

**Plastic emissions from mulch film and abatement measures - a model-based assessment  
for Germany**

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**Abstract**

Plastic mulch film application in agricultural production creates a debate between environmentalists and farmers. Mulch films are disturbing elements in the landscape and fauna habitats and cause plastic emissions. Farmers apply the mulch film to specific crops to optimise production conditions and reduce factor input and environmental impacts. In Germany, mulch film allows timely production according to the consumers' demand for asparagus, strawberries, lettuce, cucurbits, and early potatoes. Mulch film application and plastic emissions differ regionally and are high for regions where farmers are specialised in producing specific crops (e.g. gherkins). Representative statistical data on mulch film applications do not exist. Thus, the assessment of plastic emissions and abatement measures is challenging. This paper presents a conceptual framework to quantify the plastic emission from mulch films and economically evaluate abatement measures. Increasing the thickness of mulch film can reduce the emissions from plastic mulch films and maintain the advantages in production processes. In abatement scenarios, increasing the film thickness to 40 to 50 micrometres reduces plastic emissions by 20 to 40 per cent. The abatement costs reach from 120 to 130 Euros per kilogram of abated plastic. Transmitting the abatement costs to the consumer would increase the price by 1 to 10 per cent. Thus, increasing the film thickness in Germany could be an economically interesting abatement measure if consumers are willing to pay 1 to 10 per cent higher prices for products produced with less plastic emissions.

**Keywords:** plastic, pollution, abatement, mitigation, agriculture, production

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**Competing Interests**

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A-1: Introduction

Section 1 briefly reviews studies, which assess emissions from plastic mulch film in Switzerland and Germany. Table A-1 compares selected studies with the present study concerning the research question, method and assumptions and selected results.

**Table A-1** Comparison of selected studies analysing the emissions of plastic from mulch film: scope and method

	<b>Nowack and Kawecki (2019) and Kalberer et al (2019)</b>	<b>Bertling et al (2021)</b>	<b>Brandes et al. (2021)</b>	<b>The present study</b>
Research question	Quantification of emissions to water and soil	Quantification of emissions to soils	Quantification of emissions to soils	Quantification of emissions from mulch film and economic assessment of abatement options
Region	Switzerland	Germany	Germany	Germany
Temporal	Since 1960	One year	Since 1960 and 2018	Since 1960 and 2018
Plastic sources	Relevant for agriculture	Relevant for agriculture	Sludge, compost, mulch film	mulch film
Method	Mass flow analysis	Accounting of plastic balances	Regional modelling, top-down	Regional modelling, top-down
Database	Statistical data expert knowledge	Statistical data expert knowledge	Statistical data expert knowledge	Statistical data expert knowledge
Differentiation for films	Average mulch film and asparagus film	Average mulch film and asparagus film	Thickness of mulch film specified for crops	Thickness film specified for crops
parameter value				
Density of film plastic	917,5 kg m <sup>-1</sup>	950 kg m <sup>-1</sup>	917,5 kg m <sup>-1</sup>	917,5 kg m <sup>-1</sup>
Coverage by film		26% of UAA	Estimation at regional scale	
Loss rate (EF)	0-1%	3.2%	1%	depending on film thickness
Film thickness		20 µm (vegetable) and 120 µm (asparagus)	Asparagus: 100 µm cucurbits: 30 µm lettuce, potatoes: 25 µm	Asparagus: 100 µm cucurbits: 30 µm lettuce, potatoes: 25 µm

## Appendix A-2: Model and Data

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### Appendix A-2.1: Model

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#### Appendix A-2.1.1 Model: Emission and abatement

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#### Appendix A-2.1.2 Model: Abatement costs

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### Appendix A-2.2 Data

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#### Appendix A-2.2.1 Data: Mulch film area

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### **Appendix A-2.2.1.1 Data: Mulch film sales**

Section 2.2.1.1 presents the data derived for the sales quantities of mulch film in Germany. Section A-2.2.1.1 explains the challenges of estimating and deriving the missing data and presents the assumptions defined to derive the sales quantity as a consistency framework for estimating the mulch film area. In Germany, plastic films in agriculture are used for fodder production (e.g. silage film), for the control of pests (e.g. insects) and herbs (as mulch film), as protection against rain and hail (e.g. in fruit production), and to regulate or retain humidity, soil structure, temperature and solar radiation (e.g. strawberry, asparagus production). Unfortunately, no exact statistical data exists for Germany at the sector or regional level.

Surveying the production data from producers is difficult. For some plastic products (e.g. agricultural films and nets), the number of producers is small, and the companies keep their data business confidential. For mulch film, the German market is supplied by several different producers also exporting to Germany. Data on regional sales to the farmers may be recorded with the regional retailers. In Germany, some bigger retailers can be considered representative for specific products or regions. Due to data confidentiality, access to data is difficult. Furthermore, there are also some relevant retailers located in neighbouring countries. The attempt to survey data from these retailers was estimated as very labour intensive by different experts (BayWa Tettang, 2019; GKL, 2019; Expert, 2019). Thus, this work was beyond the scope of the present study. Therefore, we use sector data estimated by experts and provided by statistics to quantify the application of plastic films.

Table A-2.2.1.1-1 presents the estimates for all plastic films used in agriculture. More than half of the plastic films are used in fodder production (e.g., silage and stretch films). We assume these films are less relevant for plastic emissions to agricultural soils, as they are very stable and do not cover large areas. The nets and films in fruit production account for less than 12,000 tons. We expected the plastic emissions from these sources to be minimal as the material is robust. Furthermore, these nets and films lie on trees and bushes and not directly on the soil. Thus, we expect the plastic emissions to be diffuse and not directed to agricultural soils. We consider films that directly cover the arable land relevant for plastic emissions directed to agricultural soils. These films account for an estimated 5,400 tons applied as tarp film in asparagus production and 10,090 tons applied in the production of strawberries and specific vegetables (e.g. lettuce, gherkin, melon, zucchini). Table A-2.2.1.1-1 compares the present study's estimations with those published by Bertling et al. (2019) and GVM (2020). The range of estimated quantity for mulch film, an nets in strawberries and vegetable production is comparable to the other studies. However, with an under-overestimation of 20% compared to Bertling et al. (2019) and an underestimation of 20% compared to GVM (2020).

**Table A-2.2.1.1-1** Estimation of annual quantities of plastic films and nets applied in German agricultural production

	Present study		Bertling et al. (2021) <sup>h</sup>	GVM (2020) <sup>h</sup>
	tons per year	Source	tons per year	
Sum of all plastic films and nets	70,000	BMEL (2019)*		
Fodder production	43,000	BMEL (2019) *		
Stretch film	13,500 <sup>a</sup>	Expert (2019)**	17,680 <sup>h</sup>	16,158 <sup>h</sup>
Silage film	29,500 <sup>b</sup>	Expert (2019) **	21,900 <sup>h</sup>	26,458 <sup>h</sup>
Asparagus film (incl. tunnel film)	5,400	BMEL (2019) *		
Asparagus film (black and white film)	3,500	BMEL (2019) *	4,994 <sup>h</sup>	7,490 <sup>h</sup>
Nets fruit production for hail protection/pest and bird control <sup>c</sup>	11,000	BayWa (2019) **		
Film fruit production for rain protection <sup>d</sup>	510	BayWa (2019) **		
Mulch films and nets in strawberries and vegetable production, excluding tarp in asparagus production	10,090 <sup>d,e,f</sup>	Own computation	8,370 <sup>g,h</sup>	12,942 <sup>g,h</sup>
Mulch films and nets in strawberries and vegetable production, including tarp in asparagus production	15,490 <sup>d,e,f</sup>	Own computation	13,364 <sup>g,h</sup>	20,432 <sup>g,h</sup>

a) average computed from range 12,000 to 15,000 tons, b) average computed from range 28,000 to 31,000 tons, c) average computed from range 10,000 to 12,000 tons, d) average computed from range 460 to 570 tons, e) including fleece, f) computed as residual, g) reported as mulch film, nets and films, excl. tarp in asparagus. h) reported in Bertling et al. (2021: 73). \* for the year 2016, \*\* estimated annual average recent to 2019

### Appendix A-2.2.1.2 Data: Mulch film area in the reference year (2018)

Section 2.2.1.2 describes the estimation of mulch film area in the reference year 2018. Section A-2.2.1.2 provides more detailed information on the estimation approach. Production area data are available at the sector level for Germany and the Federal States from 1961 to 2018 (DESTATIS 2019). At the regional (NUTS3) level, the statistical data are available only for asparagus and strawberry. For other vegetable production, the survey of statistical data is executed at the Federal States level and recorded data are not accessible since the Federal States keeps the data confidential. These Federal States owned data are recorded at the municipality, farm or field level and thus partially sensitive regarding information privacy. Access to anonymised data requires administrative agreements on the data user rights, which is usually granted within frameworks of more extensive research projects in which the Federal States have a partner or a stakeholder function. Table A-2.2.1.2-1 presents the data sources and the estimation approach applied to the other crops.

**Table A-2.2.1.2-1** Overview of data source for estimating crop production area

Regional level	Data source	Computation
NUTS0 (national level)	DESTATIS (2019)	
NUTS1 (federal state level)	DESTATIS (2019)	
NUTS2 (district level)	DESTATIS (2019)	
NUTS3 (county level)	Stroh et al. (2016), Garming et al. (2018), Special survey for strawberries and asparagus, RAUMIS-2010 database for early potatoes	Estimated by respecting consistency up-scale (NUTS2, NUTS1, NUTS0) and using vegetable area from RAUMIS-2010 database

		Bavaria	Brandenburg	Niedersachsen	Nordrhein-Westfalen	Baden-Württemberg	Rheinland-Pfalz
Production area in [ha]	Lettuce	1559	96	1857	2861	2281	2997
	Cucurbits	2389	763	321	994	1101	1091
	Gherkin	1160	505	47	119	148	0
Mulch film area in [ha]	GKL (2020)	1607	500	155	150	70	340
	Coverage of Lettuce+Cucur	41%	58%	7%	4%	2%	8%
	Coverage Lettuce	103%	521%	8%	5%	3%	11%
	Coverage of cucu	67%	66%	48%	15%	6%	31%
	Coverage of gherkin	139%	99%	330%	126%	47%	NA

### Appendix A-2.2.1.3 Data: Mulch film area in the past (1960 to 2017)

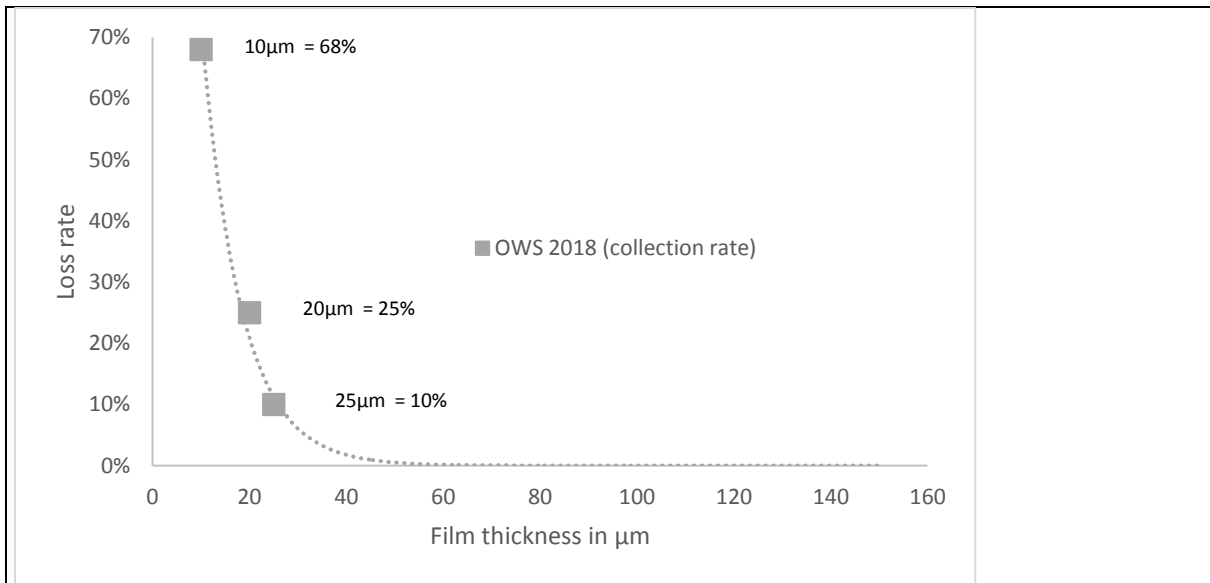
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### Appendix A-2.2.2 Data: Plastic emissions

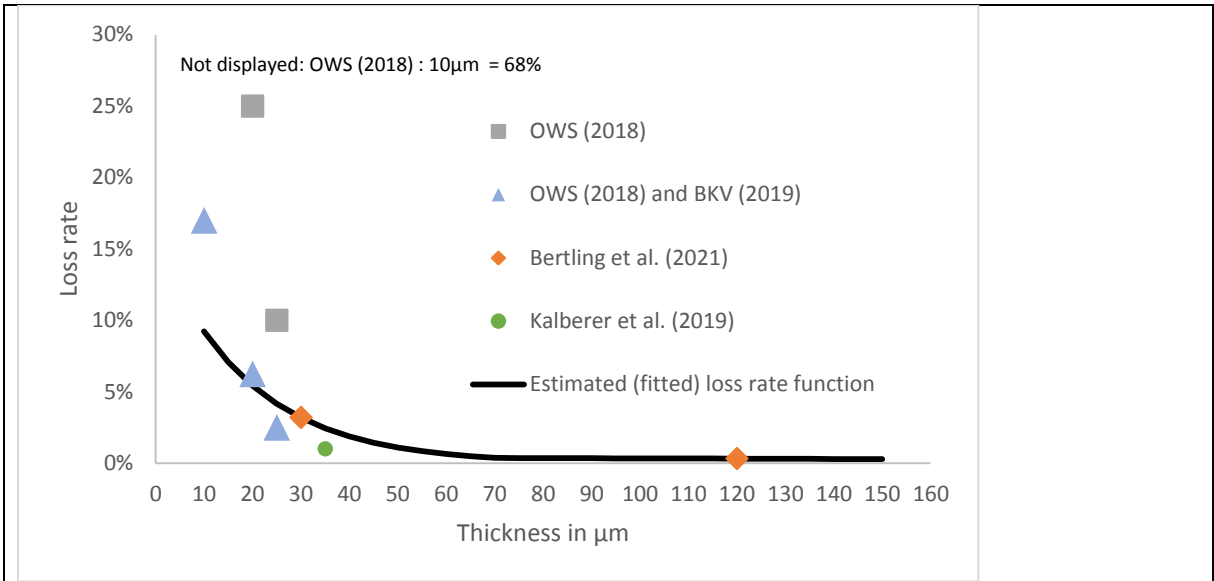
Section 2.2.2 describes the approach to estimating material losses from films of different thicknesses. Section A-2.2.2 presents more details and compares the approach and values with other studies. Figure A-2.2.2-1 to A-2.2.2-4 and Table A-2.2.2-1 present the values of the estimated loss function derived from other studies and compare the values between the present study and the other studies. OWS (2019) estimates the emission from the relatively thin film (10, 20 and 25  $\mu\text{m}$ ) based on the collection quote of mulch film, i.e. the amount of material collected from the field and being considered for recycling. OWS (2019) estimates the collection rate of relatively thin films 10, 20 and 25  $\mu\text{m}$  at 32%, 75% and 90%, resulting in material losses of 68%, 25% and 10%. However, these collection rates are based on the material collected from the field and delivered to the recycling plant. Thus, these shares do not consider the quantity collected from the field and disposed of into the trash (e.g. during after-harvest clean-up activities). In Germany, farmers know about the polluting impact of plastic in soils and understand that plastic influences the soil structure and can also impact working with soil machines. Thus, we assume that farmers aim to clean up their fields as much as possible (normative assumption). BKV (2019) estimates the share of collected

littered plastic at 75%. We apply this share to the material remaining on the field, according OWS (2019). Thus, we correct the material losses from 32%, 25% and 10% to 17% ( $68\%/4$ ), 6.25% ( $25\%/4$ ) and 2.5% ( $10\%/4$ ). For the thickness of 35 and 100  $\mu\text{m}$  we use the estimates by Kalberer et al. (2019) and derive an exponential shape of a loss function, which appears plausible in form as the thicker material should decrease with a diminishing rate. We assume material losses cannot be avoided, even with high thickness. Thus, for films thicker than 70 $\mu\text{m}$ , we define a linear curvature approaching a loss of zero.

We fit the loss function in line with the two values provided by Bertling et al (2021) for a film of 30 to 120  $\mu\text{m}$ , whose data base on experts' knowledge for Germany and which meets nearly the data of OWS (208) and BKV (2019). The fitted loss function defines higher losses than Kawecki et al. (2021). As long as no better data exists, which proves different, we assume that this function is a sufficiently good approximation, which needs to be revised as soon as better data is available. We define a film type of specific thickness for each crop based on different sources like production recommendation (LfL) guides and expert knowledge from the film industry (Raiffeisen Gartenbau, HADI) and assume a uniform density for PE material of 917.5 kg m<sup>-3</sup>. These assumptions are in line with Brandes et al. (2021) and more differentiated for vegetable crops (cucurbit, lettuce and early potatoes) than Bertling et al. (2021).



**Figure A-2.2.2-1** Fitted loss curve based on OWS (2018) We use the loss curve based on collection rates as an orientation to assume an exponential shape for the loss curve



**Figure A-2.2.2-2:** Estimation of losses as fitted loss curve based on different studies. The fitted function is in line with values by Bertling et al. (2021)

**Table A-2.2.2-1** Values of the estimated loss function of the present study with the loss function reported in other studies

Folien dicke in µm	Estimated Loss rate Function (fitted)	Bertling et al. (2021) (experts estimation)	OWS (2018) (collection rate)	Kalberer et al. (2019) --lower bound (MFA)	Kalberer et al. (2019) -- middle (MFA)	Kalberer et al. (2019) -- upper bound (MFA)	OWS (2018) (collection rate) & BKV (2019)
10	9,23%		68%				17,0%
15	7,08%						
20	5,43%		25%				6,3%
25	4,17%		10%				2,5%
30	3,20%	3,20%					
35	2,45%			0,10%	0,55%	1,00%	
40	1,88%						
45	1,44%						
50	1,11%						
55	0,85%						
60	0,65%						
65	0,50%						
70	0,38%						
75	0,37%						
80	0,36%						
85	0,36%						
90	0,35%						
95	0,35%						
100	0,34%						
105	0,34%						
110	0,33%						
115	0,33%						
120	0,32%	0,32%					
125	0,32%						
130	0,31%						
135	0,31%						
140	0,30%						
145	0,30%						
150	0,29%						



### **Appendix A-3 Result and discussion**

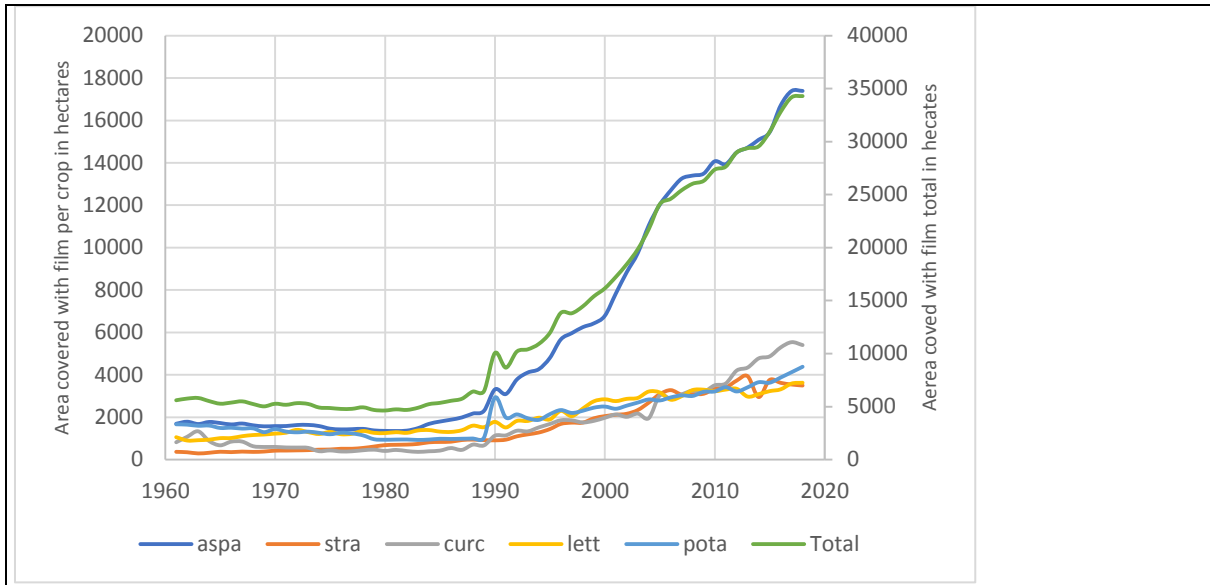
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#### **Appendix A-3.1 Emissions from plastic mulch films**

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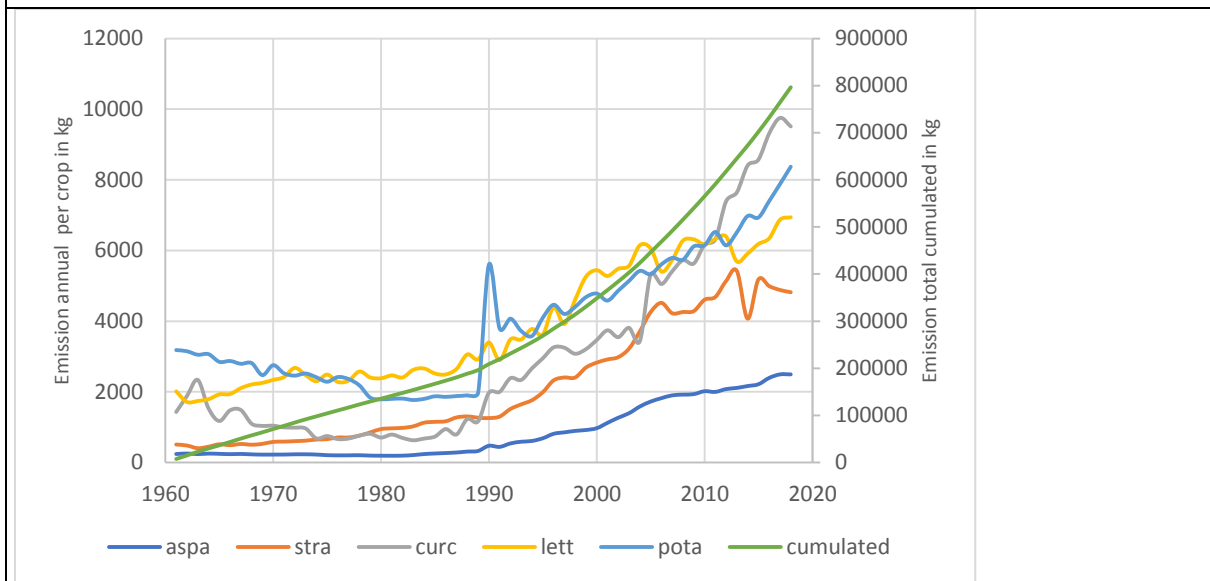
##### **Appendix A-3.1.1 Emissions at sector level**

In Section 3.1.1, Figure 4 presents the development of crop area as simplified as smoothed function. Figure A-3.1.1-1 presents the development of area in a not smoothed way with annual variation and peaks. Figure A-3.1.1-2 presents as not smoothed function the emissions from the crops and the cumulated emissions.



**Figure A-3.1.1-1** Development of crop area covered with the film presented as not smoothed curves.

Notes: aspa = asparagus, stra = strawberries, curc = cucurbits, pota = potatoes, Total = total aggregated area of all crops.



**Figure A-3.1.1-2** Development of crop area covered with film presented as not smoothed function and the total cumulated emissions

Notes: aspa = asparagus, stra = strawberries, curc = cucurbits, pota = potatoes, cumulated = total aggregated emissions from all filmed crop area

compares the results and assumptions of our study with the study by Bertling et al (2021). The differences result from the computed covered area and the assumptions for the loss rate and the plastic weight. For the emissions from asparagus, we compute a comparable value only 8% smaller than Bertling et al. (2021). In our study, we assume in our study 14% more area covered with tarp film, but we assume smaller lower plastic quantities per hectare resulting from the assumption of thinner film and smaller plastic weight. We assume a thickness of 100  $\mu\text{m}$  with a density of  $917,5 \text{ kg m}^{-3}$ , Bertling et al. (2021) assume a thickness of 120  $\mu\text{m}$  with a

density of  $950 \text{ kg m}^{-3}$ . Thus, even with a 14% more covered area, we compute less plastic emissions from asparagus tarp than Bertling et al. (2021).

We compute 25% fewer emissions for strawberries than Bertling et al. (2021). The filmed area is 6% lower although the derivation of the filmed area is very different. We use the German production area of strawberries with a coverage rate of 26%, while Bertling et al. (2021) derive the filmed area based on the survey data provided by GKL (2020) and apply a coverage rate of 70%. The effect of higher plastic weight –i.e.,  $367 \text{ kg ha}^{-1}$  in our study and  $290 \text{ kg ha}^{-1}$  in Bertling et al. (2021)– is compensated by lower material losses –i.e., in our study, 2% and 3.2% in Bertling et al. (2021). Both differences result from our assumption of thicker mulch film applied in strawberry production –i.e., 40my in our study and 30my in Bertling et al. (2021).

While the emissions from asparagus and strawberries are comparable to those of Bertling et al. (2021), the emissions from vegetables and early potatoes differ significantly. The emissions computed in our study are five times higher than in Bertling et al. (2021) because we include as annual crop also early potatoes, which increases the filmed area by 4377 ha and which are not considered by Bertling et al. (2021). We compute 80% more total emissions if we consider the early potatoes as emitters into the computation. If we exclude the early potatoes as emitter to the total, the difference reduces to 40%.

In our study, we derive for cucumber and lettuce a with 9031 Comparison of assumptions and results between the present study and Bertling et al. (2021)

		Present study	Bertling et al. (2021)	Difference absolute	Difference relative
<b>Production area in [ha]</b>	aspa	23195	19007 <sup>c</sup>	4188	22%
	stra	12464	5292 <sup>c</sup>	7172	136%
	curc	7203			
	lett	12961			
	pota	15632			
	vege	35796 <sup>a</sup>	2992 <sup>c</sup>	32803	1096% <sup>c</sup>
<b>Coverage in [%]</b>	aspa	0,75	0,8	-0,05	-6% <sup>c</sup>
	stra	0,28	0,7	-0,42	-60% <sup>c</sup>
	curc	0,75			
	lett	0,28			
	pota	0,28			
	vege	0,46 <sup>b</sup>	0,7	-0,24	-0,34 <sup>c</sup>
<b>Film area in [ha]</b>	aspa	17396	15205,6 <sup>c</sup>	2190,4	14% <sup>c</sup>
	stra	3490	3704,4 <sup>c</sup>	-214,40	-6% <sup>c</sup>
	curc	5402			
	lett	3629			
	pota	4377			
	vege	13408 <sup>a</sup>	2094,61 <sup>c</sup>	11313,39	540%
<b>Loss rate in [%]</b>	aspa	0,32	0,32% <sup>c</sup>	0	0,00% <sup>c</sup>
	stra	1,88	3,20% <sup>c</sup>	-0,01	-41% <sup>c</sup>
	curc	3,20			
	lett	4,17			
	pota	4,17			
	vege	3,80 <sup>b</sup>	3,20% <sup>c</sup>	0,005982513	18,70%
<b>Plastic weight in [kg/ha]<sup>d,e</sup></b>	aspa	918	1140 <sup>c</sup>	-223	-20%
	stra	367	290 <sup>c</sup>	77,00	27%
	curc	275			
	lett	229			
	pota	229			
	vege	247	290 <sup>c</sup>	-43	-15%
<b>Losses in [kg/ha]</b>	aspa	2,94	3,648	-0,71	-20%
	stra	6,90	9,28	-2,38	-26%

	curc	8,81			
	lett	9,57			
	pota	9,57			
	vege	9,26	9,28	0,00	0%
<b>Emissions absolute in [kg]</b>	aspa	51075	55470	-4395	-8%
	stra	24080	34377	-10297,23	-30%
	curc	47589			
	lett	34715			
	pota	41870			
	vege	124175	19438	104737	539%
<b>Total emissions incl. early potatoes in [kg]</b>		199329	109285	90044	82%
<b>Total emissions excl. early potatoes in [kg]</b>		157459	109285	48174	44%

Notes: a) computed for comparison as sum of annual crops (curc, lett, pota), b) computed for comparison as average weighted by absolute emission of the annual crops c) computed/based on the values published in Bertling et al. (2021):155,156,157,160). d) thickness of mulch film in our study: aspa (asparagus) = 100µm, stra (strawberries) = 40 µm, curc (cucurbits)=30 µm, lett (lettuce)=25 µm, pota (early potatoes) =25 µm; thickness of mulch film in Bertling et al. (2021): aspa= 120 µm, stra= 30 µm, vege(vegetable)= 30 µm, e) density of plastic: in present study = 917.5 kg/m<sup>3</sup>, in Bertling et al. (2021) = 950 kg/m<sup>3</sup>

### Appendix A-3.1.2 Emissions at the regional level

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### Appendix A-3.2 Abatement measures

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#### Appendix A-3.2.1 Scenarios and abatement costs

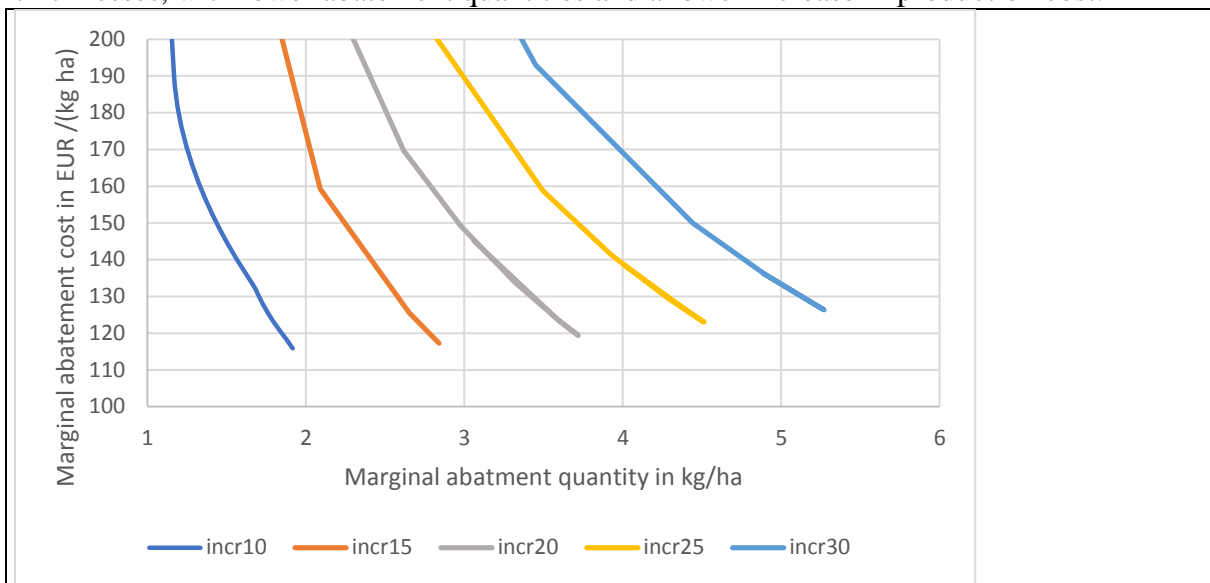
Section 3.2.1 presents the marginal abatement cost curves (MACC) of measures to increase the film thickness, with the marginal abatement cost plotted as a function to the film thickness. To estimate the marginal cost we requested information on mulch film prices from two experts from two retailers selling mulch film to the producers: ) HADI (2020) and Raiffeisen Gartenbau (2020). We retrieved the information on prices for Polyethylen (PE) plastic mulch films of the thickness 12, 30, 40, 50 µm (HADI 2020) and 20, 30, 40, 50 µm (Raiffeisen Gartenbau, 2020). We orient our estimation to prices provided by Raiffeisen Gartenbau (2020), to consider one single source. We derive the marginal material costs based on the thicknesses 20, 30, 40, 50 µm by linearly interpolating between these data. We that the different in prices between 20 and 30 µm and 40 and 50 µm, is bigger than between 30 and 40 µm. To simplify the simulation we apply the same increase to all levels of thickness (i.e., 22.1 EUR µm<sup>-1</sup>ha<sup>-1</sup>t to obtain a linear function. A non-linear increase might better reflect reality but creates challenges for the interpretation of the results. Therefore, we consider the simple functional form to describe the increase of prices caused by increased thickness.

**Table A-3.2.1** Increase of cost for increased film thickness EUR ha<sup>-1</sup> based on information provided by Raiffeisen Gartenbau, 2020 (not fitted) and fitted for simplified assumptions (fitted)

Cost for film of thickness	Cost for film EUR ha <sup>-1</sup>	Increase to film thickness						
		20 µm	25 µm	30 µm	35 µm	40 µm	45 µm	50 µm
		520	630.5	741	803	865	975.5	1086
<b>Increase by thinkness</b>	not-fitted							
	1 µm		22.1	22.1	12.4	12.4	22.1	22.1
<b>Increase by thinkness</b>	fitted							
	1 µm		22.1	22.1	22.1	22.1	22.1	22.1
	5 µm			111	111	111	111	111

10 µm	221	221	221	221	221
15 µm		332	332	332	332
20 µm			442	442	442

Figure A-3.2.1-1 displays the MACC for different levels of increase with the corresponding quantity of abated plastic. For the targeted abatement quantity between 3 and 3.7 kg ha<sup>-1</sup>, the increase by 20 µm is preferable to the increase by 25 and 30 µm. An abatement quantity higher than 4 kg ha<sup>-1</sup> can only be reached with increases of thicknesses by 25 and 30 µm. The optimal level of abatement might lay between an increase of 25 µm and increases by lower thicknesses, with lower abatement quantities and a lower increase in production cost.

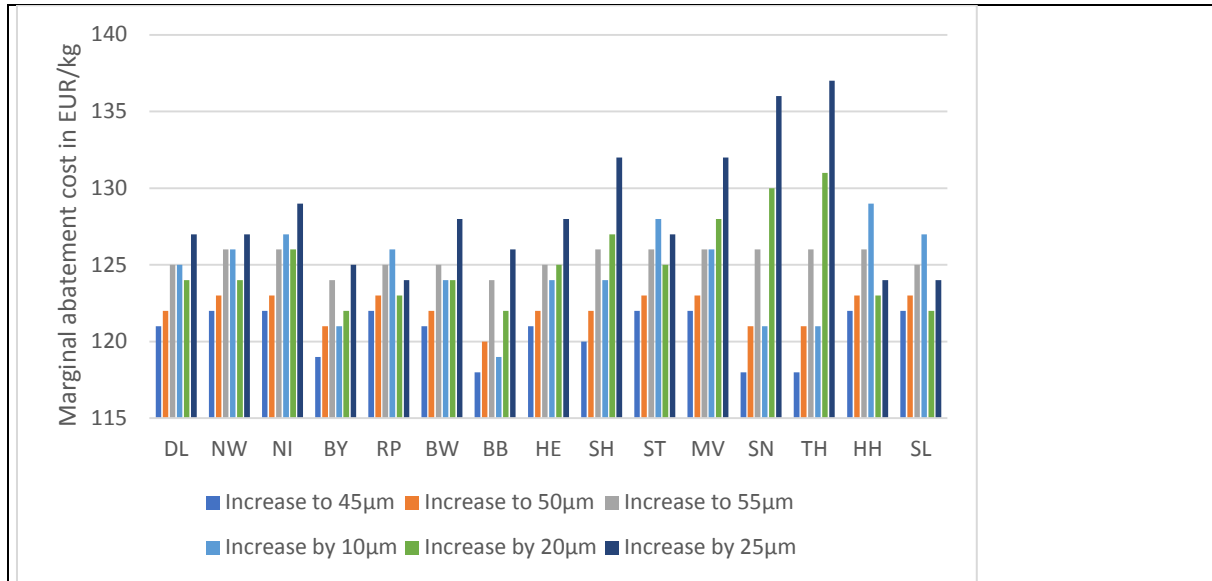


**Figure A-3.2.1-1** Marginal abatement costs related to marginal abatement quantity

Notes: incr10 = increase by 10 µm, incr15 = increase by 15 µm, , incr20 = increase by 20 µm, , incr25 = increase by 25 µm, incr30 = increase by 30 µm

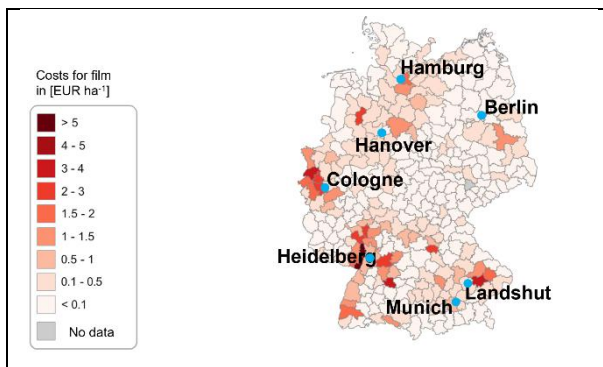
### Appendix A-3.2.2 Abatement effects and costs

Section 3.2.2 presents the results for abatement effect and cost at the sector level for Germany in table 5. Figure A-3.2.2-1 compares the marginal abatement costs of the simulated measures for Germany (DL) and the Federal States. The ranking by cost-efficiency at the national level (DL) can be found at the regional level for the biggest Federal states. The most cost-efficient measures for Germany and most of the Federal States are increasing the film thickness to 45 and 50 µm. In Bavaria (BY) and Baden-Württemberg (BW), where a large share of emissions result from cucurbits, increasing the thickness by 10 µm (i.e., for cucurbits from 35 to 45 µm) is the second best option. The results illustrate that the ranking of the first best abatement measures is comparable among all Federal States at the Federal State level. However, for ranking the fourth best cost-efficient option, the differences result from the specialisation of crop production in the Federal States.

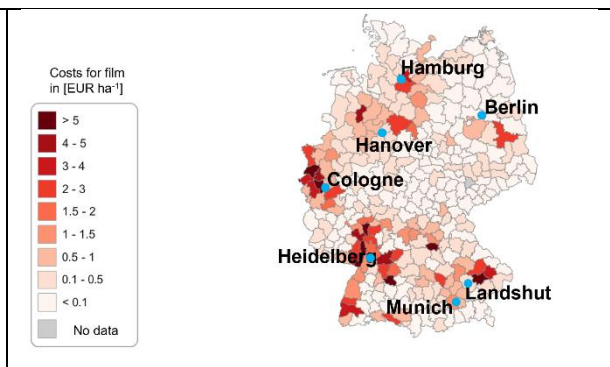


**Figure A-3.2.2-1** Marginal abatement cost of the scenarios in Germany and in the Federal States

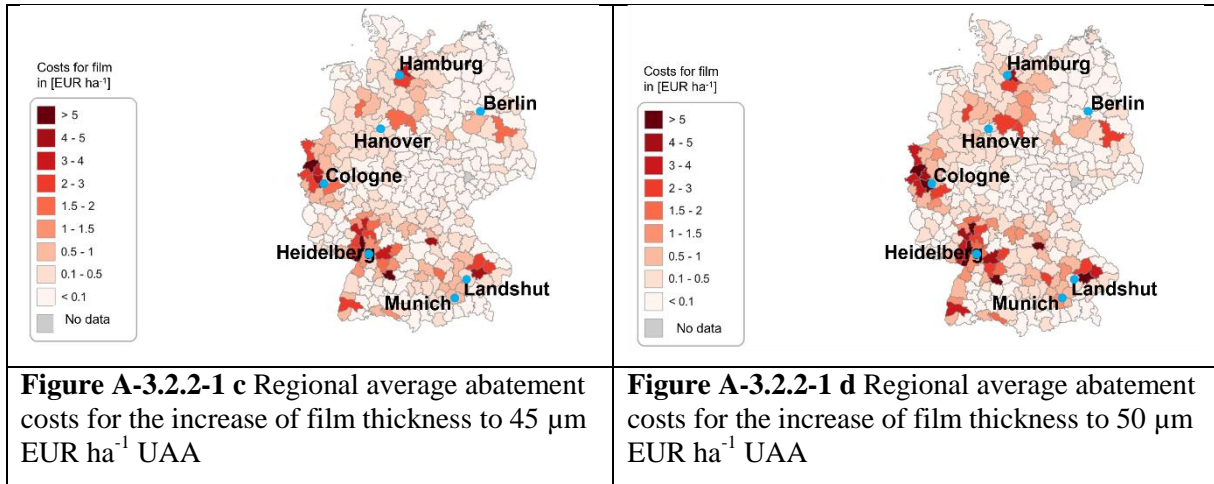
Section 3.2.2 presents with Figures 10a and b the results for average abatement and costs at regional (NUTS3) level exemplarily for the scenarios increase to 50 µm and increase by 20 µm. Figure A-3.2.2-1 a to d presents the regional costs of the measures strategies: increase to 45 and 50 µm and increase by 10 µm and 20 µm as a strategy from the other strategy. The average cost per hectare filmed production area is higher if production costs increase higher, i.e., for the increase to 50 µm and increase by 20 µm. The regional distribution, however, is very similar in all scenarios, as they are all determined by the regional crop production. The medium increase of 0.4 and 2 EUR/ha results from potatoes and strawberries in North-Western, South-West and South-East results. The higher increase (lager 3 EUR/ha) results from lettuce in Western (Rhine-Valley) and South-Western (Saarland), and North (Hamburg). The more significant increase (lager 3 EUR/ha) in Eastern from Berlin (Spreevald), in Baden-Württemberg (Heidelberg) and in Lower Bavaria result from increasing the mulch film thickness for jerking and other cucurbits.



**Figure A-3.2.2-1 a** Regional average abatement costs for the increase of film thickness by 10 µm EUR ha<sup>-1</sup> UAA



**Figure A-3.2.2-1 b** Regional average abatement costs for the increase of film thickness by 20 µm EUR ha<sup>-1</sup> UAA



### Appendix A-3.2.3 Production cost and consumer price

Section 3.2.3 presents in Table 11 The impacts on gross margin and change in market prices of the simulated scenarios for the key results and data. Table A-3.2.3-1 and Table A-3.2.3-2 presents all data.

**Table A-3.2.3-1** Changes in production costs

			incr00	incr to 45	incr to 50	incr to 55	incr to 70	incr by 10	incr by 20	incr by 25
Production cost [EUR/kg]	pota	a	0,08	0,09	0,09	0,09	0,10	0,08	0,09	0,09
	curc	b	0,40	0,40	0,40	0,40	0,41	0,40	0,40	0,40
	lett	c	0,29	0,30	0,30	0,30	0,31	0,29	0,30	0,30
	stra	d	3,24	3,26	3,29	3,31	3,38	3,29	3,33	3,36
Film cost [EUR/kg]	pota	a,e,f	0,013	0,036	0,039	0,041	0,049	0,031	0,036	0,039
	curc	b,e,f	0,007	0,017	0,018	0,019	0,022	0,016	0,018	0,019
	lett	c,e,f	0,011	0,030	0,032	0,035	0,041	0,026	0,030	0,032
	stra	d,e,f	0,185	0,393	0,416	0,439	0,509	0,416	0,463	0,486
Share film cost of production cost [%]	pota	a,e,f	17,18	42,30	43,99	45,59	49,87	38,59	42,30	43,99
	curc	b,e,f	1,67	4,14	4,41	4,67	5,45	3,88	4,41	4,67
	lett	c,e,f	3,75	10,19	10,84	11,48	13,35	8,87	10,19	10,84
	stra	d,e,f	5,71	12,05	12,67	13,28	15,06	12,67	13,88	14,47
Change production cost [%]	pota	a	0,00	13,75	17,18	20,62	30,93	6,87	13,75	17,18
	curc	b	0,00	0,84	1,11	1,39	2,23	0,56	1,11	1,39
	lett	c	0,00	3,00	3,75	4,50	6,75	1,50	3,00	3,75
	stra	d	0,00	0,71	1,43	2,14	4,28	1,43	2,86	3,57
Change production cost [EUR/kg]	pota	a	0,00	0,01	0,01	0,02	0,02	0,01	0,01	0,01
	curc	b	0,00	0,00	0,00	0,01	0,01	0,00	0,00	0,01
	lett	c	0,00	0,01	0,01	0,01	0,02	0,00	0,01	0,01
	stra	d	0,00	0,02	0,05	0,07	0,14	0,05	0,09	0,12
Change market price [%]	pota	a	0,00	4,44	5,55	6,66	9,99	2,22	4,44	5,55
	curc	b	0,00	0,90	1,20	1,50	2,41	0,60	1,20	1,50
	lett	c	0,00	1,64	2,05	2,46	3,68	0,82	1,64	2,05
	stra	d	0,00	0,65	1,30	1,95	3,90	1,30	2,60	3,25

Notes: a) LfL (2022c), b) LfL (2022a), c) SMEKUL (2022), d) LfL (2022b), e) HADI (2020) and Raiffeisen Gartenbau (2020), f) LWG (2019), aspa = asparagus, stra = strawberries, curc = cucurbits, lett = lettuce, pota = early potatoes.

**Table A-3.2.4-2** Changes in gross margin

			incr00	incr to 45	incr to 50	incr to 55	incr to 70	incr by 10	incr by 20	incr by 25
Variable cost [EUR/ha]	pota	a	3230	3674	3785	3896	4229	3452	3674	3785
	curc	b	39859	40192	40303	40414	40747	40081	40303	40414
	lett	c	14802	15246	15357	15468	15801	15024	15246	15357
	stra	d	15549	15660	15771	15882	16215	15771	15993	16104
Revenue [EUR/ha]	pota	a	9996	9996	9996	9996	9996	9996	9996	9996
	curc	b	36920	36920	36920	36920	36920	36920	36920	36920
	lett	c	27116	27116	27116	27116	27116	27116	27116	27116
	stra	d	17088	17088	17088	17088	17088	17088	17088	17088
Gross margin [EUR/ha]	pota	a	6766	6322	6211	6100	5767	6544	6322	6211
	curc	b	-2939	-3272	-3383	-3494	-3827	-3161	-3383	-3494
	lett	c	12314	11870	11759	11648	11315	12092	11870	11759
	stra	d	1539	1428	1317	1206	873	1317	1095	984
Change in gross margin [EUR/ha]	pota	a	0	-444	-555	-666	-999	-222	-444	-555
	curc	b	0	-333	-444	-555	-888	-222	-444	-555
	lett	c	0	-444	-555	-666	-999	-222	-444	-555
	stra	d	0	-111	-222	-333	-666	-222	-444	-555
Change in gross margin [%]	pota	a	0	-7	-8	-10	-15	-3	-7	-8
	curc	b	0	-11	-15	-19	-30	-8	-15	-19
	lett	c	0	-4	-5	-5	-8	-2	-4	-5
	stra	d	0	-7	-14	-22	-43	-14	-29	-36
Gross margin after price increase [EUR/ha]	pota	a	6766	6766	6766	6766	6766	6766	6766	6766
	curc	b	-2939	-2939	-2939	-2939	-2939	-2939	-2939	-2939
	lett	c	12314	12314	12314	12314	12314	12314	12314	12314
	stra	d	1539	1539	1539	1539	1539	1539	1539	1539

Notes: a) LfL (2022c), b) LfL (2022a), c) SMEKUL (2022), d) LfL (2022b), e) HADI (2020) and Raiffeisen Gartenbau (2020), f) LWG (2019). aspa = asparagus, stra = strawberries, curc = cucurbits, lett = lettuce, pota = early potatoes.

## Appendix A-4 Conclusion

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## Appendix A-5 References

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