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Published Version:
Parlato M.C.M., Valenti F., Porto S.M.C. (2020). Covering plastic films in greenhouses system: A GIS-based model to improve post use suistainable management. JOURNAL OF ENVIRONMENTAL MANAGEMENT, 263, 1-20 [10.1016/j.jenvman.2020.110389].

Availability:
This version is available at: https://hdl.handle.net/11585/935098 since: 2023-07-17

Published:
DOI: http://doi.org/10.1016/j.jenvman.2020.110389

Title page

COVERING PLASTIC FILMS IN GREENHOUSES SYSTEM: A GIS-BASED MODEL TO IMPROVE POST USE SUISTAINABLE MANAGEMENT

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Keywords: plastics waste management; land management; sustainability; GIS modelling; spatial index.

COVERING PLASTIC FILMS IN GREENHOUSES SYSTEM: A GIS - BASED MODEL TO IMPROVE POST USE SUSTAINABLE MANAGEMENT

Abstract

Yearly, in Europe, more than 1 million tonnes of plastic materials are used in agricultural activities. Among the possible applications, plastic films for protected cultivation practices are highly used worldwide because of the significant advantage deriving from the shortening of the growing period. However, in the absence of a correct policy disposal of plastic films, environmental degradation could take place with serious ecological and economic consequences.

In this study, a geographical information system (GIS) - based model to locate and quantify the yearly amount of agricultural plastic waste (APW) coming from crop-shelter coverage used in greenhouses system was put forward and was applied in a study area located in southern Italy, highly characterised by protected cultivation practices.

Firstly, the areas with the highest density of crop shelters were mapped, then a suitable index to determine APW amount was computed and applied to obtain heat maps related to covering plastic films. Finally, sensitivity analyses were carried out by varying thickness, lifetime, and density of the covering films of the greenhouses, located in the considered samples. The index ranged between 976 kg $ha^{-1}yr^{-1}$ and, 2,484 kg $ha^{-1}yr^{-1}$.

The results showed that the density of greenhouses and tunnels-greenhouses is still elevated nearby the coastline, highlighting that the guidelines of the territorial plan of the Province of Ragusa concerning the displacement of protected crops from the coast to the internal rural areas were disregarded. Moreover, the GIS-based model results could provide basic information for the analysis of the environmental impact due to transportation of APW. Therefore, these results could offer a suitable tool to improve the correct disposal management of covering plastic films and the related recycle policy.

Keywords: plastics waste management; land management; sustainability; GIS modelling; spatial index.

1 Introduction

In accordance with the main Global policies of environmental sustainability, in 2015 the European Commission adopted a Circular Economy Action Plan (CEAP) concerning actions to improve Europe's transition from a linear economy towards a circular one as well as to promote a sustainable economic grown.

The European CEAP foresees actions covering the whole economic cycle from the production process to waste management, measure for the market of secondary raw materials and a revised legislative proposal on waste.

The main objective of the revised legislative framework on waste, entered into force in July 2018, is the reduction of waste by improving disposal management, recovery and reuse rate (Directive (EU) 2018/849). This legislative framework is providing a clear and stable policy to improve long-term investment strategies focusing on prevention, reuse and recycling rates.

The conversion of waste into new raw material is an important aspect of increasing resource efficiency and closing the loop in a circular economy framework. In particular, actions on plastic waste are identified by CEAP as priority. Nowadays, plastic pollution is considered one of the biggest environmental concerns due the long-life material (plastic can take hundreds or thousands of years to be decomposed) and because more than 85% of plastic waste ends up in landfills. Yearly, in Europe about 26 million tons of plastic waste are generated and their recycling rate is less 30%, a great loss for both economy and environment. Worldwide, as it occurs in other production sectors, also for agricultural activities the use of plastic materials being increasing too. Each year, the world consumption of agricultural plastic materials is about 6,5 million tons (Scarascia-Mugnozza et al., 2012) and more than 1 million tons in Europe. A large amount of this plastic material is plastic film for covering protected crops or mulching soil, the rest is used for irrigation piping, packaging, and containers for fertilizers.

Since 1950's the use of plastic films as covering materials for greenhouses developed quickly and it is still growing. Currently protected cultivations are increasing worldwide with about 1,600,000 ha of greenhouses and walk-in tunnels

(Espí et al., 2006) of which 405,000 ha are greenhouses widespread in Europe, (mainly in Spain, Italy and France). In Europe, Almeria, in the south of Spain, is the region with the greatest concentration of greenhouses in the world, it is known as the 'Sea of Plastic' (Aguilar M. et al, 2016).

Plastic covering films shorten the growing period, defend crops from environmental risks, such as bad weather conditions, birds and parasites, and create microclimate favourable to plant growth (Ahemd et al., 2016; Demetres Briassoulis et al., 2013a; Kyrikou and Briassoulis, 2007).

On the other hand, the increased diffusion of protected crops generates a large amount of agricultural plastic waste (APW) that requires a properly collection, disposal and recycling process. Among the different types of APW collected and directed for recycling, a huge amount is constituted by plastic films used to cover greenhouses, mainly represented by low density polyethylene (LDPE), ethylene vinyl acetate (EVA), polypropylene (PP) or polyethylene (PE).

In 2011 the APW recovering rate in Europe was around 46% and the mechanical recycling rate was about 23% (European commission (DGE), 2011). In some geographical areas, where recovery and reuse processes for plastic wastes are not foreseen, plastic films are left illegally on the margins of cultivated fields, on illegal dumps, or even burned. Their abandonment close to water courses could cause groundwater pollution or an obstacle to the natural flow of water with dramatic consequences such as flooding.

Yearly, in Italy more than 350,000 tons of agricultural plastic materials are used (Picuno et al., 2012) and most of them, that are used as covering films, must be frequently replaced due to their early deterioration caused by exposition to atmospheric agents. For this reason, a correct disposal policy is crucial to avoid environmental pollution.

APW recycling could reduce pollution and prevent economical losses and environmental impacts due to the development of greenhouse cultivation system. In this regard, land conservation policies should include also guidelines for the sustainable management of APW in order to reduce soil and water consumption, soil and aquifers chemical contamination and, organic matter soil decrease (Díaz-Palacios-Sisternes et al., 2014; Picuno et al., 2011; Vox et al., 2016).Therefore, the main aim of this study is to improve post-use sustainable management of greenhouses covering films. Post-use management takes into account the execution of different steps for the disposal or for recycling of agricultural plastic covering film, such as: APW localization and quantification, APW collection, APW transport to landfill or recycling industries, APW processing in order to obtain secondary raw material (e.g. plastic granules).

This research study focused on the first step of post-use management of APW which is crucial in order to put forward a method for a sustainable disposal management and recycling process of APW. Since, Geographic Information System (GIS) tools have been considered as an appropriate platform for environmentally related issues (Valenti et al., 2018) and have been applied for both assessing, quantifying and site-location analysis, in this study a GIS-based model was developed for collecting, organizing, analysing, and visualizing geographical data related to APW. The data coming from the developed model could be adopted by local authorities as input for strategic territorial planning and monitoring.

2 Materials and methods

2.1 Case study

From the analyses of the greenhouses cultivation system in Italy (Table 1), it emerges that Sicily is the region with the greatest percentage and surface of protected cultivation. The spread of the greenhouse cultivation system in Sicily began in the early sixties of the last century thanks to the flexibility and the lightness of plastic films for the covering of crops that allowed the creation of very simple building structures for the production of vegetables. Since the development of protected cultivation took place very quickly, the surface covered by greenhouses between 1960 and 1965 reached about 700 ha from almost insignificant values. The amount of crop shelters in Sicily has been increased progressively during 70^{s}, and it is still in growth.

Among the Sicilian provinces, Ragusa has the highest concentration of protected crops (Table 2) with a covered surface of about 470,000 ha which is nearly 68% of the regional total and is distributed as follows: 58.7 %, for tomato; 33.6%, for other vegetables; and 6.7% for flowers and ornamental plants (ISTAT, 2010). Therefore, the GIS-based model described in this study was applied to the province of Ragusa (Figure 1).

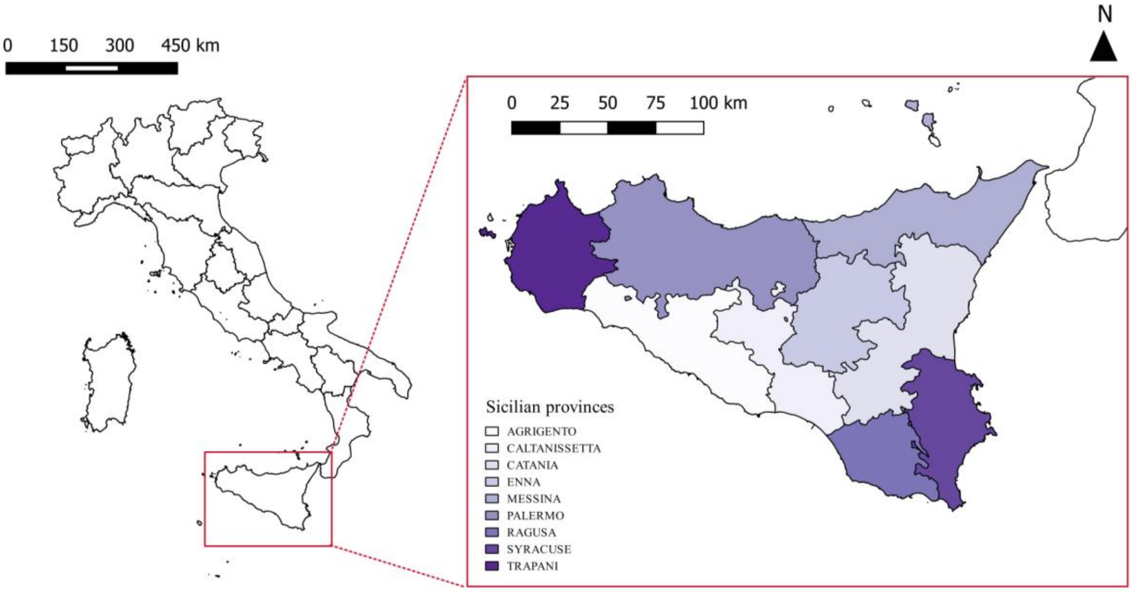

Figure 1 – Italy, Sicily and province of Ragusa

Table 1 – Incidence of greenhouse cultivation system in the Italian regions.

Italian regions	Total cultivated surface (TCS) [ha]	Greenhouse surface (GHS) [ha]	[%]
Piedmont	505,090	45,430	9.0
Valle d'Aosta	34,390	130	0.4
Liguria	58,920	58,340	99.0
Lombardy	498,980	72,530	14.5
Trentino Alto Adige	541,410	4,540	0.8
Veneto	551,920	169,530	30.7
Friuli-Venezia Giulia	94,430	5,890	6.2
Emilia-Romagna	783,910	49,700	6.3
Tuscany	846,500	69,650	8.2
Umbria	354,320	5,560	1.6
Marche	366,110	13,490	3.7
Lazio	666,610	312,410	46.9
Abruzzo	481,040	22,590	4.7
Molise	148,730	1,670	1.1
Campania	479,300	355,100	74.1
Apulia	855,850	125,090	14.6
Basilicata	471,100	45,790	9.7

Calabria	507,200	55,740	11.0
Sicily	902,430	686,760	76.1
Sardinia	994,110	64,780	6.5
Total	10,142,330	2,164,700	21.3

*The percentage was calculate as [(GHS/TCS)*100]*

Table 2 *- Greenhouses cultivation areas in the provinces of Sicily (ISTAT 2010).*

Province	[ha]
Agrigento	25,410
Caltanissetta	63,868
Catania	11,674
Enna	1,373
Messina	8,241
Palermo	6,867
Ragusa	469,057
Syracuse	81,724
Trapani	18,544
Sicily	686,760

Along the coastal areas of the province of Ragusa, there is a great concentration of tomato cultivation which requires specific features. In detail, tomato, is a warm-season vegetable crop, sensitive to frost and killed by freezing temperatures. To properly growth tomato requires a temperature range between 10°-30°C. Plants do not set fruit when night temperatures are consistently below 10°C and are damaged if temperature exceeds 35 °C. Moreover, this cultivation requires high amounts of potassium and calcium. Tomato crops are rather resistant to salinity and cherry-tomatoes develop a sweeter taste when grown under moderate salinity. In the selected study area, the most widespread typologies of protected crops are tunnel-greenhouses and A-shaped greenhouses. Tunnel-greenhouses are built with a steel bearing structure and are composed of one semi-circular arch or of more joined modules. Its shaped allows accommodating a larger volume of air inside and provides resistance to rain. As regards A-shaped greenhouses, they traditionally are built with wood bearing structure and their basic structural form is the span-type greenhouses, which has a double-sloped roof. Both typologies are covered by plastic films (Figure 2).

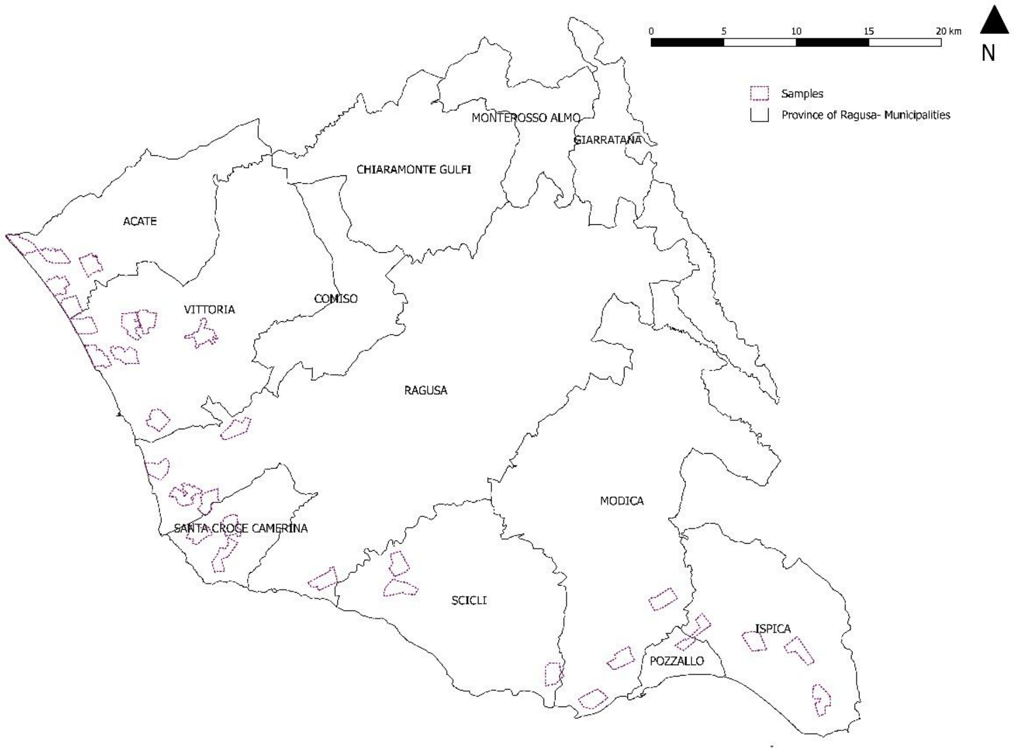

Figure 2 *– Location of the thirty samples within the study area*

2.2 Agricultural plastic waste (APW) computation

To compute APW, a plastic waste index (PWI) chosen from literature (Lanorte et al., 2017) was adapted, calculated and mapped on a GIS layer.

PWI was calculated by using the following relation:

$$PWI = Scr \times \rho \times TK \times life^{-1} \times Ucvc \; [kg\ ha^{-1} yr^{-1}] \qquad (1)$$

where *Scr* is the surface correction factor; ρ is the plastic film density; TK is the plastic film thickness; *life* is the plastic film useful lifetime; *Ucvc* is the unit conversion factor.

In relation to the different types of both building structures and covering films which characterize the protected crops located in the study area, the index was modified by changing Scr, ρ, TK, $life$.

The surface correction factor *Scr* is used in the equation (1) in order to consider more covering materials than that measured on the plan by aerial top views. It was estimated to be 1.12 (Scr_G) for A-shaped greenhouses and 1.5 (Scr_T) for tunnel-greenhouses. The plastic film density ρ was set to 920 kg m^{-3}or 930 kg m^{-3} in relation to film thickness, i.e., 180 μm or 200 μm. The useful lifetime of plastics film considered was 12 month or 24 months. Finally, the *Ucvc* factor which converts the result in kg ha^{-1} yr^{-1} unit was equal to 0.12.

To obtain the yearly APW estimation, two indices one for A-shaped greenhouses type (PWI_G) and one for tunnel-greenhouses (PWI_T) were multiplied for their covered areas, respectively.

2.3 The GIS-based model for APW computation

In this paragraph, a methodology for investigating the location and quantification of APW film is described. To accomplish this goal, a GIS software tool and statistical tools were used. Literature reports several case studies where APW was mapped and estimated by GIS tools (Blanco et al., 2018; Vox et al., 2016). In some research activities carried out in Spain and in Italy, remote sensing technologies have been used both for greenhouse mapping and for APW evaluation (Aguilar et al., 2016; Arcidiacono and Porto, 2010; Lanorte et al., 2017). Other studies compared the results obtained by using GIS-based tool and digital image processing techniques for landscape analysis and for detection of protected cultivation (Arcidiacono and Porto, 2012, 2010, 2008; D. Briassoulis et al., 2013; Demetres Briassoulis et al., 2013b; Picuno et al., 2011).

In order to explore the spatial distribution of crop shelters in the study area and identify the major contributors to the generation of plastics waste, the GIS-based model was developed by using Quantum GIS (QGIS), a GIS software tool for collecting, organizing, analysing, and visualizing geographical data.

The GIS-based model was implemented by using data collected from base and thematic maps as well as from digital colour orthophotos and farmer interviews. To be more specific, the following data set was used:

- The Regional Technical Map at a scale of 1:10,000, obtained from an aerial flight performed in 2008; it is placed in the zone EPGS:3004, Monte Mario/Italy zone 2 reference system;

- Digital colour orthophotos at a scale of 1:10,000, obtained from an aerial flight performed in 2008; they were placed in the EPGS:3004, Monte Mario/Italy zone 2 reference system and have a pixel ground resolution of 50 cm;
- Satellite color images from Google Earth Pro database, which allow the recognition of protected crops in an imagery dated 2017, which is the last available coverage. This image dataset was used in order to analyse the development of the greenhouse coverage in the last 10-year time range.

To compute APW deriving from the plastic covering films the steps reported below were performed:

- Random selection within the Province of Ragusa of thirty area samples suitable for computing the different level of plastic waste production in the whole province of Ragusa. Each sample had an average surface of 150 ha, ranging from 143.81 and 177.3 ha. The number of samples for each municipality was chosen in order to cover about 30% of the whole area covered by protected crops, i.e., A-shaped greenhouses and tunnel-greenhouses.
- Detection and further polygon extraction of protected crops located in each sample, subdivided into two typologies: A-shaped greenhouses or tunnel-greenhouses. This difference was considered because cultivation surfaces covered by tunnel-greenhouses require a greater amount of plastic films due to the geometry of their bearing structure (Figure 3).
- Implementation of a GIS database with detailed information on covering plastic materials used in the protected crops located in the previous step. The most common covering films used in the study area for protected crops are low density polyethylene films, called LDPE, and ethylene-vinyl acetate copolymer, called EVA. These materials can present different thickness (from 14 μm to 200 μm), different average life (seasonal, when they remain in operation 5-6 months; annual, if they stay outdoors for at least 12-14 months; a long duration, if they remain in place for 24 months or more). In this study, given the wide heterogeneity found for the covering films detected in each sample, two different thickness (i.e., 180 μm or 200 μm) and two different life durations (i.e., 12 months or 24 months) were considered after having carried out interview to farmers which confirmed their relevant occurrence. Therefore, significant extreme values of 6 months and of 36 months were excluded from the further analyses.

- Computation of the plastic film waste index (PWI) with the equation (1) with the aim of quantifying the yearly production of APW deriving from the two types of protected crops, i.e., A-shaped greenhouses and tunnel-greenhouses. Different values of PWI were estimated and spatially analysed in GIS. Different results were obtained by considering the two analysed typologies of protected crops.
- Basic statistic evaluations to compute the yearly amount of plastic film waste (APW) production for each sample and for each municipality located in the study area.
- Production of thematic maps showing quantity and density of APW, at municipal level.

3 Results

- Almost all samples were located close to the coast because of the highest concentration of greenhouses in this geographical area (Figure 2)

Figure 3 –. A-shaped greenhouses and tunnel-greenhouses located in the study area.

Within each sample, the classification of protected crops in two different types, i.e., A-shaped greenhouse and tunnel-greenhouses, was carried out by visual analyses of digital colour orthophotos (2012) (Table 3). Among the thirty selected samples, 17 showed a higher number of tunnel-greenhouses type than A-shaped greenhouses one.

Table 3 - Cultivation surfaces covered by tunnel-greenhouses and A-shaped greenhouses within the samples analysed.

Sample ID	Surface sample [ha]	T-G area [ha]	G area [ha]	T-G [%]	G [%]
1	148.82	6.16	88.4	4.14	59.4
2	146.79	20.15	76.88	13.73	52.37
3	144.06	45.64	38.81	31.68	26.94
4	143.81	18.14	73.44	12.61	51.07
5	146.44	11.51	38.97	7.86	26.61
6	160.53	23.73	40.73	14.78	25.37
7	154.7	17.42	42.46	11.26	27.45
8	159.12	39.84	31.14	25.04	19.57
9	145.12	36.17	17.27	24.92	11.9
10	158.26	47.39	17.58	29.94	11.11
11	145.62	17.07	5.08	11.72	3.49
12	167.45	29.73	45.03	17.75	26.89
13	177.29	38.18	57.19	21.54	32.26
14	148.54	11.51	59.91	7.75	40.33
15	151.4	13.09	32.88	8.65	21.72
16	157.05	21.15	20.04	13.47	12.76
17	155.16	20.7	16.1	13.34	10.38
18	156.76	14.85	16.48	9.47	10.51
19	143.89	12.59	21.67	8.75	15.06
20	143.38	32.75	47.41	22.84	33.07
21	171.57	24.4	7.9	14.22	4.6
22	149.98	23.84	0	15.9	0
23	149.35	10.33	5.94	6.92	3.98
24	149.33	10.08	5.25	6.75	3.52
25	152.87	33.65	0	22.01	0
26	156.22	8.24	10.03	5.27	6.42
27	146.98	46.32	0.09	31.51	0.06
28	160.05	48.72	2.57	30.44	1.61
29	157.29	12.92	0	8.21	0
30	150.84	19.07	2.08	12.64	1.38

T-G: tunnel – greenhouses; G: A-shaped greenhouses

A preliminary result obtained from the application of the GIS-based model is the heat-map reported in Figure 4, which shows the major concentration of A-shaped greenhouses and tunnel-greenhouses in the study area.

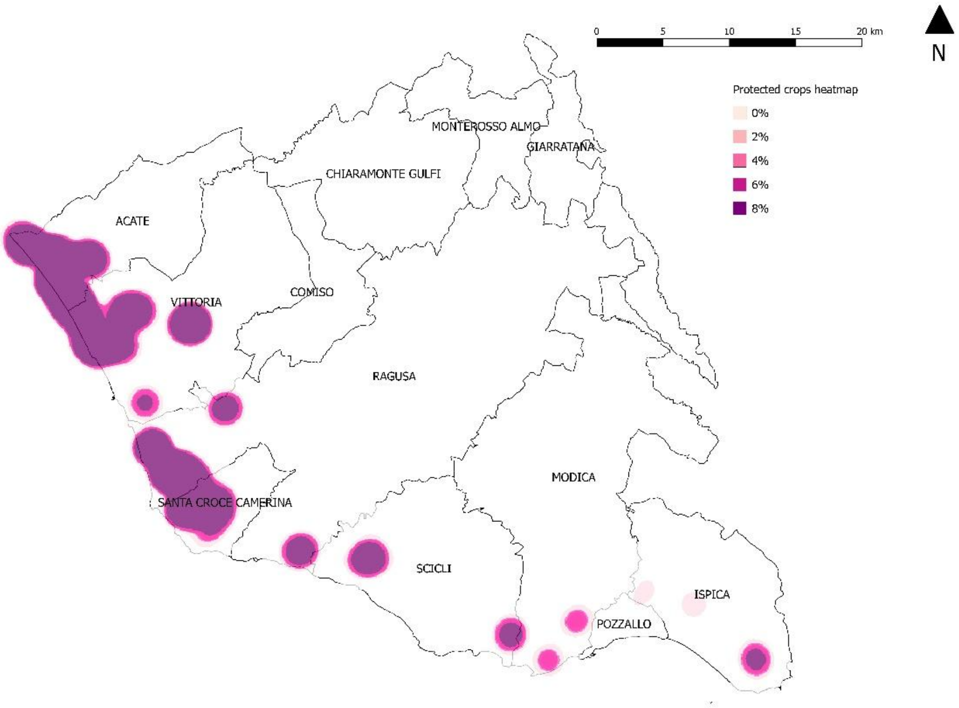

Figure 4-protected crops heat map

- For each type of greenhouses, i.e., tunnel-greenhouses and A-shaped greenhouses, four values of PWI were computed by changing thickness and life duration of the covering material (Table 4).

Table 4 - Plastic waste index (PWI) computed for tunnel-greenhouses and A-shaped greenhouses.

	PWI [kg ha^{-1} yr^{-1}]			
Type	Tunnel-greenhouses		A-shaped Greenhouses	
TK [μm]	180	200	180	200
12 [*month*]	2484.00	2790.00	1854.70	2083.20
24 [*month*]	1242.00	1395.00	976.40	1041.60
Mean	1863.00	2092.00	1415.55	1562.40
SD	878.23	986.41	621.05	736.52

The minimum value of PWI was 976.40 (kg ha^{-1} yr^{-1}) for A-shaped greenhouses type, for a film of 180 μm thickness having a life duration of 24 months. The maximum value of PWI was 2484.00 (kg ha^{-1} yr^{-1}) by considering tunnel-greenhouses type, 200 μm thickness film and a material life duration of 12 months. Mean values and standard deviation were also evaluated as appear in Table 4.

For each territorial sample, the values of PWI_G and PWI_T were computed in order to obtain the yearly amount of plastic waste production (APW kg yr^{-1}) (Table 5).

By comparing the APW values, based on same life duration, a variation of about 11% was observed between 180 μm and 200 μm for both tunnel-greenhouses and A-shaped greenhouses.

Table 5- APW evaluation, results obtained by multiplying the four different values of PWI for the corresponding area of protected crops.

		Thickness/life duration [μm/month]							
id	Area	180/12	180/24	200/12	200/24	180/12	180/24	200/12	200/24
	[ha]	APW Tunnel-greenhouses [kg yr^{-1}]				APW A-shaped Greenhouse [kg yr^{-1}]			
1	148.82	15301.44	7650.72	17186.40	8593.20	163955.50	86313.76	184154.90	92077.44
2	146.79	50052.60	25026.30	56218.50	28109.25	142589.30	75065.63	160156.40	80078.21
3	144.06	113369.80	56684.88	127335.60	63667.80	71980.91	37894.08	80848.99	40424.5
4	143.81	45059.76	22529.88	50610.60	25305.30	136209.20	71706.82	152990.20	76495.1
5	146.44	28590.84	14295.42	32112.90	16056.45	72277.66	38050.31	81182.30	40591.15
6	160.53	58945.32	29472.66	66206.70	33103.35	75541.93	39768.77	84848.74	42424.37
7	154.7	43271.28	21635.64	48601.80	24300.90	78750.56	41457.94	88452.67	44226.34
8	159.12	98962.56	49481.28	111153.60	55576.80	57755.36	30405.10	64870.85	32435.42
9	145.12	89846.28	44923.14	100914.30	50457.15	32030.67	16862.43	35976.86	17988.43
10	158.26	117716.8	58858.38	132218.10	66109.05	32605.63	17165.11	36622.66	18311.33
11	145.62	42401.88	21200.94	47625.30	23812.65	9421.87	4960.112	10582.66	5291.32
12	167.45	73849.32	36924.66	82946.70	41473.35	83517.14	43967.29	93806.50	46903.25
13	177.29	94839.12	47419.56	106522.20	53261.10	106070.30	55840.32	119138.20	59569.10
14	148.54	28590.84	14295.42	32112.90	16056.45	111115.10	58496.12	124804.50	62402.26
15	151.4	32515.56	16257.78	36521.10	18260.55	60982.54	32104.03	68495.62	34247.81
16	157.05	52536.6	26268.30	59008.50	29504.25	37168.19	19567.06	41747.33	20873.66
17	155.16	51418.80	25709.40	57753.00	28876.5	29860.67	15720.04	33539.52	16769.76
18	156.76	36887.40	18443.70	41431.50	20715.75	30565.46	16091.07	34331.14	17165.57
19	143.89	31273.56	15636.78	35126.10	17563.05	40191.35	21158.59	45142.94	22571.47
20	143.38	81351.00	40675.50	91372.50	45686.25	87931.33	46291.12	98764.51	49382.26
21	171.57	60609.60	30304.80	68076.00	34038.00	14652.13	7713.56	16457.28	8228.64
22	149.98	59218.56	29609.28	66513.60	33256.80	0	0	0	0
23	149.35	25659.72	12829.86	28820.70	14410.35	11016.92	5799.81	12374.21	6187.10
24	149.33	25038.72	12519.36	28123.20	14061.60	9737.17	5126.10	10936.80	5468.40
25	152.87	83586.60	41793.30	93883.50	46941.75	0	0	0	0
26	156.22	20468.16	10234.08	22989.60	11494.80	18602.64	9793.29	20894.50	10447.25
27	146.98	115058.90	57529.44	129232.80	64616.40	166.92	87.87	187.48	93.74
28	160.05	121020.50	60510.24	135928.80	67964.40	4766.57	2509.34	5353.82	2676.91
29	157.29	32093.28	16046.64	36046.80	18023.40	0	0	0	0
30	150.84	47369.88	23684.94	53205.30	26602.65	3857.77	2030.91	4333.05	2166.52

The computed average values of PWI_G and PWI_T were 1,477 kg $ha^{-1}yr^{-1}$ and 1,978 kg $ha^{-1}yr^{-1}$, respectively. These amounts were applied to obtain the yearly production of agricultural plastic waste (APW kg yr^{-1}) per municipality (Table 6).

The results demonstrated that Acate was the municipality with the highest amount of APW_G, 467,375 kg yr^{-1}, corresponding to the 37.5 % of the total APW_G deriving from A-shaped greenhouse cultivation system. The highest value of APW_T was found in Vittoria municipality where the computed yearly production is 417,978 kg yr^{-1}, almost the 29.5 % of the APW_T whole amount.

Table 6. Agricultural Plastic Waste (APW) yearly amount.

Municipality	Density [kg ha^{-1}]	$APWI_G$ [kg yr^{-1}]	$APWI_T$ [kg yr^{-1}]	Surface area [ha]
Acate	65.58	467,375	200,928	10,190
Chiaramonte Gulfi	0.01	100	100	12,659
Comiso	0.02	100	100	6,501
Giarratana	0.02	100	100	4,335
Ispica	21.32	3,928	236,943	11,297
Modica	4.35	22,564	103,708	29,048
Monterosso Almo	0.02	100	100	5,619
Pozzallo	11.55	3,072	14,279	1,502
Ragusa	10.90	274,838	206,944	44,181
Santa Croce Camerina	68.71	159,717	121,527	4,093
Scicli	9.84	20,437	114,902	13,757
Vittoria	39.28	294,287	417,978	18,135
Total	-	1,246,618	1,417,609	161,317

The entire amount of APW ($APWI_G$ + $APWI_T$) was computed for the whole province of Ragusa and reported on thematic GIS maps. Furthermore, two maps describing the quantity and the density, respectively, of plastic waste film yearly production (Figure 5 and 6) were elaborated.

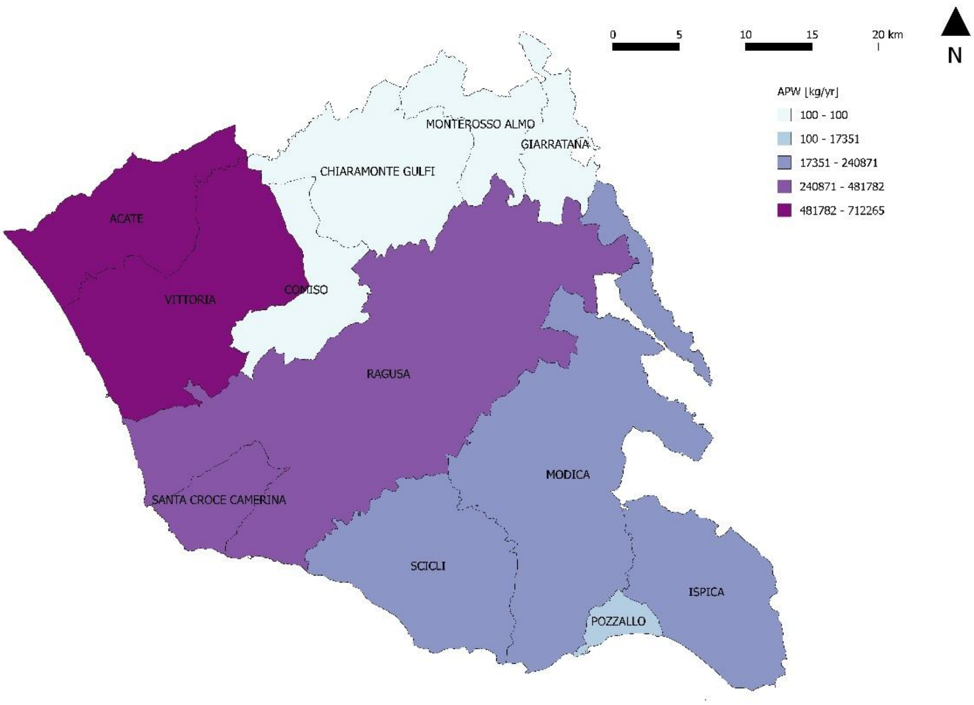

Figure 5-APW yearly amount in the municipalities of the province of Ragusa.

As clearly highlighted in Figure 5, Acate and Vittoria resulted the municipalities with the greatest amount of APW, i.e., 668,303 (kg yr^{-1}) and 712,265 (kg yr^{-1}), respectively. Whereas, Acate and Santa Croce Camerina municipalities reported the highest density, i.e., 65.58 (kg ha^{-1}) and 68.71 (kg ha^{-1}) (Figure 6).

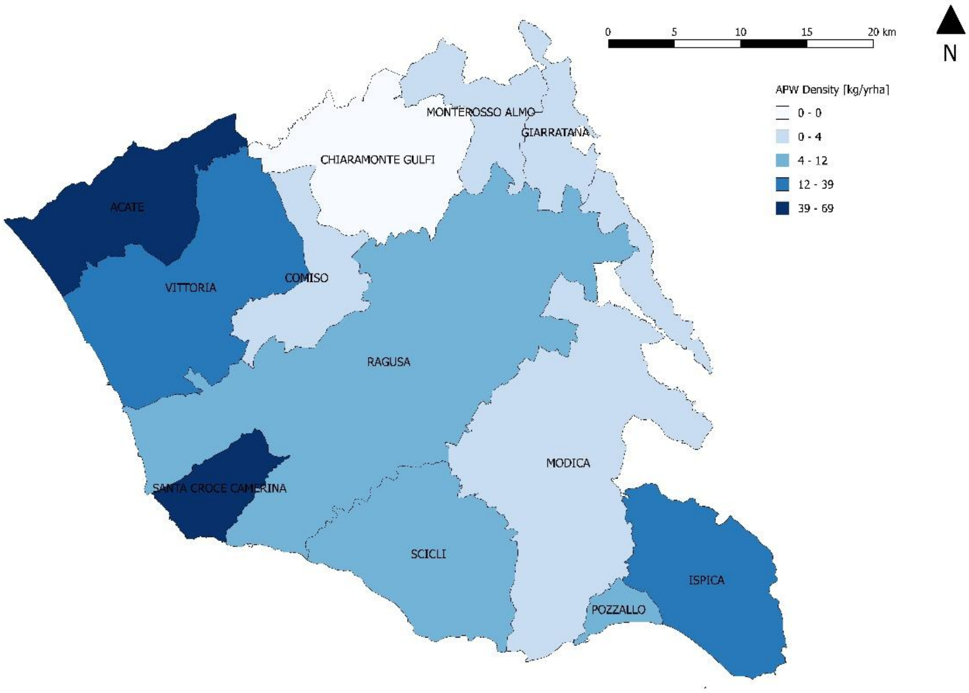

Figure 6 *-APW density in the municipalities of the province of Ragusa.*

The analysis of the achieved results shows that, considering the mean value of PWI, the total amount of plastic waste deriving from covering films of protected cultivation is about 1,7 tons per hectare per year. The computed yearly amounts of APW, $APWI_G$, and $APWI_T$ per municipality are shown in Figure 7. By taking into account only the municipalities with the highest APW amount, i.e., Acate, Vittoria, Ragusa and Santa Croce di Camerina, $APWI_G$ values resulted higher than APW_T values, except for Vittoria municipality.

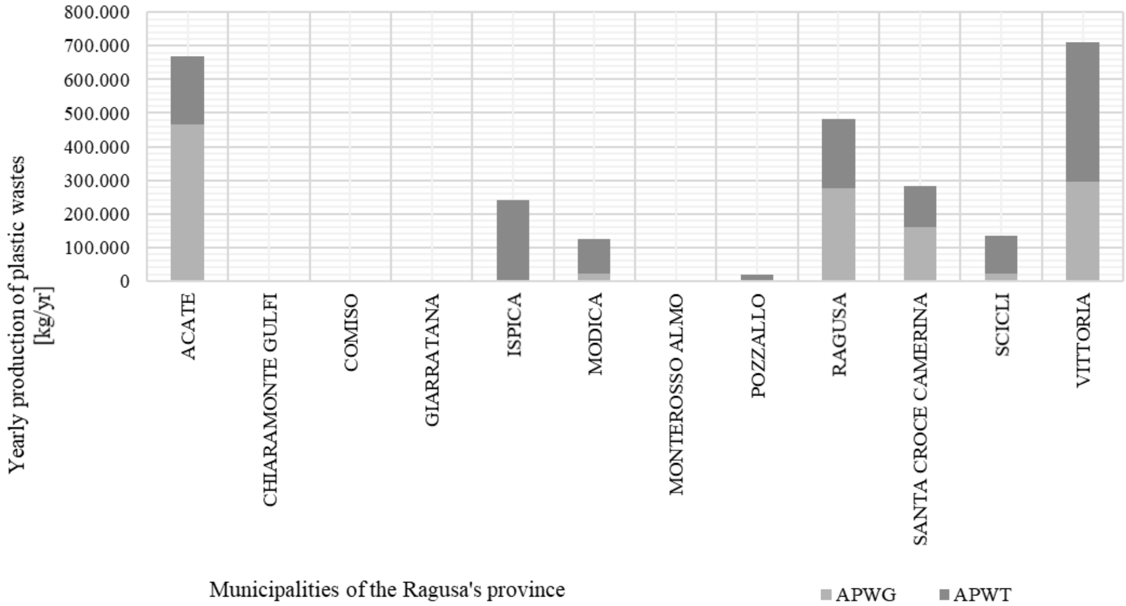

Figure 7- APW total, APW_G deriving from A-shaped greenhouses and APW_T deriving from tunnel-greenhouses computed for each municipality of the province of Ragusa.

4 Discussion

Through the GIS-model proposed in this study it was possible to compute the APW deriving from greenhouse cultivation system in the whole province of Ragusa, which was chosen for its relevance with regard to the development of protected cultivations. The obtained results concerning the amount and location of APW are essential for a better management of collection centres taking into account the existing infrastructures in order to optimize the collection process and reduce CO_2 emissions that is the major responsible for the global warming. During the research activities it was possible to observe that only one collection and recycling centre was located in the study area, in the municipality of Vittoria. Therefore, in view of obtaining new materials from APW and in order to reduce the transport cost for transferring APW to the recycling plants (De Montis, 2014; Osmani and Zhang, 2017), the optimization of the location of new collection centres is required. In this context, the GIS-model proposed in this study could be also used to plan the location of such collection centre by using the heat maps. This could also limit the APW mechanical recycling costs which often is higher than making plastics from virgin material because of the collection, transportation and cleaning costs (Demetres Briassoulis et al., 2013a).

Furthermore, the application of the GIS-based model to the study area made it possible to monitor at a municipality scale the state of application of the territorial policies aiming at the limitation of the environmental impact due to greenhouse cultivation system. The results of the research study showed that despite the indications of the Coastal Area Plan (CAP) contained in the Territorial Plan of Coordination of the Ragusa province (Country Council of Territory and Environment, 2004), the major part of protected crops is localized along coastline (Figure 4). In the study area considered for the GIS-based model application, the CAP had the aim of a 'reorganization of the coastal use' concerning agricultural activities, tourism, infrastructures, urbanization, etc., in order to reduce the anthropic load of this zone and allows the presence of ecological corridors in the coastal system. For a sustainable growth of the territory and assuring landscape quality, the requalification actions foreseen the displacement of greenhouses from coastal to rural areas. The CAP of the province of Ragusa directives were disregarded because protected crops are still concentrated in the coastal area. This result confirms the reluctance of farmers to move their agricultural activity far from the coast, probably because vegetable crops, especially tomatoes, suffer from the cold climate. So, this study confirms again what stated by Arcidiacono and Porto (2010) with regard the need of a policy action for the identification of new areas of agricultural value where greenhouse cultivation system could be moved as well as for providing incentives to farmers for the construction of new greenhouses far from the coasts. Public financial aids to farmers should be increased for both new land acquisition and installation of heating systems for greenhouses. Currently, in Sicily the PSR 2014/2020 supports the investments in agricultural sector ("Sottomisura 4.1") and aids farmers in order to introduce technological innovations. However, the contribute for the renovation of greenhouse system is too low and quite insufficient to delocalize protected cultivation far from the coast. Currently, farmers are reluctant to move greenhouses from the coast to inner areas characterized by less favourable climate conditions because of the higher cost required to heat greenhouses. Therefore, technological innovations should be financially supported in order to improve the development of new heating systems for greenhouses.

As demonstrated by applying the GIS-model, most protected crops are tunnel-greenhouses which are structures built with modern construction systems, replacing traditional greenhouses. This means a major consumption of plastic materials for the same quantity of covered surface, due to the greater slope of tunnel-greenhouse typologies, as reported in Table 4. In future the use of newer generation of biopolymers (plastics made from biomass sources materials) as covering films, currently used for mulching (Kasirajan and Ngouajio, 2012), could represent an alternative solution to cope with concerns related to agricultural plastic use. Meanwhile, the method proposed in this study could be useful to compute density and spread of these tunnel – greenhouses in order to make policymakers able to evaluate the financial aid for farmer to replace conventional covering films with more sustainable ones.

Finally, the research study reported in this paper is in line with the Waste Framework Directive (WFD) of European Union (Directive 2008/98/EC) that provides correct procedures for collection, disposal and recycling of post-consumption plastics in order to reduce the environmental effects of the use of plastics in agriculture. More specifically, Waste Management Plans (WMP), that is an obligation of EU Member States, must establishes the objectives to be achieved, to formulate strategies and to identify the implementation means to improve protection of environment and human health and to reduce impacts of the waste production and management. Since EU Member States can ask the regional or local authorities to put forward WMP on regional or local base, the GIS-based model proposed in this study could allow local authorities to manage APW deriving from greenhouse cultivation system.

5 Conclusions

In this study, a GIS- based model to locate and quantify the yearly amount of APW coming from greenhouses cultivation system was developed and applied in the province of Ragusa.

The index PWI to determine APW amount was chosen from literature and applied to obtain heat maps related to covering plastic films. Then, by taking into account different thickness, lifetime, and density of the covering films of the greenhouses within the considered samples, the index was computed and ranged between 976 kg $ha^{-1}yr^{-1}$ and, 2,484 kg $ha^{-1}yr^{-1}$.

The achieved results showed that the highest density of A-shaped greenhouses and tunnels-greenhouses is located nearby the coastline. Furthermore, the results obtained by the development the GIS-based model could be useful at a regional level since provide relevant information for the analysis of the environmental impact due to transportation of APW to collection centres, recycling industries or landfills located in the neighbouring of the study area. By using the GIS-model proposed in this research study local administrators could take advantage of a suitable tool for monitoring land consumption and putting forward adequate corrective actions to achieve the planned objectives and improve the sustainable disposal management of covering plastic films. In this context, the results of the study highlighted that the guidelines of the Territorial Plan of the Province of Ragusa were disregarded.

Moreover, from an economic point of view, if plastic materials are not recovered after their use, the European Commission Directives purpose to transform Europe into a more circular and resource efficient economy would be disregarded.

Acknowledgements:

This study was part of a dissertation PhD Thesis of the Dr. Eng. Parlato Monica Concetta Maria within the Agricultural, Food, and Environmental Science Doctorate (XXXIV Cycle) of the University of Catania (Advisor: Dr. Eng.Simona M.C. Porto, Co-Advisor: Prof. G. Cascone). All the authors contributed equally to the paper. The authors declare that there is no conflict of interest.

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