associated with Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land use. In a 2020 submission which relates to the previous year (2019) the land area of Ireland was 6.9 million hectares, of which 4.9 million hectares or about 69% of total land area was used for agriculture and 773,229 hectares or about 11% of total area for forestry [40] accessed 26 May 2022. The total land use of industrial hemp cultivation in Ireland at its peak in 2019 represented 547 hectares or approximately 0.0079% of total land use and 0.011% of agricultural land use as seen in Table 2.

Table 2. Industrial hemp cultivation estimated percentage (%) land use in Ireland 2019. Source: Total land use, agriculture and forestry land use obtained from land use change and forestry (LULUCF) [40] accessed 26 May 2022, which was used to inform the calculation percentage of the amount of industrial hemp cultivated in Ireland.

Land Use	Hectares Ha	Percentage %
Total land	6,900,000	100
Agriculture	4,900,000	69
Forestry	773,229	11
Industrial hemp % of total land	547	0.0079
Industrial hemp % of agriculture	547	0.011

A Behaviour over Time Graphs (BoTG) was created to illustrate the number of industrial hemp licenses issued and land used in Ireland between 2016–2021 as seen in Figure 3. The number of industrial hemp licenses issued is shown in grey and the number of hectares cultivated with industrial hemp is shown in green. There were 7 licenses issued in 2016 although there was no data available on the amount of land cultivated with industrial hemp.

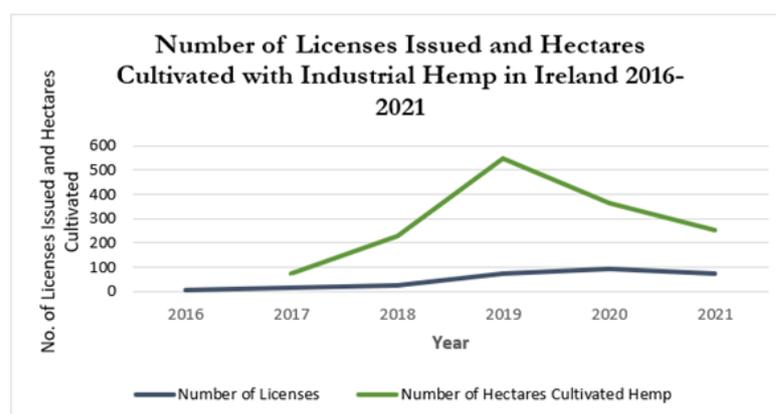


Figure 3. Behaviour over Time Graph (BoTG) illustrating the number of industrial hemp licenses

issued in Ireland between 2016–2021, the number of industrial hemp licenses issued is shown in grey and the amount of hectares cultivated with industrial hemp is shown in green. Data was requested from the HPRA, and email correspondence was received on 12 May 2021 relating to the data from 2016 to 2020. A second email correspondence was received on 13 October 2021 regarding the data for 2021.

4. Impact

The potential environmental and economic contribution of industrial hemp cultivation toward CO₂ emissions in Ireland from 2017 to 2021 in terms of CO₂ measured in tonnes and carbon tax measured in Euros can be seen in Tables 3 and 4. The environmental impact is measured by using the number of hectares of land used to cultivate industrial hemp and multiplying it by either 10 t, 15 t, or 22 t of CO₂ sequestered for each year from 2017 to 2021 as seen in Table 3. The economic contribution is calculated by multiplying the total annual amount of CO₂ sequestered from industrial hemp cultivated by the appropriate carbon tax for that year as seen in Table 4.

Table 3. Estimated environmental contribution of industrial hemp cultivation in Ireland from 2017 to 2021 in terms of carbon emissions in tonnes (t).

Year	Land Use Ha	Sgl Crop 10 t CO ₂	Dbl Crop 10 t CO ₂	Sgl Crop 15 t CO ₂	Dbl Crop 15 t CO ₂	Sgl Crop 22 t CO ₂	Dbl Crop 22 t CO ₂
2016	-	-	-	-	-	-	-
2017	76	760	1520	1140	2280	1672	3344
2018	230	2300	4600	3450	6900	5060	10,120
2019	547	5470	10,940	8205	16,410	12,034	24,068
2020	362	3620	7240	5430	10,860	7964	15,928
2021	251	2510	5020	3765	7530	5522	11,044
Contribution		14,660 t	29,320 t	21,990 t	43,980 t	32,252 t	64,504 t

Table 4. Estimated economic contribution of industrial hemp cultivation in Ireland from 2017 to 2021 in terms of carbon tax (Euros).

Year	Land Use Ha	Carbon Tax €	Sgl Crop 10 t €	Dbl Crop 10 t €	Sgl Crop 15 t €	Dbl Crop 15 t €	Sgl Crop 22 t €	Dbl Crop 22 t €
2016	-	-	-	-	-	-	-	-
2017	76	20	15,200	30,400	22,800	45,600	33,440	66,880
2018	230	20	46,000	92,000	69,000	138,000	101,200	202,400
2019	547	20	109,400	218,800	164,100	328,200	240,360	481,360
2020	362	26	94,120	188,240	141,180	282,360	207,064	414,128
2021	251	33.5	84,085	168,170	126,127.5	252,255	184,974	369,974
Contribution			€348,805	€697,610	€523,207.5	€1,046,415	€767,371	€1,534,742

4.1. Potential Carbon Sequestration

The International System of Units (SI) base unit for mass is kilograms (kg), 1000 kg equals 1 tonne [39]. For multiples of the tonne, it is more usual to speak of thousands (kilotonnes), millions (megatonnes) or billion of tonnes (gigatonnes). Globally CO₂ emissions are measured in Gigatonne (Gt), 1 Gt is equal to 1 billion tonnes, 1 Megatonne Mt is equal to million tonnes and 1 kilotonnes (kt) equals 1000 tonnes. For this study, each carbon unit is equal to one tonne (t) of CO₂. One tonne of CO₂ that has been removed from the atmosphere equivalent is measured as CO₂e. The total CO₂ emissions from agriculture in 2019 was 21,156.92 kilotonnes CO₂e equivalent [37]. If 1 kilotonne equals 1000 tonne, then 21,156.92 kilotonnes equals 21,156,920 tonnes. Taking the low scenario estimation of 10 tonne (t) multiplied by number of hectares h/a cultivated 547 h/a equals 5470 tonnes of CO₂ sequestered.

At its peak in 2019, there were 547 hectares of industrial hemp cultivated in Ireland, which accounted for 0.0079% of total land use and 0.011% of total agricultural land use in Ireland. Due to the novelty of industrial hemp and the nature of the licensing timeline, it is assumed for this study that one crop of industrial hemp was cultivated annually during this time. The results that follow show the ranges of possible carbon sequestration from conservative estimates, mid estimates to overestimates of the possible CO₂ sequestration benefits of industrial hemp cultivation in Ireland.

Low scenario conservative estimate, based on a sequestration rate of 10 tonnes of CO₂ [19,42], it is estimated a single cultivated crop could have sequestered a total of 14,660 t of CO₂ and a double crop could have sequestered 29,320 t of CO₂ from 2017 to 2021.

Mid scenario mid estimates, based on a sequestration rate of 15 t of CO₂ [43,44], it is estimated a single cultivated crop from 2017 to 2021 could sequester a total of 21,900 t of CO₂ and a double crop could have sequestered 43,980 t of CO₂ from 2017 to 2021.

High scenario overestimates, based on a gross sequestration rate of 22 t of CO₂ per hectare [16–19,22], it is estimated a single cultivated crop could sequester up to 32,252 t of CO₂ and a double crop could have sequestered a total of 64,504 t of CO₂ from 2017 to 2021.

The results show in 2019 that at a conservative estimate of 5470 t of CO₂ sequestration using 10 t per hectare for a single crop and an overestimate of 24,068 t of CO₂ sequestration using 22 t for a double crop of hemp cultivated in Ireland, using 0.0079% of total land use and 0.011% of total agricultural land use in Ireland. Figure 4 Behaviour over Time Graphs (BoTG) illustrates the estimated carbon sequestration from industrial hemp in Ireland from 2017 to 2021.

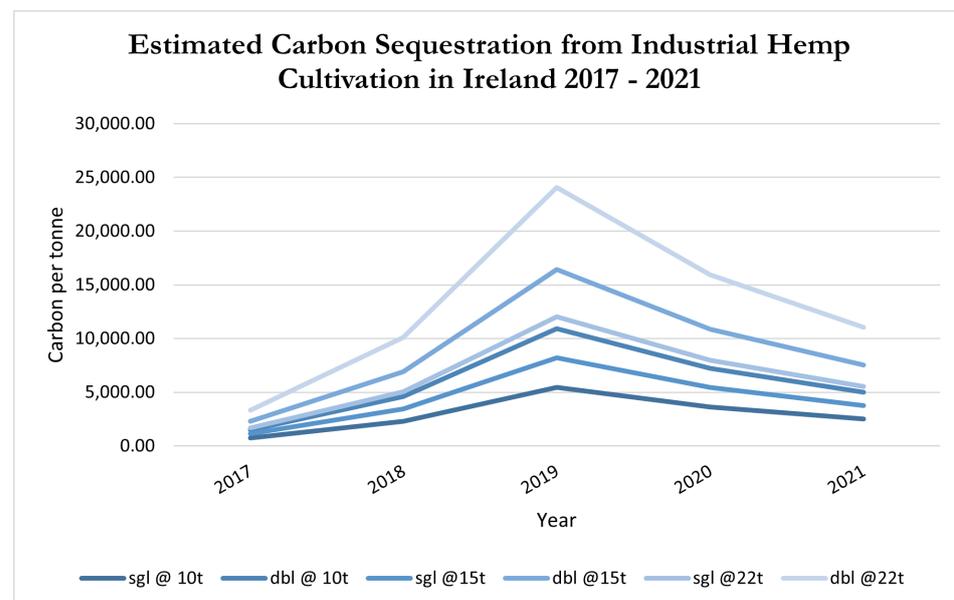


Figure 4. Behaviour over Time Graph (BoTG) estimated carbon sequestration from industrial hemp cultivation in Ireland at CO₂ sequestration rates of 10 tonnes (t), 15 t and 22 t from 2017 to 2021.

4.2. Estimated Economic Contribution towards Carbon Emissions

From 1 May 2013, to 1 May 2014, the carbon tax rate was €10 per tonne of CO₂ emitted. As of 1 May 2014, the levy was raised to €20 per tonne. The Finance Act 2020 has planned increases in a carbon tax of €7.50 per tonne annually through to 2030. Budget 2021 implemented a €7.50 increase in the price per tonne, from €26 to €33.50. The increase for motor fuels took effect in October 2020, while the increase for solid fuels took effect in May 2021. The 2022 budget announced another €7.50 rise in the carbon price from €33.50 to €41.00 per tonne of CO₂ emissions emitted [26].

The minimum and maximum estimated economic contribution of cultivating industrial hemp in Ireland from 2017 to 2021 was between €348,805 and €1,534,742 carbon tax equivalent, based on the assumption that either 1 or 2 crops were cultivated annually for

these years. In 2019 the economic contribution of cultivating industrial hemp in Ireland was between €109,400 and €481,360 carbon tax equivalent, based on between 10 t and 22 t of CO₂ sequestered and the assumption that either 1 or 2 crops were cultivated for that year. Figure 5 shows BoTG illustrating the potential financial contribution for CO₂ emissions shown as a carbon tax credit in Euros.

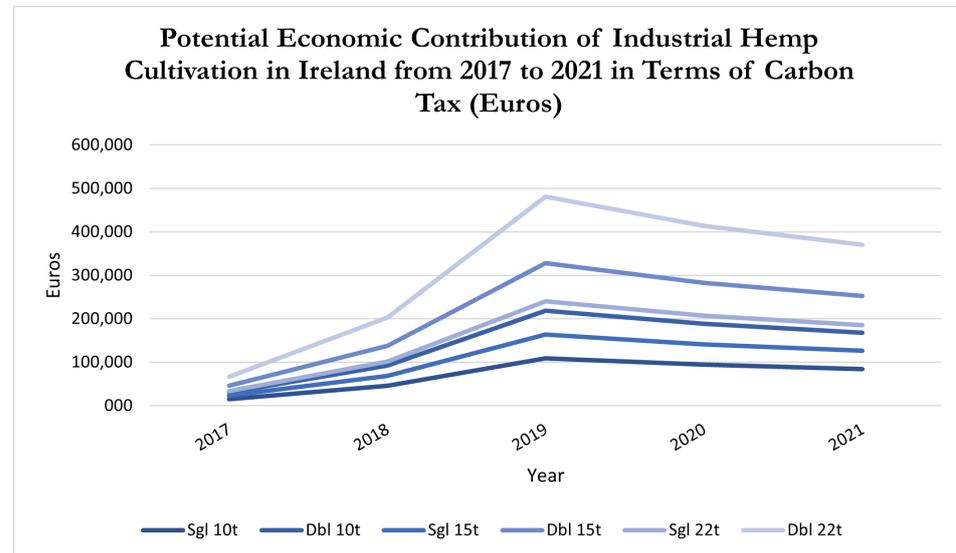


Figure 5. Behaviour over Time Graph (BoTG) estimated financial contribution for carbon emissions in terms of carbon tax credit in Euros.

5. Discussion

5.1. Environmental Impact

The international academic community has long recognised the impacts of CO₂ emissions on our climatic system. Under the United Nations Framework Convention on Climate Change (UNFCCC), countries have negotiated to work together to reduce CO₂ emissions. In addition, the European Union (EU) has established a long-term climate and energy policy objective of cutting CO₂ emissions by 80–95% by 2050 compared to 1990 levels. In July 2017, the Minister of Communications Climate Action and the Environment (DCCA) in Ireland issued a plan [57]. In terms of mitigation, the Act establishes a legal foundation for the national goal of achieving a low-carbon transition by 2050 [49].

Sustainable agriculture entails maintaining the status quo or improving the local ecosystem's environmental health [66]. A sustainable harvest strategy must take into account four interrelated factors: (1) the landscape, (2) communities and ecosystems, (3) plant populations, and (4) genetic diversity [67]. The international community faces a future in which it must balance the need to boost food and fibre production while also assisting farmers, foresters, fishers, and society in reducing CO₂ emissions, strengthening resilience, and adapting to climate change consequences. In addition, agriculture and land use (including forestry) are critical to the development of renewable energy systems and the sequestration of CO₂ from the atmosphere [15].

Due to hemp's ability to remediate contaminated soils through phytoremediation, convert high levels of atmospheric CO₂ into biomass through bio sequestration, and produce bioenergy from hemp biomass, hemp has significant environmental benefits [17]. Hemp also has excellent potential to remove heavy metals from land [68]. It is a promising candidate species for soil remediation because of its high biomass output and ability to thrive in a variety of situations [69]. The fertiliser requirements vary with the type of hemp grown, whether for seed, fibre, or CBD oil and can require a wide range of nutrients [17]. Growing energy crops does not inflict a higher impact on the environment when compared to potato and wheat [70]. Cultivating hemp does not affect agricultural lands used for food production. It is also possible to incorporate hemp into other crops [71]. The use of

the entire hemp plant could be the key to long-term economic, environmental, and social viability [72].

The results showed that in 2019, the total CO₂ emissions from agriculture was 21,156.92 kilotonnes, and at its peak the same year, there were 547 hectares of industrial hemp cultivated, which accounted for 0.0079% of total land use and 0.011% of total agricultural land use in Ireland. The results show that in 2019 a conservative estimate of 5470 t of CO₂ was sequestered using 10 t per hectare for a single crop and an overestimate of 24,068 t of CO₂ sequestered using 22 t for a double crop.

5.2. Economic Impact

In Ireland, the agriculture, forestry, and land-use (AFOLU) sectors will have significant challenges meeting interim climate targets in 2020 and 2030 and achieving carbon neutrality by 2050. Mitigation of methane and N₂₀, combined with CO₂ sequestration, could result in a 4.82 million tonne reduction in CO₂ emissions from 2021 to 2030, at a net cost of €20 million per year. This cost includes €147 million in possible efficiency savings and €167 million in gross costs. In the context of the expansion of the sector, efficiency measures may not yield absolute CO₂ emission reductions, but they will minimise any rises. At a net cost of €58 million per year, an additional 1.37 million tonne CO₂ emissions can be contributed by fossil fuel displacement via energy savings and the use of bioenergy [38].

The Climate Change Advisory Council has outlined that carbon tax will increase annually and intend to implement a carbon tax rate of at least €80 per tonne by 2030. According to recent estimates by the Environmental Protection Agency (EPA) [73], CO₂ emissions are expected to rise in most sectors in Ireland due to robust economic growth and the expansion of the agricultural sector. It is estimated that Ireland surpassed its compliance limits by 11.6 million tonne CO₂ between 2013 and 2020. Purchases of carbon units resumed in November 2019 due to a government decision and a direction from the then Department of Communications, Climate Action and Environment to solve the goals compliance gap. Since 2007, the Irish government has spent approximately €125 million euros on carbon credits [51,74]. In 2020, the National Treasury Management Agency (NTMA) purchased €1,117,466 Certified Emissions Reduction (CER's) units. The fund earned additional carbon units from Ireland's involvement in multilateral funds. The fund had €7,484,925 carbon credits as of the end of 2020 [51].

Figure 4 BoTG illustrates the estimated carbon sequestration from industrial hemp in Ireland. The minimum and maximum estimated total financial contribution of cultivating industrial hemp in Ireland from 2017 to 2021 were between €348,805 and €1,534,742 carbon tax equivalent, based on the assumption that either 1 or 2 crops were cultivated annually from 2017 to 2021. In 2019, the minimum contribution concerning carbon tax was between €109,400 and €481,360. Due to the novelty of industrial hemp and licensing timelines, it is assumed one crop of industrial hemp was cultivated annually during this time.

5.3. Limitations

Sequestration occurs when the input of CO₂ is greater than removals from harvesting and decomposition. The harvest of biomass may lead to a change in carbon stored above and below ground, and in general, these changes are not considered in the CO₂ balance of bioenergy systems [31]. In the case of arable displacement, there will be a net increase in CO₂ sequestration. Croplands have been shown to be net emitters of CO₂ of between 1 to 3 tonnes CO₂ per year [75]. Most of this carbon loss is assumed to be associated with both ploughing and extended fallow periods. Hemp cultivation in Ireland gives rise to annual CO₂ emissions of almost 3 t CO₂e, intermediate between Miscanthus and SRC (both approximately 2 t of CO₂e per year) and sugar beet and OSR (both approximately 3.5 t CO₂e per year, respectively) [23].

CO₂ values absorbed by 1 hectare of hemp vary considerably according to the agronomic practices adopted and the biomass produced per hectare. CO₂ sequestration potential is highly dependent on location, climate conditions and farming practices. Carbon

storage in soils is hard to measure because it's a slow process and also due to the variation in the use of fertilisers. The different combinations make the calculations complex, and methodological assumptions may lead to a wide range of results expressed on a per hectare basis [31]. The availability of land for the cultivation of biomass raw materials is the biggest weakness. High biomass yields are essential in achieving high CO₂ emissions savings. The use of fertilisers can reduce this saving, an exact quantification of CO₂ sequestration is not possible considering the number of variables involved. Therefore, uncertainties cannot be avoided [31]. It is unlikely that, from literature data alone, an accurate assessment of hemp's ability to sequester CO₂ can be made due to the different methods utilised and the cultivation environment. The annual carbon sequestration estimations for hemp in this study are based on a single and double crop per year, as hemp can be cultivated twice annually. It is assumed due to the novelty of this crop and licensing timeline that only one crop of industrial hemp was cultivated. The results are provided as a means of wide ranges which made it possible to draw insights into the potential environmental and economic historical benefits and possible emerging implications of cultivating industrial hemp in Ireland.

The research on hemp fertiliser requirements consistently suggests that phosphate and potassium should be applied at the time of planting, generally at a rate comparable to wheat output [76]. The difference is most important relative to potato and sugar beet, which can be characterised as high-input and high-impact crops. Despite significant differences among the crops concerning the impact values, only minor differences were found for the relative contribution of substances and resources to impacts and the relative contribution of processes to impacts. Hemp and sunflower are low-input crops concerning the use of fertilisers, pesticides, diesel, and agricultural machinery. Hemp, like corn, requires much nitrogen. There are few studies to show whether or not it grows well in poor soil [17]. The importance of the land use impact category will depend on the regional and national context [77]. Hemp is associated with higher annual costs than perennial energy crops due to annual soil preparation and seed purchase costs and higher fertiliser requirements [23].

When hemp is grown on a large scale, researchers have discovered that cultivation might be a pollutant that could negatively impact air quality. Studies show terpenes are a form of Volatile Organic Compounds (VOC). The total environmental impact of hemp production varies depending on the local climate, the number of plants planted, and the strains developed. Ref. [32] measured monoterpenes in the air at Cannabis Cultivation Facilities (CCFs) in Denver, Colorado. They found total monoterpene mixing ratios were 4 to 8 times greater surrounding CCFs than at a background area. Due to differences in strains or life cycles, monoterpene composition analysis revealed regional diversity, implying that various clusters of CCFs may have different monoterpene emission patterns. In commercial buildings that are designed for rapid growth, actual emissions may be significantly greater. Many indoor grow houses utilise large carbon filtration systems to eliminate VOCs to lessen the impacts. This is more difficult in an outdoor grow environment, although ozone levels are less likely to surge in plant-rich areas that suit themselves to outdoor growing. There is little research conducted on the effects of cannabis production on air quality.

Hemp is a crop that requires a lot of water and nutrients to grow [78]. Illegal growing and inappropriate operations have the potential to pollute the water supply. Water pollution and diversion are caused by high water demand, which can have a severe impact on the ecology [79]. The demand for water will remain a key issue.

Cultivating industrial hemp can lead directly to soil erosion which negatively affects land use. However, it can also have the ability to absorb and store heavy metals from the soil [79]. Removing toxins from the soil has shown promise in small-scale testing in Italy and the United States. Willow, a perennial plant, could be more sustainable than an annual like hemp [80] because it can be planted once and then harvested for wood chips for 25 to 30 years without harming the soil. When a field is tilled or ploughed, carbon is released into the atmosphere [81]. Due to cannabis cultivation's recent popularity, plant pathogens are becoming more prevalent and severe. This has led to a range of

previously unknown diseases being reported. A diverse group of fungal, viral, bacterial, and nematode pathogens have been discovered to affect cannabis and hemp crops in North America in the past four years. It is common for producers who use biological control agents for the prevention of disease to encounter obstacles in the approval process for cannabis products [82].

5.4. Opportunities

Green growth is founded on ecomodernist thinking, which places its faith in scientific and technological advancement (e.g., eco-design, green innovation) aimed at achieving sustainability. In other words, “green growth” means “promoting economic growth and development while guaranteeing that natural resources and environmental services on which our well-being depends continue to be available” [83]. Customers are becoming more environmentally conscious and prepared to pay more for green services and products, which presents new challenges and opportunities for entrepreneurs around the world [84]. Commodity prices are the market mechanism through which the signal to generate additional farm output is conveyed to producers [85]. Ref. [86] examines a method involving attempts to alter the most widely used value criteria in the market by incorporating principles of worth based on a product’s environmental performance. Through market-mediation advocates, organisations suggest new criteria for product valuation and attempt to convince firms that consumer preferences are changing. If customers believe the agri-food sector does not contribute to national reduction targets, the clean green image of the farming sector emphasised in the Food Wise 2025 [14] then the agri-food sector development strategies could be harmed [87]. This is aside from the possibility of national penalties.

Recent research has shown that hemp can positively reduce agricultural greenhouse gases through its nitrogenous nutrition. Fertiliser application to agricultural land affects the nutrient balance of the soil. Emissions from fields vary depending on soil type, climate, crop, tillage method, and fertiliser and manure application rates [88]. In Ireland [89] research revealed that high yields of hemp might be achieved with comparatively little fertiliser inputs. The study indicated that hemp might be utilised as a low-input break crop if adequate markets exist. Their results also showed that hemp crops require little potassium [90]. According to [17], the dry matter of the stem (where 80 per cent of atmospheric carbon is stored) increases as the nitrogen balance of the soil changes, with nitrogen levels between 0 and 120 kg/ha having the potential to sequester up to 22 t of CO₂ per hectare. When slow-release fertilisers like UREA are utilised instead of synthetic fertilisers like ammonium nitrate, hemp farming has a superior vegetative development and seed quality [18]. Ref. [23] used a nitrogen fertilisation rate for hemp ranged from 90 kg N/ha to 150 kg N/ha with a mid-point of 120 kg N/ha. An economic spreadsheet model, which utilised Microsoft Excel, was used to calculate CO₂ abatement from hemp production in these areas for yields of 8 to 14 tons per hectare. They showed a yield range of 8 t to 14 t per hectare per year with a corresponding net CO₂ abatement range between 8.7 t and 16.1 t of CO₂e per hectare per year.

Reducing cultivation emissions through the use of organic fertilisers could further increase net CO₂ abatement by up to 1.5 t CO₂e per hectare per year. [91] researched the energy requirements and environmental impacts of *Miscanthus* production and processing in Ireland. They found that replacing synthetic fertilisers with bio solids reduced global warming potential by 23–33% but raised acidification and eutrophication potential by 290–400% and 258–300%, respectively. Nitrogen is a limiting factor in crop cultivation; however, the continuous use of inorganic Nitrogen has become a threat to soils and the environment. Ref. [92] recommends environmental approaches like organic manures, bio fertilisers and similar strategies to bind Nitrogen to help the cultivation of crops. These practices should be adopted for healthy and sustainable agriculture. Refs. [93,94] studied the advances in pyrolytic technologies with improved carbon capture and storage to combat climate change. They found that bio char can potentially deplete atmospheric carbon levels and enhance CO₂ sequestration to help combat climate change. When integrated into food

crop rotations, hemp does not have to compete with food sources and is an interesting choice for developing more sustainable non-transport bio energy supply chains. Hemp has fewer negative environmental effects than most other crops cultivated locally. Herbicides are not usually required because of hemp's rapid growth when planted in the appropriate conditions. Decision-makers could regulate and promote hemp cultivation with specified geno types and soil conditions [95]. More research is required on heavy metals in plant-soil interactions [79].

Industrial hemp is a scalable crop that has the potential to improve both the economy and the environment [72]. The true valorisation of industrial hemp will hinge on significant innovation and the development of high-value applications [72]. The newest technological applications of hemp may be the most promising [96]. Stem material from hemp can be harvested in large quantities, at between 10 t and 14 t per hectare. Ref. [61]. Using no agro chemical input and with only minimal fertilisation, hemp produced a high biomass yield in Ireland (>10 t/ha). Hemp had a much lower gross margin than OSR and sugar beet but exceeded that of *Miscanthus* when organic fertiliser was used [23]. The carbon sequestration rate of fibre-based hemp crops can surpass both urban and forest tree plantations. However, the main solution in maintaining good quality and better yield of hemp is 'crop rotation' [97]. According to [61], biomass provides a long-term solution to Ireland's energy needs while also addressing greenhouse gas mitigation in the agriculture sector. However, because these crops take three to five years to establish, urgent strategies are needed to encourage the widespread adoption of these systems. Ref. [41] recommend alternative energy resources, especially biomass, should be considered as a reliable and sustainable option. Refs. [93,98] studied the role of biotechnology in climate-resilient agriculture and highlighted some significant examples from the areas of genomics, genetic engineering and genome editing for developing sustainable agriculture in the face of climate change.

The development of regionally and commodity specialised industrial hemp breeds and processing capability, including complimentary processing infrastructure and other innovation in the U.S. market, has been stifled through strict regulations [96]. Based on the unique properties of hemp, prohibition has had an impact on a wide range of businesses, from those with primarily local economic relevance to worldwide sectors and products that we use every day [96]. To improve compliance, public safety, environmental outcomes, and rural development in hemp cultivation, policy efforts to reduce administrative burdens of compliance, such as streamlining permitting processes, extending agricultural support services, and supporting farmer collectives, deserve more attention [99]. Due to its physical and genetic similarities to its psychoactive-rich (>0.3 per cent tetrahydrocannabinol (THC)), extensive community outreach and education are required to eliminate the stigma associated with industrial hemp [72].

6. Conclusions

The environmental impact in this study is measured by using the number of hectares of land used to cultivate industrial hemp and multiplying it by either 10 tonnes (t), 15 t, or 22 t of CO₂ sequestered for each year from 2017 to 2021. The total amount of CO₂ sequestered between 2017 and 2021 is estimated between 14,660 t and 64,504 t of CO₂. The minimum and maximum estimated total financial contributions were between €348,805 and €1,534,742 equivalent in a carbon tax, based on the assumption that either 1 or 2 crops was cultivated annually from 2017 to 2021. It is assumed based on the novelty of industrial hemp and the licensing timelines in Ireland that one crop of industrial hemp was cultivated annually in these years. When hemp is grown on a large scale, researchers discovered that cultivation might be a pollutant that could negatively impact air quality. Therefore, further reductions in CO₂ emissions until 2050 will necessitate investment in research to create breakthrough mitigation approaches, as well as the establishment of integrated information transfer techniques and policies to encourage adoption or a fundamental transformation in Irish agriculture.

The results showed that in 2019, the total CO₂ emissions from agriculture was 21,156.92 kilotonnes. There were 547 hectares of industrial hemp cultivated, which at its peak in the same year accounted for 0.0079% of total land use and 0.011% of total agricultural land use. Based on a sequestration rate of between 10 t and 22 t of CO₂ industrial hemp had the potential to sequester between 5470 t and 24,068 t of CO₂. This equates to a carbon tax equivalent of between €109,400 and €481,360 in Ireland for 2019. The total carbon tax equivalent from 2017 to 2021 could be a contribution of between €348,805 and €1,534,742 carbon tax equivalent.

Behaviour over Time Graphs (BoTGs) are created early in the planning stages of a research study, project, or programme to understand the situation at hand better. The time path of CO₂ emissions is similar to cash flow. Under an investment, emissions tend to be higher before net emission reduction begins to accrue, and so entail a carbon payback period [100]. Further work will be needed to include this information in the emission inventory for CO₂ emissions modelling [79]. Modelling work would also help ascertain future benefits and profits obtained from cultivating industrial hemp in Ireland. The BoTGs in this case study are an initial step to understanding this complex system and can be used as a strand in a multi-layered approach to understanding a potential solution to carbon sequestration efforts in Ireland. The BoTGs can be further used to engage diverse stakeholders in discussions in the form of Group Model Building workshops.

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