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Perennial vs Annual Energy Crops-SWOT Analysis (Case Study: Greece)

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ABSTRACT: *The EU biobased economy needs sustainable biomass supply for multiple uses: pharmaceuticals, food, feed, biobased materials and bioenergy. The yielding potential of the energy crops (annual and perennial) has to be as effiecient as possible in order to minimize the competition for land. For the last two decades several perennial and annual energy crops have been cultivated for biofuel production at a European level. The main advantage of the annual energy crops is that agronomic management can be easily adapted from more traditional cultivation practices since they can easily fit in current (rotation) farming systems. On the other hand, perennial energy crops are being specifically developed for biomass production. Moreover, their great production potential lies in their low production costs, suitability to marginal and erosive lands, relative low water needs, low nutrient and agrochemical requirements, and positive environmental benefits.*

This paper aims to discuss the most socio-economical and environmentally suited crops for biofuel production in Greece and the Mediterranean area, by comparing some annual and perennial energy crops, through the SWOT Analysis. Our study focuses a) on three perennial energy crops: Miscanthus (Miscanthus giganteus), Cardoon (Cynara cardunculus), and Switchgrass (Panicum virgatum) and b) on four annual energy crops: Sunflower (Helianthus spp.), Kenaf (Hibiscus cannabinus L.), Rapeseed (Brassica napus), Sorghum (Sorghum bicolor).

The SWOT results show that the three perennial energy crops under study are an excellent alternative choice for marginal lands, especially since there is no need for annual installation. They have high biomass yields with generally low crop costs (cardoon, switchgrass) and a wide array of end uses. They are particularly beneficial to the environment because they have low chemical requirements (cardoon), high energy content and can be used for soil remediation (miscanthus) and phytoextraction of harmful or polluting substances. However, some have a high initial installation cost (miscanthus, switchgrass) and some are potentially invasive species (miscanthus, cardoon) while almost all mature crops are particularly flammable. Moreover, the market is relatively new and the extended life cycle may force farmers into a long term commitment with uncertain results. On the other hand the four annual energy crops under analysis are some popular and well accepted plants (sunflower, rapeseed) as well some not so widespread ones (kenaf, sorghum as an energy crop). They can be included in the existing rotation farming schemes and most of them can be cultivated with techniques which are already familiar to farmers, similar to the winter cereals (rapeseed). They present an environmentally friendly alternative crop choice, in lands with poor or moderate water availability (sunflower, kenaf), with high yields and a multitude of possible uses, suitable both for small farmers' cooperatives as well as large scale farming. However, sunflower is self-incompatible requiring insect pollination and is threatened by migratory birds and disease while kenaf has high chemical requirements. Additionally, rapeseed yields heavily rely on timely seeding because it is very sensitive to high temperatures. Finally, both for kenaf and sorghum, additional research is needed regarding harvesting and storage methods.

Choosing the ideal energy crop, annual or perennial, will depend on multiple factors, both socio-economic and environmental.

KEYWORDS*: Biofuel, Energy crops, Annual, Perennial, Miscanthus, Cardoon, Switchgrass, Sunflower, Kenaf, Rapeseed, Sorghum, SWOT analysis*

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I. INTRODUCTION

Energy consumption and demand worldwide have increased disproportionately to the population increase. Global problems due to climate change and energy security issues have greatly augmented the interest for renewable energy including energy crops grown on agricultural land [1].

EU energy policy has set specific goals for biofuel share (5.75% by 2010 and 10% by 2020). This has led to the cultivation of 2.5 million ha with biofuels, almost exclusively annual crops, and it is expected to reach 25 Mha in the next few years, depending on CAP 2020 and on market needs [16]. However, each European country presents different needs and opportunities for biomass production. Although forest biomass is currently dominating the supply, agricultural biomass has better yields and may partly replace forest biomass in the near future [3].

The most basic controversy concerning biomass production is the effects of this land use change on global nutrition. More specifically, it is accused of stressing soil and water resources, harming biodiversity and negatively affecting food and feed supply [1][16]. However, this can be avoided by observing the principles of targeted and sustainable agriculture. Farmers can include non-food crops as well as food crops in current rotation systems and land competition can be avoided by utilizing marginal lands. Finally, next generation biofuels present an attractive option [16] [2].

In Greece farmers are very familiar to the cultivation techniques of cotton and wheat crops (traditionally grown crops.) and have adjusted all equipment (sowing and harvesting machinery, etc) accordingly. There have been studies in Central Greece regarding three alternative biomass crops with high yields namely Cardoon (Cynara cardunculus), Miscanthus (Miscanthus giganteus) and Switchgrass (Panicum virgatum) [14].

Choosing the most suitable bio-energy crops (rapeseed, sunflower, switchgrass, cardoon, Miscanthus, etc.) for Greece is complicated issue and several key factors have to be taken into account [14] such as existing conversion technologies, energy type needs, production environments, harvesting periods, storage costs and the general preference for non-irrigated perennial energy crops [15].

Another important factor is the opportunity cost of the land. For example, in the Thessaly region, the opportunity cost of irrigated land is much higher than the cost of dry land, because of the cultivation of demanding industrial crops such as cotton. In other Greek regions, for example in Northern Greece, where the opportunity cost of land does not differ so much between irrigated and dry land, selection among energy crops could be different. Consequently, the Thessaly region may not be the most appropriate area to introduce energy crops in Greece [15].

It becomes therefore clear that the question, which energy crop is best suited for a specific region, becomes very important. However, no single crop can be the answer and the combination of more than one crop is very often the best option. The need to determine the optimal crop choice or choices is the scientific basis for this study [2].

Taking into account the increasing interest of Greek farmers for new crops with modest inputs and cultivation requirements, this paper attempts to determine the most socio-economical and environmentally suited crops for biofuel production in Greece and the Mediterranean area, carrying out a comparison between some annual and perennial energy crops, through the SWOT Analysis [14].

Our study focuses α) on three perennial energy crops: Miscanthus (Miscanthus giganteus), Cardoon (Cynara cardunculus), Switchgrass (Panicum virgatum) and b) on four annual energy crops: Sunflower (Helianthus spp.), Rapeseed (Brassica napus), Sorghum (Sorghum bicolor), Kenaf (Hibiscus cannabinus L.).
All seven crops are currently used for bioenergy production.

II. THE ENERGY CROPS

Energy crops are generally grown for two different markets, i.e., solid bio-fuels for heat and power generation on one hand, and liquid transport fuels on the other hand (Table 1&2). Biodiesel and bioethanol, which are known as first generation biofuels, dominate the biofuel transport sector today and are mainly produced from annual crops such as rapeseed and cereals. However, second generation biofuels are becoming more popular. They are mainly produced from ligno-cellulosic biomass and their future development will affect agriculture, and industry alike [1].

Table 1.

Biofuels produced from different energy crops and yields per acre in seed and oil

[Source: "Possibilities cultivation of energy crops in the Greek area", Ioannis Eleftheriadis, CRES-CRES, Biomass Department (http://www.lignite.gr/events/eleftheriadis.pdf)]

Biofuel	Raw material	Crop yield (Kg / ha)	Yield of biofuel (Kg / ha)	Yield of biofuel (Lt / ha)
Biodiesel	Sunflower	120-300	40-70	43-75
	Cardoon	100-150	24-36	28-41
	Rapeseed	120-300	40-83	43-90
	Cotton	120-160	17-23	18-25
	Soybean	160-240	27-41	29-44
Bioethanol	Wheat	150-800	36-190	45-240
	Corn	900	213	270
	Beet	6000	475	600
	Sweet sorghum	7000-10000	553-790	675-900

Energy crops can be categorized according to plant species, cultivation and development methods and ultimate use. The type of required annual agricultural activities and supply chains are significantly affected by cultivation and development methods. The potential suitable perennial and annual energy crops among others for Europe are shown in Table 2.
Two major categories, depending on their life cycle, are annual and perennial energy crops (Table 2).

Table 2.Data of energy crops in Greece
[Source: "Possibilities cultivation of energy crops in the Greek area", Ioannis Eleftheriadis, CRES-CRES, Biomass Department (http://www.lignite.gr/events/eleftheriadis.pdf)]

Scientific name	Common name	Time duration of the crop	Kind of produced biofuel	Yields (tonnes of dry matter / ha / year)
Arundo donax	Giantreed	perennial	thermal and electrical energy	
Cynara cardunculus	Cardoon	perennial	thermal and electrical energy	1-2
Eucalyptus sp.	Eucalyptus	perennial		
Miscanthus sp.	Miscanthus	perennial	bioethanol	1-3
Beta vulgaris	Sugarbeet	annual	bioethanol	
Brassica sp.	Rapeseed	annual	biodiesel	0,3-0,8
Helianthus spp	Sunflower	annual	biodiesel	
Hibiscus cannabinus	Kenaf	annual	thermal and electrical energy	1,5
Hordeum vulgare	Barley	annual		
Secale cereale	Rye	annual		
Sorghum bicolor	Sweetsorghum	annual	bioethanol	1-4
Triticum aestivum	Wheat soft	annual	bioethanol	
Glycine max	Soybean	annual	biodiesel	
Gossypium hirsutum	Cotton	annual	biodiesel	
Panicum virgatum L	Switchgrass	annual	thermal and electrical energy- bioethanol	1,4-2,5
Zea mays	Corn	annual	bioethanol	

2.1 Perennial Energy crops

Bioenergy can be delivered by a variety of crops, cropping systems and conversion technologies [7]. It is argued that, faced with the combined challenge of food and energy security, low input perennial crops are environmentally superior to annual crops [8]. Perennial energy crops are herbaceous plants with a multi year life cycle, usually about 10 to 15 years. Such plants include many well-known energy crops like cardoon, miscanthus, switchgrass, giantreed and reed canary grass [4] (Table 2).

The study of solar capture by plants reveals C4 perennial energy crops' photosynthesis to be as efficient as photovoltaic devices [36]. The major advantage of perennial crops is that ploughing, and planting are not necessary every year. Consequently, while annual irrigation, fertilizers, pesticides and insecticides are required, the initial cultivation cost can be divided throughout the duration of the crop life. On the other hand, the extended life cycle may seem to farmers as a long-term commitment with unsure prospects, especially when there is no clear market outlines for the end product [4].

Generally perennial grasses are suitable for biomass production due to their high yield potential, the high contents of lignin, cellulose and hemicelluloses polysaccharides and their positive social and environmental benefits [10].

Also, perennials are a great potential source for second generation biofuels. Moreover, these crops have some advantages over annual crops in terms of agricultural inputs, yields, production costs, food security, reduced GHG emissions, and environmental sustainability [16]. Moreover, although input requirements are very low and pesticides are necessary only for the first two years, they present high biomass productivity [11] [10] [9]. Due to their ability to survive environmental stresses they are ideal for underused or abandoned land [5]. The OPTIMA project which stands for 'Optimization of perennial grasses for biomass production' and is funded by the EU, examines perennial traits and varieties ideal for the Mediterranean area [5].

Extensive root systems of perennial grasses can potentially bind soil. This would prevent erosion and aid in filtering heavy metal contaminants from wastewaters [5]. Furthermore, it improves soil structure and reduces erosion compared to intensively managed land [10] [47].

Several studies indicate that water induced soil erosion will be reduced, particularly when cardoon, miscanthus or switchgrass replace conventional annual crops [12]. Bical Energy reports a high reduction of the rate of soil erosion when cereals are replaced by perennial grasses [13].

Perennial crops have been found to reduce nitrogen and phosphorus loss to surface and groundwater compared to arable land uses. Moreover, they can potentially increase the organic carbon soil content particularly in soils with previously depleted carbon levels [47]. They may also be used to phytoremediate sites contaminated with heavy metals and to treat water waste, farmland drainage, sewage sludge and landfill leachate [47] [10].

In general, perennial crops differ from annual crops by having a viable root system during autumn, winter and spring when N is potentially leached from the root zone [6]. Loss of N from agriculture, reduces biodiversity of natural ecosystems, pollutes drinking water, thereby affecting human health, and contributes to global warming. However, to meet the targets of the EU Water Framework Directive further reductions are necessary, and as a measure towards achieving this, perennial energy crops have been suggested [8].

Perennial energy crops also lead to less greenhouse gas emissions. Compared to annual crops such as cereals there will be a drop in N_2O- emissions equal [9]. In addition, such grasses could potentially help reduce atmospheric greenhouse gasses by acting as carbon sinks [5][10]. The perennial energy crops will secure carbon storage (sinks) of 1,565 tones CO_2- equivalent per hectare [9][10].

Rural communities could generate new sources of income, as well as employment opportunities, by growing these perennial bio-factories on marginal lands, without compromising existing crops grown for food [5][10]. It will also bring about the development of regional economic structures and improve the education, training and assistance services provided for farmers [10].

Certain agronomic features of perennial grasses such as blossom sterility, high initial installation cost, relative low harvest mechanization, high humidity during harvest and high ash percentage present considerable weaknesses [35]. Another important drawback is that they use more water than traditional crops and grass land [47].

Where landscape is concerned, there is concern about “forestification” of the open agricultural landscape, where 4-6 meter high “green walls” of perennial crops blocking the view [9] thus potentially having a significant impact on landscape. Moreover, if large areas are planted it could lead to monoculture. Finally, root depth and hydrological impact may negatively affect archaeology [47].

Perennial energy crops will benefit some animals connected to more closed landscapes to the disadvantage of birds of the open land, thereby negatively affecting biodiversity [9] [10].

Perennial grasses require a long-term land commitment by the farmers. What is more, some of them are exclusively planted by rhizomes and/or plants and that makes it more expensive than the seed planting. Consequently, they have lower farmer/public acceptance compared to the annual energy crops [16].

4FCROPS proposes certain plant species suitable for different parts of Europe, based on their ability to adapt to climatic conditions, the feasibility of agronomic management and most importantly their biomass yield. As shown at Table 2, eucalyptus, sweet sorghum, giant reed and cardoon are more suitable for southern Europe while poplar, willow, reed canary grass, switchgrass and miscanthus are suggested for northern Europe. Perennials present an attractive choice for advanced biofuels particularly if they are domesticated and genetically improved [16].

2.2. Annual Energy Crops

Annual energy crops have a lifecycle of a year or a season and have to be replanted every time. Such crops are fibrous sorghum, kenaf, cannabis as well as most traditional crops which are suitable for energy production [4] (Table 2&3). They are mainly used for the production of first generation biofuels (bioethanol and biodiesel), while some of them can be used alternatively for food or fiber production [16].

Annual energy crops are widely adopted by farmers because they can be easily integrated with the conventional agricultural systems and the existing rotation systems. Moreover, they can easily be established by seed and can be cultivated with the existing machinery used for other conventional crops with minor adjustments [16].

The fact that these plants resemble conventional annual crops regarding cultivation and harvest methods ensures cost reduction at low market levels. Furthermore, they can be rotated with other spring crops such as cotton, sugar beet and corn. Thus, annual energy crops present a feasible, safe choice for farmers, leaving them free from long term commitment demands, while they can contribute to the biodiversity of an area. Additionally, many of these crops can be used as raw material for the fiber industry or even as feed. However, the disadvantage is that the final fuel price is increased, due to the cost and the energy demands of annual planting, as they have to be replanted every year [4].

Annual energy crops have higher agrochemical requirements and present a greater risk of soil compaction, erosion and nitrogen leaching (particularly rapeseed) [47]. Perennials, unlike annual energy crops, have higher biomass yields with lower N inputs [1].

Increased demand of ethanol production has stressed corn production which has led to negative environmental consequences. An alternative option is biofuel production from crop residues but this presents several sustainability concerns. Lignocellulose from perennial species, particularly C4 grasses, is better suited than grain or sugar from annuals [36].

Table 3.

Data of Annual Energy crops in Greece -2013 [Source: Greek Payment Authority of Common Agricultural Policy (OPEKEPE -ΟΠΕΚΕΠΕ)]

Region	**Kind of Energy Crop**	**Area** (ha)	**Production** (kgr)
Eastern Macedonia & Thrace	Rapeseed	4 424.20	1 027 650.00
	Sunflower	458 556.10	107 364 759.80
	Soya bean (soybean)	15 849.60	5 316 352.00
Central Macedonia	Rapeseed	34 391.90	7 862 254.00
	Sunflower	180 613.30	47 829 813.40
	Soya bean (soybean)	2 971.60	792 834.00
Thessaly	Sunflower	10 484.80	3 213 507.00
	Soya bean (soybean)	35.90	13 130.00
West Macedonia	Rapeseed	656.30	135 350.00
	Sunflower	18 899.10	5 506 579.00
	Soya bean (soybean)	87.10	5 820.00
Central Greece	Sunflower	7 470.50	2 343 927.00
Peloponnese	Sunflower	309.40	85 980.00
Total of Energy Crops		**734749.80**	**1027650.00**

III. MATERIAL AND METHODS

3.1. SWOT analysis

A SWOT analysis is a decision-making tool. By evaluating the Strengths, Weaknesses, Opportunities and Threats related to a project or business venture and by identifying the internal and external factors that are affect it, strategy and course planning are facilitated. [17].

The aim of any SWOT analysis is to identify the key of internal and external factors that are important to achieving the objective. SWOT analysis groups key pieces of information into two main categories:

- Internal factors – The strengths and weaknesses internal to the organization or project.
- External factors – The opportunities and threats presented by the external environment [40].

The results are often presented in the form of a matrix which is shown below (Figure 1):

Fig. 1. General scheme of the SWOT tables [17].

3.2. The objective of the SWOT analysis

We used the Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis to examine the features of perennial and annual energy crops cultivation for biofuel production, determine which bioenergy crops should be promoted and identify the actions needed regarding economic viability, environmental impact, and social development.

We can consider the cultivation of perennial and annual energy crops for biofuel production as an action or project to be analyzed by SWOT. Internal factors (characteristics of cultivation and conversion) are classified as Strengths (S) or Weaknesses (W), and external factors (regarding markets, policies and sustainability) present the Opportunities and Threats [17].

The SWOT analysis was carried out to analyse the opportunities and threats in the global external environment, and the strengths and weakness inherent to the project.

The analysis stages were the following (Figure 2):

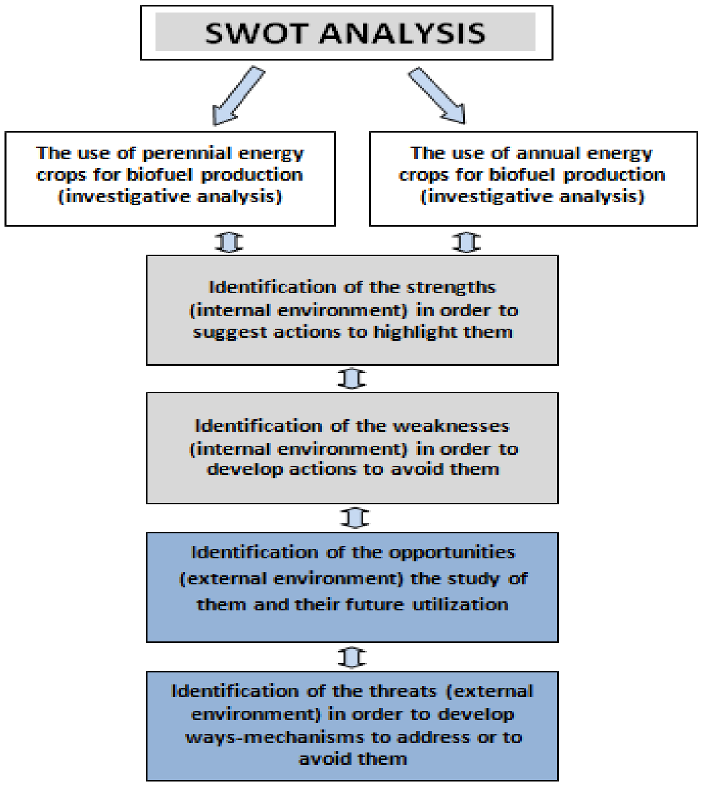

Fig. 2. Stages of the SWOT Analysis

The use of some perennial and annual energy crops for biofuel production (investigative analysis):

- Identification of the **strengths (internal environment)** such as yields, energy content, chemical requirements and adaptability, as well the environmental impact. Identifying the strengths is necessary in order to suggest actions that highlight them and also develop ways to make the best use of these strengths.
- Identification of the **weaknesses (internal environment)** such as cultivation costs, harvest mechanization levels, agrochemical use and generally environmental impact as well as possible actions to prevent or remedy them.
- Identification of the **opportunities (external environment)** such as soil remediation, marginal land use, integration with existing agricultural systems and degree of acceptance together with ways to maximize their future impact.
- Identification of the **threats (external environment)** such as competition with other biomass sources, the state of the market, danger of fire in mature crops, migratory birds, disease, and insect pests-market state, in order to develop ways and mechanisms to address or to avoid them.

The objective of the annual and perennial sustainability analysis is to identify the best ways to use annual (Sunflower, Kenaf, Rapeseed, Sorghum) and perennial (Miscanthus, Cardoon, Switchgrass) plants as energy crops from an environmental, economic and social point of view.

SWOT analysis is a tool to reach this objective. Results of the SWOT analysis can help in decision making processes for choosing the best energy crop (perennial or annual) in various conditions in order to guarantee environmental, social and economic sustainability and to formulate optimisation strategies for their production. Moreover, potential future developments are considered and integrated in the SWOT analysis.

However, several characteristics are common to annual and perennial plant species as energy crops and thus, initially, the SWOT analysis identifies general strengths, weaknesses, opportunities and threats. The SWOT tables provide brief statements (in bullet form) on the strengths, weaknesses, opportunities and threats of each perennial or annual energy crop. They address a large variety of environmental, social, economic and sustainability aspects. Depending on the energy crop, some of these statements may include the following sustainability aspects (Table 4) [17].

Table 4. Aspects of the perennial and annual energy crop Swot analysis (source: [17]

Environment	Economics	Social aspects
• GHG emissions	•Productivity and processing efficiency	•Benefits for smallholders
• Biodiversity	•Competitiveness and comparative advantage of the feedstock	• Income opportunities
• Soil conservation and soil quality	• Net energy balance	• Employment opportunities
•Water availability, use and efficiency	• State of commercialization / competitiveness with reference products	• Change in traditional use and knowledge
• Nutrient input requirements	• Market conditions	• Supply with modern energy as substitute for traditional bioenergy
• Pesticides requirements	• Price competition with other types of energy plants	• Energy security
• Soil remediation	• Policies	• Gender aspects
• Soil erosion control	• Crop yield	• Food security
	• Energy content	• Food and feed prices
		• Cultivation knowledge
		• Social and public acceptance

IV. RESULTS AND DISCUSSION

4.1. Perennial Energy Crops- SWOT Analysis

This chapter presents a SWOT analysis for three perennial plant species (Miscanthus: Table 5, Cardoon: Table 6, Switchgrass: Table 7) as energy crops identifying general strengths, weaknesses, opportunities and threats.

4.1.1. Miscanthus (Miscanthus giganteus)

Miscanthus (Miscanthus giganteus) is a rhizomatous perennial C4 grass, triploid hybrid of uncertain origin, which was probably the result of a cross between Miscanthus sinensis and M. sacchariflorus. It is widely used for biomass production mainly because its varieties are suitable for most of European climatic conditions and its cultivation is both cost effective and environmentally friendly [18] [19].

It is a high yielding energy plant - test beds yields are about 15 tons per acre per year [22][32]. In terms of liquid biofuel production, it is estimated that 700 – 800 lt of bioethanol per acre of cultivated land are produced, utilizing the existing technology in conversion of lignocelluloses biomass [24].

4.1.1.1. Strengths (Table 5.)

Miscanthus has low requirements in light, water and nitrogen [20]. It is a plant with a C4-photosynthetic pathway and is therefore able to convert solar radiation into dry matter very efficiently [11]. It has an annual cropping cycle and an estimated productive lifetime of at least 20 - 25 years. The crop will yield annually without replanting [19] and without need for annual tillage [32].

Giant Miscanthus differs from other biomass crops due to its high lignocelluloses yields [19]. The advantage of supplementing crops such as corn and soybeans with Miscanthus is that its lignocelluloses enables farmers to harvest the grass long after the corn and soybean harvests have been completed, a time when farmers typically have more time to do harvesting work [19]. Miscanthus can be left to dry in field, thus farmers are able to choose harvesting time when needed or convenient (November - March) [33].

It has low nutrient and water requirements though irrigation seems to be important in southern Europe and there are no reports of plant diseases limiting its production [20]. Fertilizers are not needed in the first two years of establishment, but maintenance fertilizer rates are required in later years [48]. It recycles nutrients back to its roots in autumn and in spring fertilizer requirements are low [33] which is a big advantage for its energy balance [25]. The results from life cycle analyses show that Miscanthus, compared to other energy crops, yields the highest energy ratio, which is reported to vary from 3 to 9.5 [24]. Miscanthus requires minimal inputs once established and there are no energy requirements during the season to apply pesticides [19]. Very few insect pests have been found to infest Miscanthus, and no reports of yield reductions have been cited [48] [22]. Also due to its rapid growth in spring, it outgrows weeds and there is no need of annual herbicide application [33].

Miscanthus x giganteus can adapt to a wide range of soil conditions but is most productive on soils well suited for corn production [19] [48]. Its biomass yield is limited on shallow, arid, cold, and waterlogged soils [49]. Moreover, it has good cold tolerance [22] and very good erosion control [33]. It is a sterile hybrid and so the crop cannot become invasive, and it is formed by natural hybridization [22] [33] [19].

Miscanthus is more environmentally efficient at producing biomass than annual crops such as cereals [19], presenting additional carbon sequestration benefits. As it is a perennial grass, it accumulates much more carbon in the soil than an annual crop such as corn or soybeans. Analysis of the whole chain from crop to fuel shows high carbon savings and greenhouse gas reductions are achievable [23]. Annual crops that use nitrogen fertilizer contribute only to a small reduction in CO_2 emission [19] [32] while for every ton of Miscanthus that replaces coal, two tons of carbon dioxide are prevented from being emitted - making an instant impact on carbon emissions. Consequently, Miscanthus originated fuel consumption is carbon neutral [33].

Finally, the crop contributes to biodiversity proving shelter for animals much better than annuals [33].

In summary, giant Miscanthus is a fast-growing perennial, it is not a food crop [23], and is one of the most promising biomass crops in the world today [19].

4.1.1.2. Weaknesses (Table 5.)

Despite the deep root system and the consequent effective use of the available ground moisture, Miscanthus cultivation presents higher water requirements compared to other biomass crops [24]. It will not tolerate stagnant water or prolonged periods of drought [20].

Rhizomes or micropropagated plantlets are used to establish the crop, thus raising the cost (7% of crop production) [21]. Moreover, addition of Nitrogen, Phosphorus and Potassium is required, in order to ensure high yields and to maintain ground fertility [24].

4.1.1.3. Opportunities (Table 5.)

Miscanthus can be grown on marginal land and it tolerates some flooding. It can be used in co-generation at coal fired power stations to generate electricity but also as ethanol. In addition, it can be utilized in fermentation, in the production of industrial materials such as bio-composites, specialized high quality paper, and in animal bedding, as it is very absorbent [19] [18] [32]. Moreover, it can be used for soil remediation against nematodes, but not cadmium-contaminated soils [19].

4.1.1.4. Threats (Table 5.)

The most important threat is that the mature crop is prone to fire. This could be avoided if farmers plan an early harvest while the water content of the crop is still high [22]. Moreover, the plant could be a vector for crop pests and diseases. Monitoring and stewardship programmes are possible ways to deal with that [22]. Miscanthus may present increased water use. A possible remedy could be targeted irrigation [22]. Finally, M. sinensis & M. sacchariflorus are potentially invasive. Breeding for sterility and slowly extending rhizomes are the appropriate actions to avoid that [22].

Table 5.

SWOT Analysis – Miscanthus (Source: [11], [18], [19], [20], [22], [23], [24], [25], [32], [33], [48], [49]).

Strengths		**Weaknesses**	
S	1. High yields of green and dry matter 2. Rapid growth 3. High performance biomass rich in lignocellulose 4. Easy mechanization of farming 5. Long productive life 6. Using existing equipment for harvesting 7. Perennial crop without the need for an annual installation 8. Low maintenance costs 9. The production cost is reduced after the first years of establishment 10. Utilization of water available even in deep sandy soils 11. Very good adaptability 12. Disease resistance - no need of pesticides 13. Minimal requirements of nutrient elements; no need of fertilizers 14. It has the highest energy balance compared to other crops of grasses 15. Sterile hybrids (M.x giganteus) without risk of uncontrolled spreading 16. Low herbicides requirements 17. Contributes to the conservation of wild fauna biodiversity- Shelter for wildlife much better than annuals 18. Additional benefits of carbon sequestration 19. Resistance to cold 20. Small nutrient losses 21. Low nitrogenous fertilization requirements 22. Low greenhouse gas (GHG) 23. Long growing season allowing farmers to work on other crops 24. Important farmers' income 25. Easy to grow 26. Very good erosion control 27. M. x giganteus is non-invasive 28. It shows a good combination of high light, water and nitrogen use efficiencies 29. Miscanthus is reported to be resistant to nematodes	**W**	1. Ensuring effective crop establishment and development in the first year requires sufficient irrigation 2. Miscanthus has a high initial establishment cost due to the prize of its rhizomes 3. It will not tolerate stagnant water or prolonged periods of drought 4. In order to secure maximum yields, addition of Nitrogen, Phosphorus and Potassium is required.
Opportunities		**Threats**	
O	1. Miscanthus can be used in co-generation at coal fired power stations to generate electricity and as ethanol. 2. It can be utilized to produce industrial materials such as bio-composites, specialized high quality paper, and in animal bedding 3. Miscanthus can be grown on marginal land and it tolerates some flooding 4. Used for the remediation of soils against nematodes **5.** Miscanthus is a promising non-food crop	**T**	1. Fire in mature crop 2. It could be a vector for crop pests & diseases 3. Increased water use 4. M. sinensis & M. sacchariflorus is invasive

4.1.2. Cardoon (Cynara cardunculus)

Cardoon (Cynara cardunculus) is a Mediterranean native plant. Cardoon life cycle, which has been recorded for at least 15 years, has adapted to the region's climate of low annual rainfall that mostly occurs in the winter. Its leaf-branched floral stem develops in late spring and dries up during summer. This above ground lignocellulosic, oil-seed rich matter can be used for biodiesel [18] [50].

In Greece, the plant can grow up to 2,6 m while dry matter production varies between 1,7 to 3,3 tons per acre, [27] or 10 to 35 tons of dry biomass per hectare (ha) per year [22], depending on plant line density.

4.1.2.1. Strengths (Table 6.)

Cardoon is a plant that is very well adapted to dry Mediterranean climate. Being a winter plant, it yields its maximal capacity for biomass production, even without irrigation, by taking advantage of rainfall [26]. Moreover, it is has a good tolerance of low temperatures [26]. It has been documented in experiments that have been carried out in Greece over the recent years that it is a well adaptable and high yielding plant [27].
After the first autumn rains Cardoon's growth is accelerated and forms a canopy. This prevents soil erosion, which is a crucial environmental risk that Mediterranean lands face [29].
Furthermore, due to its extensive root system, it takes excellent advantage of soil resources [31].
Intensive cultivation of crops like cotton and maize brings about nitrate pollution of surface and ground water. Many field experiments have shown this pollution can be controlled with cardoon cultivation which has high biomass yields with low N inputs (0 up to 50 kg N/ha in shallow and poor soils) [28].
Due to its great adaptability and fast (re)growth it outgrows weeds in many environments and therefore weed control is important only in the first year [18]. Moreover, in all field experiments, no evidence of cardoon suffering from any pest or disease was present. Therefore, cardoon can be cultivated without the use of any agrochemicals, thus further reducing the production cost and the environmental risk from the use of these substances [28]. It should be noted that compared to other crops, cardoon cultivation is of very low cost [69]. Other advantages include low moisture content at harvest and high heating value. Finally, existing machinery can be used for a mid-summer harvest [18].

4.1.2.2. Weaknesses (Table 6.)

Apart from the fact that Cardoon thistles, it also presents frost resistance problems [34]. There can be lack of homogeneity in ripening or sprouting [34]. Finally, from the second year onwards, additional fertilization is needed in winter or spring [18].

4.1.2.3. Opportunities (Table 6.)

Cardoon cultivation can help reduce fossil fuel use and meet the increasing demand for renewable, safe and environmentally friendly energy, helping prevent the greenhouse effect and acid rain [31]. Cardoon cultivation systems for bioenergy production present a lower environmental impact than those of traditional crops [31].

After its establishment, the only field work is harvesting, thus cardoon fields do not suffer from soil compaction [29]. The first leaves formed fall off creating a humus rich top soil with improves soil physical and chemical characteristics [29]. It can also be used to phytoextract CD from polluted soils or stabilize arsenic soil content [30].
Cardoon energy uses include the production of thermal and electric energy as well as biooil [27]. It can also be used as a source for ruminant's forage, for paper pulp production, and for natural rennet, and its roots are used for inulin extraction [18].
To sum up, Cardoon is a promising crop with a lot of potential for solid biofuels from lignocellulosic plant fractions, biodiesel from oil seeds for and nutraceutics from residues. However, plant protection, the mechanization of cultivation and certain dedicated varieties are areas that should be covered by future research [51].

4.1.2.4. Threats (Table 6.)

Cardoon is essentially a weed. Consequently, its taxon poses a double threat: it may lead to hybridization with different population of wild artichokes, and it may compete for natural resources with other native species especially in disturbed habitats. Although domestication generally leads to reduced fertility, it is a potentially invasive species [52].

Table 6.
SWOT Analysis – Cardoon (source: [18], [22], [26], [27], [28], [29], [30], [31], [34], [50], [51], [52], [69])

Strengths		**Weaknesses**	
S	1. High yields 2. Small crop costs 3. Practically zero chemical requirements. 4. Very good adaptability 5. No irrigation required 6. The winter crop does not require high water inflows 7. Cardoon is resistant at low temperatures 8. Zero soil pollution due to non-use of pesticides 9. Reduction of nitrates 10. Protects soil from erosion	**W**	1. Cardoon thistles 2. Frost resistance problems 3. Lack of homogeneity in ripening or sprouting 4. Additional fertilization is needed in winter or spring
Opportunities		**Threats**	
O	1. Heat and electricity and bio-oil production. 2. Suitable for cultivation in marginal lands 3. Enhances soil with cadmium and arsenic content 4. Increases soil fertility 5. Cardoon fields do not suffer from soil compaction	**T**	1. Cardoon is one of the potential invasive species which could harm different types of habitats

4.1.3. Switchgrass (Panicum virgatum)

Switchgrass (Panicum virgatum) is a North America native perennial C4 grass which has a deep rhizomatous root system. Since 1990's the US Department of Energy has been using it in ethanol and electricity production [53]. Its many varieties are suited to most of the climatic conditions in Europe [54].

The yields of switchgrass range from 12,69 t /ha to 24,05 t /ha depending on the treatment [55]. Average energy content reaches up to 18MJ/kg of dry matter while energy yield varies between 18 to 36 GJ per acre per year [27].

4.1.3.1. Strengths (Table 7.)

Switchgrass has a high climatic and soil adaptability and is drought tolerant. Moreover, it can be established by seed and cultivated conventional methods and equipment [18].

Switchgrass, is a plant with a C4-photosynthetic pathway and is therefore able to convert solar radiation into dry matter very efficiently. However, it has been observed it might perform better on marginal sites with light and sandy soils [2] [11].

Switchgrass is not heavily dependent on inputs after the establishment years. In general, production costs decrease after the first few years of establishment. The only input remaining relatively constant is the application of Nitrogen at a rate of about 60 pounds per acre though this is not required in the first year [11] [18]. Fertilizing can have an important effect on production since crops that were not treated with Nitrogen fertilizers yielded about 1,4 tons of dry biomass per acre while, during the same period, crop yields treated with 4 and 12 kg of Nitrogen per acre were 2,1 and 2,5 tons of dry biomass per acre, respectively [27].

Switchgrass usually grows in association with mycorrhizae and these help it to become a very efficient user of soil nutrients particularly phosphorus and water [18].

It is a resilient, versatile, and adaptable plant that performs well under harsh conditions such as droughts. If managed with a one cut system, the plant can help manage soil erosion—keeping soil losses to a minimum. Switchgrass provides flexibility for the farmer [11] [33].

Optimal productivity occurs in two to three years and it has long-term annual productivity potential of greater than 15 years [18] [14]. However, irrigation has been shown to be beneficial as seen in Greece where a third year crop yielded of 12.7 t dm/ha whereas the addition of irrigation produced 24.1 t dm/ha [55]. Few pesticides are required as there are no pest problems in Europe at present [18]. Moreover, it is not invasive and offers shelter for animals much better than annuals [33].

4.1.3.2. Weaknesses (Table 7.)

Switchgrass cultivation is still relatively new to farmers and yields are expected to improve as farmers become more experienced. During the first years, crops management and weed control are crucial and yields are varied and unreliable, which means that farmers may have little or no income. The crop may grow to uneven height and require reseeding. Finally, due to the volume of the crop, there are transportation, storage, and harvesting challenges [11] [54].

4.1.3.3. Opportunities (Table 7.)

Due to the increasing interest in renewable energy sources and since Switchgrass is a carbon neutral energy source, educational programs, and financial support in the form of research grants or subsidies to farmers are put forward by the state and the private sector [11].

Switchgrass can be easily integrated into existing farming operations because conventional equipment for seeding, crop management and harvesting can be used [14] [33].

Furthermore, by utilizing marginal lands, and due to its low water and nutritional requirements, Switchgrass can enhance farmers' income and profit [11] [14].

Switchgrass has many applications such as forage for cattle, or as a potential feed stock for biofuels or power plants. It can even be used to help generate wildlife refuges [11]. It can also be used for direct power production as well as for lignocellulosic ethanol production [18]. The main future uses in Greece can be the production of liquid and solid biofuels or industrial feed stock [27].

Overall, Switchgrass cultivation, although challenging to establish, is an attractive opportunity for farmers especially as the market and technology develops and experience grows [11].

4.1.3.4. Threats (Table 7.)

The lack of experience as well as market uncertainty may lead to price insecurity, especially if it is not determined by the farmers. In addition, Switchgrass faces competition from other biomass sources. The lack of biomass standards makes it difficult for investors and farmers to estimate the opportunity cost and decide on a crop. Moreover, although weed control in the establishment year is crucial, the availability of herbicides is limited. Finally, there is always the danger of fire in mature crop [11] [33].

Table 7.

SWOT Analysis – Switchgrass (source: [2], [11], [14], [18], [27], [53], [54], [55])

Strengths		**Weaknesses**	
S	1. Perennial crop without the need for an annual installation 2. Low maintenance costs 3. The production cost is reduced after the first years of establishment 4. Reduced fertilization requirements 5. Competitive with weeds - Low herbicide requirements 6. Efficient use of water 7. Reduction of soil erosion 8. Uses available water even in deep sandy soils 9. Very good adaptability 10. Drought tolerance 11. Contributes to the conservation of wild fauna biodiversity 12. Additional benefits of carbon sequestration 13. Resistance to cold 14. Small nutrient losses 15. Low nitrogenous fertilization requirements 16. Low greenhouse gas (GHG) 17. Normal farm equipment 18. Good erosion control 19. Not invasive 20. Shelter for animals much better than annuals 21. It has long-term annual productivity	**W**	1. Increased initial installation cost 2. Increased harvest, transport and storage costs 3. Necessity of nitrogen fertilization to maximize yields 4. Yields heavily dependant on rainfall 5. Insufficient knowledge of the cultivation 6. During the first three critical installation years switchgrass is prone to weeds and weed control is crucial 7. Lack of homogeneity in height may lead to reseeding needs 8. Yield variability especially problematic in the establishment years
Opportunities		**Threats**	
O	1. The main future energy uses in Greece are the production of liquid and solid biofuels and industrial raw materials 2. There is substantial political and social support 3. There is a growing interest in alternative fuels by many institutions	**T**	1. Difficulty in pricing 2. The market is new and growing 3. Competition with other biomass sources 4. Fire in mature crop 5. Shortage of available herbicides for the critical establishment years

4.2. SWOT Analysis – Annual Energy Crops

This chapter presents a SWOT analysis for four annual plant species (Sunflower: Table 8, Kenaf: Table 9, Rapeseed: Table 10, Sorghum: Table 11) as energy crops describing general strengths, weaknesses, opportunities and threats.

4.2.1. Sunflower (Helianthus spp.)

Sunflower (Helianthus spp.) is an annual spring crop, of the Compositae family, which originates in subtropical and temperate zones. Although it is native in the American continent, it has been adapted to warm temperate regions though selective breeding. It is widely grown in EU as cooking ingredient, mainly as oil used for human consumption, but also for biodiesel production in southern European countries. In Greece, the majority of sunflower crops are located in Evros in the northern part of the country. It usually cultivated on non-irrigated clay loam soils in rotation with winter cereals [37] [56]. The similarities that Sunflower (Helianthus annuus L.) oil shares with canola and soy oil make it an important potential source of biodiesel [39].
For every hectare of sunflower, there is an average production of 12-21 kg of seed with a respective 4,3 – 7,5 lt of biodiesel production. According to FAO data, in Central Europe there is a 2 tn /ha average yielding (dry). The energy content is 39,4 MJ/kg for oil, 26,3 MJ/kg for seed and 19,6 MJ/kg for flour [38].

4.2.1.1. Strengths (Table 8.)
Sunflower cultivation is a low risk investment, hardly affected by unforeseen factors. It is considered ideal for crop rotations, maximizing future yields [42].
Due to practically zero maintenance needs, sunflower is highly preferred by farmers mainly in northern Greece [42]. Sunflower cultivation development cost varies between 30 to 60 Euros per acre, depending on inputs and rent rates. With a yield that reaches 500 kg per acre, a substantial income can be achieved, since there is no need for hired work and the ensuing expenses, as is the case with other arable crops [42].
Sunflower is suitable for both small and large-scale farming [39]. The most suitable type of soil is well-drained, pH neutral soil with a high capacity for holding water, but it is highly adaptable to other soil conditions [37]. It has a deep root system and tolerates drought therefore is it suitable for the southern semi-arid EU countries with better results than common crops [37]. Although it is a long season crop, many hybrids allow a September harvest [41].
During sunflower biodiesel combustion the only CO_2 that is released into the atmosphere is the amount of CO_2 that had been absorbed by the plant during the day, therefore contributing to the reduction of greenhouse gases [42].
Sunflower is an ideal biofuel crop due to the high oil content of the seed. Moreover, it is low on saturated and high on unsaturated fatty acids. The crop has low input requirements and high adaptability. Since it has already been cultivated as food crop, there are well established practices for it [37] [39].
4.2.1.2. Weaknesses (Table 8.)
Pest and weeds present an important risk for Sunflower and their control might place an excessive strain on the farmer, as it requires practices like crop rotation, resistant cultivars, use of herbicide-tolerant hybrids, or even chemical pesticides and herbicides [39] [41]. Insect pollination may be needed even though current hybrids are self-compatible. Conditions of stress may affect leaves size and oil yields [37].
In drier regions it often needs at least supplemental irrigation for best yields [41] especially during spring, which is proven to be crucial.
Harvest is best before the end of September to reduce huge losses to flocks of migrating birds, which can also be dealt with by avoiding nesting habitats [41]. The best control method is the random but frequent changes in bird deterrent methods.
Nitrogen fertilisation is necessary for achieving high yields [37].

4.2.1.3. Opportunities (Table 8.)

Sunflower has proven to be one of the most reliable energy crops, providing farmers with a steady income with a low investment cost, within the framework (standards) of contract farming [42].

Sunflower is a good choice for both small and large-scale growers because the oil has several potential market uses and because the pressed meal can fill niche cattle feed markets [39]. It is often suggested as an alternative crop on severely iron deficient soils [57].
Sunflower oil, after being processed, can be used for a variety of industrial products (detergents, lubricants, fuels) exactly as rapeseed [38]. Moreover, biodiesel production may further boost sunflower cultivation [56].

4.2.1.4. Threats (Table 8.)

Insect pests present a major threat to sunflower production which in consequence requires effective pest management programs. Also harvest timing is particularly important to regulate moisture levels and avoid seed shattering [39].

The crop is susceptible to migratory bird damage after seeds are formed. Under certain conditions, birds have been known to consume considerable quantities of seed in the field [57].

Another threat is sunflower's susceptibility to sclerotinia diseases and downy mildew, which can be avoided by using resistant varieties, plant rotations and wider rows [41].

Finally, the value of sunflower for biodiesel end-use may not provide adequate economic returns in some oil producing regions [39].

Table 8.

SWOT Analysis – Sunflower (source: [37], [38], [39], [41], [42], [56], [57])

Strengths		**Weaknesses**	
S	1. The crop is highly productive 2. Provides farmers with a steady income, within the standards of contract farming 3. Low cost investment 4. Practically zero maintenance needs 5. No need for hired work and the ensuing expenses, as with other arable crops 6. Low risk investment 7. Ideal for crop rotation, maximizing future yields 8. Contributes to the reduction of greenhouse gases 9. Many new hybrids shorten the maturity period, allowing early harvest 10. It yields well in a variety of conditions 11. The high oil content of sunflower seed makes it an excellent choice for a biofuel crop. 12. Agronomic practices are well established for regions where it is a common component of field rotations 13. Often requires fewer agricultural inputs than more common crops 14. Sunflower can adapt to a wide range of soil conditions 15. It is considered as one of the most drought resistant crops 16. The sunflower oil is considered as high quality oil	**W**	1. Native sunflower and the early varieties were self-incompatible and required insect pollination 2. The number and the size of the leaves are reduced and also the seed and oil yields are reduced under conditions of stress 3. Sunflower does not compete well with weeds early in its development 4. In drier regions it often needs at least supplemental irrigation for best yields
Opportunities		**Threats**	
O	1. Sunflower is a good choice for both small and large-scale growers 2. It is one of the most reliable energy crops 3. It is an alternative crop on severely iron deficient soils 4. It can be used for a variety of industrial products such as detergents, lubricants, fuel 5. The increased interest for utilizing oil seeds for biodiesel production and the anticipated unfavourable economic conditions for winter cereals may encourage sunflower cultivation in the near future	**T**	1. Combining the plants earlier at high moisture contents can reduce losses from seed shattering and birds 2. The major challenge to pre-harvest production is losses to pests 3. Migratory birds, disease, and insect pests all pose as a threat to sunflower production 5. Huge losses to flocks of migrating birds 4. The value of sunflower for biodiesel end-use may not provide adequate economic returns in some oil producing regions

4.2.2. Kenaf (Hibiscus cannabinus L.)

Kenaf (Hibiscus cannabinus L.) is an annual crop, tropical in origin, but well adapted to diverse geographical and climatic conditions. It was introduced in Italy more than fifty years ago mainly for textile fibre production but after 1980s it was also used in paper pulp production. After 2003, kenaf has been examined for its possible uses in the bio-energy sector [58] [59] [60].

It can reach 12 to 18 feet in five months and can yield between 6 and 10 tons of dry matter per acre [44]. Kenaf produced pulp is of equal or superior quality to that of many wood species and 3–5 times larger in quantity per unit area than pulpwood trees [43].

4.2.2.1. Strengths (Table 9.)

Kenaf is a high productivity non-food crop that can provide raw material for industrial and energy applications. It presents an attractive crop choice for farmers due to the high biomass potential and the low inputs of the crop. As an annual crop, it can be easily incorporated in regular crop rotations and managed as other conventional crops without a long-term commitment in land use. Its water requirements, except from the time shortly after germination, are much lower than in conventional crops which makes ideal for lands with poor and moderate water availability, commonly found in Mediterranean areas. It is also somewhat tolerant of saline conditions. It can be used for several high value fiber applications (30-40% of the stem) and thermochemical process (60-70% of the stem). Since Kenaf stalks are harvested free of leaves, the leaves remain in the field resulting in organic matter, rich in nitrogen, which is returned to the soil [44] [45]

4.2.2.2. Weaknesses (Table 9.)

Paper mills generally process material in the immediate area because of high transportation costs. Choosing a seasonal crop such as kenaf presents problems. Failure of a kenaf crop could result in high transportation costs to supply adequate processing materials. The potential for crop failure will place a higher priority on storage facilities, which increases the costs of using kenaf [44].

Weeds generally are not considered a problem because of kenaf's rapid growth resulting in shaded ground conditions, which prevents weed emergence. However, favorable conditions are needed to promote this rapid growth, and pre-emergent herbicides maybe required [44]. It may require nitrogen, phosphorus, potassium, and calcium inputs. In very dry areas, some irrigation may be needed [44].

Kenaf is vulnerable to standing water or water-logged soils threatened by root nematodes. Most kenaf cultivars are photoperiod sensitive and require day length of about 12.5 hours of light in the fall to flower [44].

4.2.2.3. Opportunities (Table 9.)

In areas devoted to monocultures (cotton, cereals), low yields, local crop disease, weed competition or soil fertility degradation may be remedied by crop rotation with Kenaf presenting a promising alternative crop. Moreover, as an annual crop, cultivation and harvest are similar to food crops and existing production and management systems can be utilised, thus reducing delivery costs [43] [45] [61].

The environmental benefits worth noting are soil remediation, removal of toxic waste, reducing soil erosion, as well as replacing or reducing the use of fiberglass in industrial products [46].

The commercial success of kenaf has important potential economic benefits by creating new jobs and promoting economic growth [44]. Kenaf can be used as bedding material, in substrate mixtures, as building material and as forage for livestock [43].

Furthermore, kenaf can be used in the paper industry, reducing energy demand and chemical use for paper production and providing greater recycled paper quality [46]. More potential uses for kenaf include carpet padding, stamp or banknotes paper and cardboard [44]

4.2.2.4. Threats (Table 9.)

Research is required to improve harvesting equipment. What is more, storage conditions need to be improved and added attention must be paid to air circulation and/or water cooling to avoid overheating. Finally, further research is still needed to develop kenaf products [44].

Table 9.

SWOT Analysis – Kenaf (source: [43], [44], [45], [46], [58], [59], [60], [61])

Strengths		**Weaknesses**	
S	1. Kenaf cultivars are well adapted to a wide geographical and climatic range 2. It is a multi-purpose crop and can provide raw material for industrial and energy applications 3. High biomass potential and low input needs 4. Well accepted by farmers 5. An important alternative land use in lands with poor and moderate water availability 6. Tolerant of saline conditions 7. Tolerant of dry conditions 8. Nitrogen could be returned to the soil in the form of organic matter	**W**	1. Failure of a kenaf crop could result in high transportation costs for paper mills to supply adequate processing materials 2. Favorable conditions are needed to promote rapid growth, and pre-emergent herbicides maybe needed. 3. It will not tolerate standing water or water-logged soils 4. The most serious pest kenaf faces is root nematodes 5. Most kenaf cultivars are photoperiod sensitive and do not flower until day length decreases 6. Kenaf may require nitrogen, phosphorus, potassium, and calcium inputs
Opportunities		**Threats**	

O	1. Large biomass amounts at low production cost 2. It offers alternative land use and can be used in a crop rotation 3. It is an annual non-food crop 4. Important potential economic and environmental benefits 5. Reduced energy demand chemical use for paper production 6. Reduces soil erosion 7. In some areas it could lead to job creation and economic growth	**T**	1. Research to improve harvesting equipment is needed 2. Storage needs to be improved 3. Major research is still needed to develop kenaf products

4.3.2. Rapeseed (Brassica napus)

Rapeseed (Brassica spp.) is an annual plant of the Brassicaceae family [37]. It is a long time cultivated plant originating from Asia and the Mediterranean area. Rapeseed has been important to Europe since the 13th century as a source of food and oil for fuel [37].

According to experiments recently carried out in Mediterranean countries (European Rapeseed Network FAIR CT98 – 1946) the results regarding the crop adaptability and productivity were very encouraging. The oil yield of the seeds varies between 30 to 50%, depending on procurement techniques, cultivars, soil, seeding season, temperature etc. More specifically, seed and dry biomass yields ranged from 150 to 300 kg and from 300 to 800 kg per acre, respectively [69]. After oil extraction, the plant residue, which is very rich in protein, is used as feed for livestock [62].

It is widely adapted and distributed in the cool temperate climates of EU27. EU accounts for nearly 17% of the world production. Rapeseed is an annual crop that can be cultivated as winter or spring crop [37].
In Greece, rapeseed crops are mostly located in Central Macedonia, followed by Eastern Macedonia and Thrace, with Western Macedonia being a potential area for expansion [62].

4.3.2.1. Strengths (Table 10.)

Today, winter oilseed rape is the most important oil crop in northern Europe [37]. The cultivation techniques are similar to those of winter cereals [62]. Of the major oilseeds cultivated today, soybean is by far the world's largest, followed by rapeseed and cottonseed. However, in Europe nearly 85% of biodiesel comes from rapeseed oil, followed by sunflower seed oil, soybean oil and palm oil. It tolerates pH as low as 5.5 and saline conditions [37].

4.3.2.2. Weaknesses (Table 10.)

Rapeseed is an important oilseed crop in the agricultural systems of many arid and semiarid areas where its yield is often restricted by water shortfalls and high temperatures during the reproductive growth stage [62] [63]. Rapeseed prefers medium textured, well drained soils [37] [62].

In Greece, the main restrictive factor for rapeseed is high temperatures from blooming to seed filling. Temperatures of 27 °C cause blossom dropping and bad seed filling, resulting in yield reduction (-40 kg / per acre for a temperature rise from 21 to 24°C) and oil content (-1,7% for every 1°C rise) [62]. One of the most crucial factors for a successful crop is choosing the seeding season. The significance of this choice stems from the fact that the plant needs to sprout leaves before winter sets in. Winter rapeseed requires low temperatures to blossom, this being the most important difference from spring rapeseed. [62].
Special caution is needed to avoid dense seeding, due to the very small seed size. Seed quantity is determined by seed sprouting ability, anticipated losses (frost, drought, soil conditions) and cultivar or hybrid choice of seeds. A worldwide practice is rapeseed in rotation with cereals [62].

4.3.2.3. Opportunities (Table 10.)

Rapeseed has a diverse and varied array of uses, apart from the food and feed industry, in biofuels, lubricants, surface coatings, polymers and medicinal products, as well as adhesives, cosmetics, lawn care products, and combustion materials [37]. It can be incorporated in crop rotations in the European area. Although it is already an important oil crop in Europe, new varieties should be developed that are better adapted for the Mediterranean region [37]. It also presents an attractive crop choice for small farmers' cooperatives with an additional advantage from home produced fuel [65]. Rapeseed is highly beneficial to climate and resource protection [64].

4.3.2.4. Threats (Table 10.)

Special caution is needed at harvest, as well as choosing the harvest time itself, in order to avoid seed loss due to high temperatures [62]. Harvest time choice is also important to prevent shattering, which is a frequent problem and may cause significant crop losses at harvest and may affect subsequent crops in crop rotation systems [37].

Table 10.
SWOT Analysis – Rapeseed (source: [37], [62], [63], [64], [65])

Strengths		**Weaknesses**	
S	1. Worldwide prominent oil crop 2. It is the most important oil crop in northern Europe 3. Cultivation techniques are similar to winter cereals thus already familiar to farmers 4. Adequate adaptability 5. Adequate productivity 6. It tolerates pH as low as 5.5 and saline conditions	**W**	1. Requires well drained soils 2. In Greece, the main restrictive factor for rapeseed is high temperatures from blooming to seed filling. 3. One of the most crucial factors for a successful crop is timely seeding. 4. Special caution is needed to avoid dense seeding, due to the very small seed size
Opportunities		**Threats**	
O	1. Better adapted varieties should be developed for the Mediterranean region 2. Rapeseed is the ideal crop type for extending crop rotations 3. Rapeseed opens up a range of utilization opportunities and final uses 4. Perfect crop for growing in small farmers' cooperatives 5. Rapeseed makes a substantial contri-bution to climate and resource protection	**T**	1. Risk of seed loss due to high temperatures 2. Rapeseed is prone to shattering which leads to crop losses at harvest and problems in crop rotation systems.

4.3.3. Sorghum (Sorghum bicolor)

Sorghum (Sorghum bicolor) is a single-stemmed annual C4 grass, member of the Poaceae family, which reaches a height of 1-5 m [18]. It is of tropical origin, with high photosynthetic efficiency under appropriate conditions of light and temperature, indicating a good potential for biomass production [66]. The crop is well adapted to warm southern European Union regions, especially in various geographic locations throughout Greece [66].

Sweet sorghum is a plant with many potential advantages, including high water, nitrogen and radiation use efficiency, broad agro-ecological adaptation as well as a rich genetic diversity for useful traits [17].

Sorghum can be used for food, fodder and fiber as well as fuel (thus earning the nickname a "Four F's Crop"). In Asia it is widely cultivated for all of the four uses, whereas Europe and Brazil are increasing sugar production for fuel [18].

Many varieties have recently been tried in Greece. Their yields vary, depending on the region, climatic conditions, ground fertility and applied farming techniques. Green biomass yield ranged from 5,0 to 8,0 tons per acre while there have been cases with documented yields of 14,1 tons per acre [70].

4.3.3.1. Strengths (Table 11.)

Sorghum is an annual crop with a flexible cultivation program which, because of its short growth cycle, is ideal for incorporation in traditional crop rotations and suitable for intercropping and non-till planting [17]. Moreover, the development of new improved cultivars, better suited for ethanol production is particularly feasible because of the well-known sweet sorghum crop genetics and their high variability and diversity [17] [67].

It can grow in a broad environmental and soils range from tropical to temperate regions. It is also suitable for cultivation on marginal lands, albeit with lower yields [17]. It has an extensive root system, which aids drought tolerance, can grow on neutral to acid soil and is temperature tolerant [71] [18].

It is characterized by high water, radiation and nutrient use efficiency in comparison with other energy crops [17]. It has low fertilizer requirements, making it ideal when used in a crop rotation scheme with high biomass yields and dry matter accumulation rates [66].

Sorghum, compared with other crops, is more environmentally friendly particularly because of its relatively low nitrogen needs and water requirements [66]. It is photo sensitive under certain conditions providing high biomass production in a short time [17]. Sorghum has potentially 2-3 crops per year and a growing period 3-5 month [71]. Full mechanization of cultivation is possible, thus allowing for industrialized value chains [17].

As an efficient C4 plant, Sorghum is one of the most efficient crops to convert atmospheric CO_2 into sugar and starch [17] [67]. The net CO_2 benefit from the use of Sorghum as an energy source is estimated at 90%. This percentage, when compared to equivalent petrol energy, represents a benefit of 25-40 tons of CO_2 per hectare. Furthermore, it contributes to the reduction of SO_2 emissions due to its low Sulphur content, compared to other fuel types [68].

Sorghum cultivation and processing is exceptionally scalable. Therefore, it can be a choice for everybody from smallholders to industries thus contributing to food security [17].

4.3.3.2. Weaknesses (Table 11.)

There are insufficient varieties of sweet sorghum with high Brix (Bx) which are specifically well suited for ethanol production. Moreover, there is a limited availability of commercial well-defined cultivars [67]. Sucrose peak is shorter for sweet sorghum [71]. Genetic improvement new cultivars research, which are not as advanced as in other crops, are required to enhance particular traits important for increased yields and ethanol production [17] [67]. Harvesting technologies for separating seed, stalk and leaf need to be improved otherwise harvesting is laborious and time consuming. The crop has short harvesting season, usually 20-40 days, resulting in a limited feedstock supply period through the year [17] [67].

Sorghum has poor tolerance to cold in temperate climate [17]. It may need irrigation in dry season [71]. Irrigation has proven to be a decisive factor in ensuring high yields while nitrogen input was of little consequence [70].

Since the economics of crop cultivation and returns are almost on par with the Maize crop any economics fluctuation of sweet sorghum, may cause farmers to switch back to maize cultivation thus affecting ethanol production [67].

Large-scale industrial sorghum producers may not be interested in the production of both food and ethanol and this may have a negative impact on local food security [17].

The relative recent energy use of sweet sorghum may account for low farmer awareness and acceptance [67]. Furthermore, incorrect agricultural practices present a potential environmental hazard, threatening biodiversity, soil fertility and water resources, especially if cultivation is carried out on a large scale [17].

4.3.3.3. Opportunities (Table 11.)

Sweet sorghum has achieved a status of a most promising energy crop, largely due to the plant’s own growth features and not only because of the environmental impact of its cultivation [68].

Ethanol fuel market may present an important opportunity for its cultivation. Although it already ranks higher than other energy crops, new varieties and technology development on ethanol production may reduce production costs and improve yields [17] [68] [71]. Sweet sorghum can also provide raw material for 2nd generation bio-ethanol in areas with temperate climate or with a high level of industrialisation [17]. In countries where the local energy policy dictates ethanol production to rely on non-food crops grown on marginal lands (e.g. China), sweet sorghum can play that part [67].

Concerns about food-fuel competition create opportunities for dual purpose crops such as sweet sorghum especially since it can be grown on infertile soils, soils with declining fertility or in case increased droughts and increasing water scarcity due to climate change [17] [66]. Furthermore, it can be a favourable crop choice for developing countries where the production of food and bioenergy improves both food and energy security [17].

Moreover, the introduction of policies on climate change mitigation and adaptation creates opportunities for the use of new energy crops such as sorghum [17]. Policies on rural development which focus on the support of small-scale farmers may also support sorghum production [17]. Sorghum could be a promising energy crop in both developed and developing countries as well as for small and large-scale value chains [17].

It can be used for the production of food, 1st and 2nd generation ethanol, biomaterials, electricity from bagasse combustion, thermochemical biofuels and products, biogas, feed and fodder [17]. Vinasse and calcium carbonate are other by -products with economic value [67].

Alternative products of sweet sorghum can be potable alcohol, syrup as a sweetener from the juice, and beer. Stalks can be alternatively used as cooking fuel, presenting many market choices for farmers [17]. Sorghum biomass can also be used for thermal energy production or subsequently for second generation bioethanol production [68].

4.3.3.4. Threats (Table 11.)

As an energy crop, sorghum is still relatively new to many farmers and large-scale cultivation could have a negative impact on (local) food security as well as environmental risks. Moreover, increasing global prices of agricultural commodities may affect and reduce the competitiveness of ethanol [67] while technological advances in ethanol production from biomass, such as second-generation biofuel technology, could reduce the sorghum ethanol competitiveness [67].

Genetic research and new varieties breeding, especially in developing countries, heavily relies on financial support, without which there can be very little progress [17].

Generally, adequate experience and further research is needed about sorghum cultivation [71]. The general negative image of imported biofuels into the EU may also affect bioethanol production from sorghum in other continents [17].
Since sorghum is an important food crop, its energy use may increase land competition and aggravate the food crisis [17] [71].

Table 11.
SWOT Analysis – Sorghum (source: [17], [18], [66], [67], [68], [70], [71])

Strengths		Weaknesses	
S	1. High genetic variability 2. It can grow in a broad environmental range 3. It can be cultivated and further processed at very different scales. 4. High water, radiation and nutrient use efficiency 5. Suitable for cultivation on marginal soils, 6. It is one of the most efficient crops to convert atmospheric CO_2 into sugar and starch. 7. Sorghum is an annual crop with a short growth cycle, which can be easily integrated in many cultivation systems. 8. The crop rotation cycle of sorghum is very flexible 9. Sorghum is suitable for intercropping. 10. It can be well adapted to non-till planting. 11. Full mechanization of sorghum cultivation is possible 12. Commercial technologies are available for ethanol production from sorghum. 13. Small-scale cultivation of sorghum in rural communities can benefit local energy supply and it can contribute to food security. 14. Sorghum is a climate-change ready crop. 15. It is photo sensitive under certain conditions providing high biomass production 16. It has high yields in a short amount of time 17. Drought/ saline/ temp tolerant 18. Potentially 2-3 crops per year, growing period 3-5 months	**W**	1. Specific sorghum varieties for ethanol production are insufficient. 2. Specific traits important for the ethanol industry still need to be defined for rapid genetic improvements. 3. Research on new cultivars is needed. 4. Sorghum as energy crop is still relatively new to many farmers with many environmental risks due to lack of knowledge. 5. May have a negative impact on (local) food security. 6. Environmental risks of large-scale sorghum cultivation 7. Monocultures have negative impacts on the landscape. 8. Harvesting technologies for separating seed, stalk and leaf are not yet mature 9. Sorghum has poor tolerance to cold in temperate climate 10. May need irrigation in dry season 11. Sucrose peak shorter for sweet sorghum
Opportunities		**Threats**	

O	1. It's a most promising energy crop due to its growth features, as well as the environmental impact of its cultivation. 2. Generally, the global demand for biofuels is increasing thus creating market opportunities for bioethanol from sorghum. 3. Emergence of new market opportunities for ethanol fuel 4. Technology development may reduce production costs and improve the efficiency of the sorghum value chain. 5. The policies on climate change create opportunities for the use of new energy crops such as sorghum. 6. Policies on rural development may support sorghum production. 7. Discussions on food-fuel conflicts create opportunities for double purpose crops such as sorghum. 8. Increased droughts and increasing water scarcity due to climate change favour water use efficient plants such as sorghum. 9. A lot of alternative sorghum products present different market choices. 10. Sweet sorghum appears to rank higher than other energy crops at energy level 11. Capability of high energy varieties to be efficient bioenergy crop 12. It could be a promising energy crop in both developed and developing countries as well as for small and large scale value chains. 19. All aboveground parts of the plant are valuable products.	**T**	1. Current and future prices for ethanol from sorghum could be too high when compared with fossil fuels. 2. Increasing global prices of agricultural commodities may reduce the competitiveness of sorghum ethanol. 3. If research on sorghum is not financially supported only limited improvements in its breeding and crop management can be achieved. 4. General negative image of imported biofuels into the EU may also affect bioethanol production from sorghum in other continents. 5. General increasing resource competition for food, fuel, and fibres may lead to conflicts and reduce available land for sorghum cultivation. 6. Important food crop 7. Adequate experience /further research is needed.

V. CONCLUSIONS

As discussed in this paper and based on the analysis of the Strengths/Weaknesses and Opportunities/Threats of three perennial and four annual energy crops for biofuel production (Table 3-4), deciding on a crop or a combination of crops depends on a lot of factors. The aim was to describe a methodology that can be applied in order to quantify the advantages and disadvantages of the question and to find ways of development and improvement as well as to suggest the necessary actions.

Our study focused α) on three perennial energy crops: Miscanthus (Miscanthus giganteus), Cardoon (Cynara cardunculus), Switchgrass (Panicum virgatum) and b) on four annual energy crops: Sunflower (Helianthus spp.), Rapeseed (Brassica napus), Sorghum (Sorghum bicolor), Kenaf (Hibiscus cannabinus L.).

From the SWOT analysis of the three perennial energy crops we could point out the following:

Miscanthus (Miscanthus giganteus) (Table 5.) has high yields, low requirements of herbicides, no need of pesticides and fertilizers. It also has the highest energy balance compared to other crops of grasses. While the weaknesses are that it requires sufficient irrigation in the first year and has a high establishment cost, the opportunities are that it can be grown on marginal land, it is a promising non-food crop and can be used to generate electricity and as ethanol. Threatening effects include fire in mature crop and it could be vector for crop pests & diseases.

Cardoon (Cynara cardunculus) (Table 6.) has high yields and small crop costs but presents resistance problems and it thistles. The opportunities are the improvement of soil with cadmium and arsenic content and the increase of soil fertility. One of the threats is that Cardoon is a potentially invasive species.

Switchgrass (Panicum virgatum) (Table 7.) is not invasive, has a long-term annual productivity and low greenhouse gas. However, the knowledge of the culture is insufficient, and the initial installation cost is high. It can be used in the production of liquid and solid biofuels and industrial raw materials. The threats include fire in mature crop, competition with other biomass sources and most importantly, that the market is still new.

Analyzing through the SWOT analysis the four annual energy crops we can resume:

Sunflower (Helianthus spp.) (Table 8.) yields well in a variety of conditions, often requires fewer agricultural inputs than more common crops and is considered as one of the most drought resistant crops. On the other hand, it is self-incompatible requiring insect pollination and often needs at least supplemental irrigation for best yields. Sunflower is a good choice for growers as an alternative crop on severely iron deficient soils. Migratory birds, disease, and insect pests all pose as a threat to sunflower production.

Kenaf (Hibiscus cannabinus L.) (Table 9.) is a multi-purpose crop and can provide raw material for industrial and energy applications. Moreover, it has a high biomass potential and low input requirements. It is an important alternative land use in lands with poor and moderate water availability. On the contrary, it may require nitrogen, phosphorus, potassium, and calcium inputs and it frays in high temperatures. It may produce large biomass amounts at low production cost and it is an annual non-food crop. However, research is necessary to improve harvesting equipment and storage.

Rapeseed (Brassica napus) (Table 10.) is the most important oil crop in northern Europe and the culture technique is the same as winter cereals, already familiar to farmers. The main limiting factor of rapeseed in Greece is the risk of seed loss due to high temperatures. Rapeseed opens up a range of utilization opportunities and final uses and is a perfect crop for growing in small farmers' cooperatives. However, it is prone to shattering which leads to crop losses at harvest and problems in crop rotation systems.

Sorghum (Sorghum bicolor) (Table 11.) has high biomass yields in a short period of time and is one of the most efficient crops to convert atmospheric CO2 into sugar and starch. There is a multitude of possible end uses, energy oriented and more. However, because it is an important food crop and its energy use still relatively new to many farmers, large scale cultivation could have a negative impact on (local) food security as well as environmental risks. Although new, potentially high efficient, varieties can be developed further research and considerable financial support is still needed, especially in developing countries.

Successful energy crops must incorporate practical considerations that permit realistic deployment in the existing agricultural infrastructure with a foundation of long-term environmental and economic sustainability. The ideal energy crop will depend on multiple factors, both societal and environmental [36].

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