THE ECONOMICS OF
LAND DEGRADATION

ELD Initiative:
Reducing Wildfires in Georgia

A Cost Benefit Analysis of Agricultural Burning Practices in the Dedoplistskaro Municipality, Georgia

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ALTUS IMPACT

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List of Abbreviations

a	Annuity factor
AFOLU	Agriculture, Forestry and Other Land Use
B	Above ground biomass
BAU	Business as Usual
BCR	Benefit Cost Ratio
CBA	Cost Benefit Analysis
CE	Choice Experiment
EANB	Expected Annual Net Benefit
EANC	Expected Annual Net Cost
ETo	Evapotranspiration
Ha	Hectare
GEL	Georgian Lari
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HI	Harvest Index
IRR	Internal Rate of Return
LR	Likelihood Ratio
MoENPR	Georgian Ministry of Environment and Natural Resource Protection
NPV	Net Present Value
PV	Present Value
r	The discount rate
SCC	The Social Cost of Carbon
t CO_2-eq	Tonnes of carbon dioxide equivalent emissions
Tr	Crop Transpiration
USD	United States Dollar
WTP	Willingness To Pay
WTA	Willingness to Accept compensation
WP	Crop Water Productivity

Table of contents

Executive summary

Crop residue burning has proven to be an inexpensive and effective way of managing excess straw stalks, controlling weeds and certain pests. There is, however, ample and mounting evidence that excess burning could jeopardise the long-term quality of the soil and affect the profitability of farming systems (Fasching 2001).

Crop residue, if left, can provide a protective layer for soil erosion by wind or water, increase the organic matter and water holding capacity of the soil, and provide "feed and forage" for earth worms. When crop residue is burned, all these benefits are lost and other damage may be done (Holmgren et al. 2014). What 'other damage' can look like was witnessed in the Shiraki valley in Dedoplistskaro Municipality in Georgia in the summer of 2015 when wildfires swept the 34,000 hectares of arable land and destroyed the majority of windbreaks in the area.

At the national level, this event has precipitated interest in tightening government regulation around crop residue burning in Georgia. As mentioned above, burning has both positive and negative impacts. To understand the relative weight of these impacts, the Georgian Ministry of Environment and Natural Resource Protection (MoENPR) deemed it necessary to undertake a rigorous economic assessment of the true economic costs and benefits of burning compared to that of no-burning. This study was carried out by the Programme "Integrated Biodiversity Management, South Caucasus" of Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

With focus on the Shiraki valley and the Dedoplistskaro municipality in Georgia, the study presented within this report assesses the consequences of terminating crop residue burning on ecosystems and livelihoods. The main results hereof are summarised for a 10-year time horizon and using a 4 per cent discount rate.

Through a combination of satellite imagery and farmers' own elicited practices, we find that approximately 10,000 hectares of arable land are burned yearly in Dedoplistskaro. Using a projection of possible fire events in the future and an established relationship between agricultural fires and windbreak mortality, it is demonstrated that remaining windbreaks in Dedoplistskaro will be lost within less than 10 years if no policy action is taken.

This has negative impacts on livelihoods. Using a stated preference valuation survey with 300 farmers in the Dedoplistskaro district, we showed that the average farmer would experience an average annual present value welfare loss for both small and large farmers of 6.4 Georgian Lari (GEL) per year[1] over the 10-year time horizon if remaining windbreaks were to be lost.

The valuation exercise also showed that 70% of all farmers would prefer a legally enforced ban of crop residue burning and that the ban would deliver an Expected Annual Net Benefit (EANB) of GEL 36 to 38 per hectare land cultivated,[2] with small farmers enjoying the slightly larger EANB.

This implies that farmers – whether small or large – have a preference for using collective action through enforcement rather than voluntary action to better protect them and Shiraki valley landscapes and soils against damages from fires originating on other farms.

Secondly, using a detailed agronomic analysis, including laboratory tests and the soil sampling on farms with different land management practices, it is shown that ending burning leads to several improvements in soil parameters. These include:

- Increased soil porosity and soil organic matter;
- a reduction of water evaporation and crust formation; and
- enhanced water retention capacity of the soils.

This latter effect has a particularly beneficial impact on agricultural yields given the low precipitation levels in the summer. In particular, using a water-crop balance model, we find that:

[1] *1 GEL= 0.43 USD (2016).*

[2] *Expressed in terms of willingness to pay for a higher land registration fee, which is essentially a tax per hectare of farmland cultivated.*

- Farmers who occasionally burn residues can obtain increases in yield of approximately 11 per cent within three years after they stop residue burning if they integrate straw in the soil as opposed to burning it;
- Farmers who burn on an annual basis can obtain increases in yields of approximately 23 per cent within three years after they stop burning.

Small (less than five hectares) and large farmers (five hectares or larger) face different rental costs of machinery that can be used to collect straw residue or integrate it into the soil. Large farmers, however, burn more frequently than small farmers. Accounting for these differences, whilst using 2015 farmgate market prices for cereals, we find that:

- Small farmers who stop burning and integrate crop residue in the soil can expect on average an additional annual net benefit of GEL 78 per ha, whilst large farmers can expect GEL 105 per ha in annual net benefits.[3] Expressed in terms of the Benefit Cost Ratio (BCR), for every additional GEL invested in crop residue integration, small and large farmers can expect respective GEL 3.7 and GEL 5.2 of benefits (Table S.1 and S.2);
- Farmers may also decide to collect and compress crop residue in straw bales and sell them. Using lower-bound farmgate market prices for straw, the EANB of collecting straw over a 10-year horizon is GEL 147 per ha per for large farmers, using conservative straw prices. Small farmers, however, have inferior agricultural yields, higher machine rental costs and face lower straw bale sale prices. With an average loss of GEL 5 per ha, this makes it uneconomical for the average small farmer to collect, compress and sell straw bales (Table S.1).

Finally, the termination of crop residue burning will also lower greenhouse gas emission from crop residue burning itself and from the reinforced protection of windbreaks. The global benefits in terms of avoided climatic damages from these emissions amount to GEL 4.4 million over a 10-year period for the whole of the Shiraki valley.

Bringing together all these benefits, whilst accounting for the additional costs of shredding,

TABLE S.1

EANB (GEL), NPV (GEL) and Benefit-Cost Ratios (BCR) for small farmers under a ban on burning scenario

Small farmers	EANB/ha	NPV/ha	NPV district wide	BCR
Ecosystem service benefits from not burning				
Residue retention and integration in soil (100%)	78	632	0.8 million	3.7
Collection and sale of straw residues (100%)	- 5	-40	- 32’000	0.9
Welfare economic impacts from a ban of burning				
Welfare benefit from ban of residue burning	38	306	489600	N/A*
Protection of remaining hedges	6.8	56	89600	N/A*
Aggregate net-benefits				
Burning banned and all residues are integrated in the soil	**123**	**994**	**1.1 million**	**5.2**

**Assuming that government authorities bear the costs of prohibiting burning, there is no cost involved for farmers.*

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[3] *Also known as annuity values, which is equivalent to the present value the average annual additional income generated over the 10-year accounting period.*

TABLE S.2

EANB (GEL), NPV (GEL) and Benefit-Cost Ratios (BCR) for large farmers under a ban on burning scenario

Large farmers	EANB/ha	NPV/ha	NPV district wide	BCR
Ecosystem service benefits from not burning				
Residue retention and integration in soil (100%)	105	855	7.8 million	5.2
Collection and sale of straw residues (100%)	147	1196	11.0 million	2.4
Welfare economic impacts from a ban of burning				
Welfare benefit from ban of residue burning	36	295	5.4 million	N/A*
Protection of remaining hedges	6.8	56	1.0 million	N/A*
Aggregate net-benefits				
Burning banned and all residues are integrated in the soil	**148**	**1206**	**15.8 million**	**6.9**
Burning banned and all straw collected and sold	**190**	**1547**	**17.4 million**	**2.9**

**Assuming that government authorities bear the costs of prohibiting burning, there is no cost involved for farmers.*

TABLE S.3

Aggregate EANB (GEL), NPV (GEL) and Benefit-Cost Ratios (BCR) for farmers, the Georgian and global society

Societal net-benefits	EANB/ha	NPV/ha	NPV district wide	BCR
Farmers as a whole	**166**	**1343**	**16.9 million**	**3.8**
Georgian society			**16.8 million**	**4.4**
Global society, including carbon sequestration			**21.2 million**	**5.3**

**Assuming that 8% and 92% of land in Dedoplistskaro district is cultivated respectively by small and large farmers (as revealed by the household survey undertaken for this study), and that large farmers adopt a mixed strategy of collecting half the straw and integrating the other half.*

integrating or collecting crop residues and enforcing a policy to ban crop residue burning, we find a global net benefit from a ban on burning in Dedoplistskaro district to be in the order of GEL 21.2 million in net present value (NPV) terms over a 10-year period. This figure includes the social benefits of avoided carbon emissions. The societal NPV benefit to Georgia amounts to GEL 16.8 million. Assuming that small farms retain and integrate all crop residues in the soil (Table S.1), the NPV over a 10-year period for small farmers is GEL 994 per hectare cultivated, while large farmers can expect to enjoy a NPV benefit of between GEL 1206 and 1547 per hectare depending on whether they decide to sell straw or retain it in in the soil (Table S.2). It should be kept in mind though, that these results are sensitive to the actual level of enforcement of the ban on burning by authorities, the decisions made by farmers regarding what they do with the leftover straw after harvest, as well as changes in farm gate market prices for straw bales, wheat and machinery rental costs.

Conclusively, a ban on crop residue burning is a policy that can bring significant net benefits in terms of improved protection of windbreaks, carbon sequestration, soil fertility and sense of well being amongst the majority of farmers. However, in order to more effectively confront the challenges of the agricultural sector in Dedoplistskaro, the avoidance of burning should ideally be adopted as part of a package of sustainable land management practices, including integrated pest management, conservation or no-tillage and frequent crop rotations. This will enhance soil biota, fauna and flora, food security and livelihoods in Dedoplistskaro, while favouring the mitigation and adaption to climate change.

CHAPTER

01

Introduction

Fire is used extensively in agricultural practices around the world, contributing to an estimated 8–11 per cent of global fires. On a regional basis this proportion can be significantly higher. The Russian Federation, for example, is the largest contributor to agricultural burning globally producing 31–36 per cent of all agricultural fires (Korontzi et al. 2006). Georgian farming systems are no exception – fire is used extensively during pre planting and post harvesting periods from May to October (see Figure A1.2 in Appendix 1). Agricultural burning is undertaken to clear crop residue, eliminate pests and weeds and is often a firmly entrenched cultural practice (Ekboir 2002). If poorly managed, fires pose risk to agricultural and natural ecosystems, cultural values, properties and human health. Despite the prevalence of this practice, little is known – at global or local level – about the impacts of fires on biodiversity and livelihoods.

In the summer of 2015, large-scale destructive wildfires swept the so-called "wheat basket of Georgia". They originated from farmers practicing open field burning of crop residues. In the aftermath of this event, the Georgian Ministry of Environment and Natural Resource Protection (MoENPR) began the process of drafting a law to ban crop residue burning. Enforcing such a policy, however, would need to be justified on economic and ecological grounds. This study was assigned by MoENPR and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in order to assess the associated economic and ecological benefits and costs of a ban of burning.

In response to this, the study elaborated in this report has been conceived to value the impacts of implementing and enforcing a ban of crop residue burning. To do so, agronomic field data, laboratory testing and different economic valuation methods are combined to estimate the economic benefits and costs to society and farmers alike. The main results are presented in the following section, starting with an overview of the case study area, followed by a presentation of the methodology used (Chapter 2), an assessment of the biophysical and ecosystem services impacts (Chapter 3) and a subsequent economic valuation of these impacts (Chapter 4). The results are finally aggregated and the relevant scenarios presented (Chapter 5). Chapter 6 and 7 contextualise the results and draw conclusions. The time frame for the analysis is 10 years, (2017-2026) using an interest rate of four per cent and presuming that the policy could be enacted in 2017. The actual study was undertaken from the end January 2016 to June 2016.

1.1 Case study area

Georgia is situated in the South Caucasus, between latitudes 41° S and 44° N, and longitudes 40° W and 47° E, covering an area of 67,900 km^2 and has a total population of 3.7 million (Geostat Census 2014). Georgia is divided into 9 regions and 69 municipalities. Dedoplistskaro is one of them, located within the region of Kakheti. It has a population of 21,221 (Geostat Census 2014) and covers an area of 2,529 km^2 (80,000 ha). 74 per cent of Georgia's wheat is produced in Kakheti, and within Kakheti the main wheat growing area is Shiraki valley located in Dedoplistskaro Municipality (see Figure 1). Barley, sunflower and wine is also grown in the valley, as well as some pastures under private ownership. Figure 2 shows the proportion of land dedicated to different farm systems on the basis of a valuation survey undertaken in relation to this project (see Chapter 3 for more information).

The valley covers a total of 43,000 ha of which 34,000 ha is arable land. With its very fertile and deep soils with high humus content, the valley has ideal farming conditions. However, the combination of warmer climates, more frequent droughts, strong winds, the degradation of windbreaks and non-sustainable agricultural practices, including crop residue burning, have led to reduced agricultural yields in the past decades (Camacho et al. 2015).

In Georgia as a whole, about a third of its three million hectares of agricultural land is affected by soil erosion, 11 per cent is affected by acidity, 8 per cent by waterlogging due to malfunctioning drainage systems, 5 per cent is affected by excessive potassium and nitrates, and another 20–40 per cent is affected by salinity (World Bank 2007). With low levels of productivity, a variable climate and high reliance on rain fed agriculture, Georgia has a significant food security risk. Additionally, the increasing occurrence of extreme dry spells and heat waves currently observed, as well as climate modelling-based predictions, suggest that extreme weather periods favouring the recurrence of more frequent and larger fires and higher associated damages will aggravate in the coming years and decades (GFMC 2015).

In this context, it is imperative that climate change adaptation options that give the greatest return on investment from an economic, social and environmental perspective are prioritised. In the remainder of this paper, we investigate the economic case for terminating the use of post-harvest burning of crop residues in Georgia.

The social and economic consequences of agricultural fires have received comparatively little attention in Georgia media and literature, despite the scale of the practice and its implication for climate, nature and livelihoods. It is therefore due time that a study of this kind is undertaken to help clarify grey zones, specifically with regard to farmers' preferences and agricultural productivity.

FIGURE 1

Location of Shiraki Valley in Dedoplistskaro Municipality of Georgia
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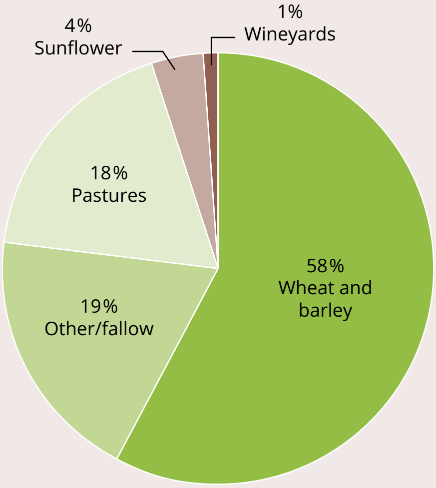
FIGURE 2

Share of types of land use in Shiraki valley



CHAPTER

02

Methodology and research methods

2.1 Terminology

Agricultural burning affects a range of ecosystem goods and services, in addition to marketable goods such as straw. It is thus of relevance to undertake a comprehensive economic valuation of both the market and non-marketable goods and services impacted by burning. This is operationalised using cost benefit analysis (CBA).

In CBA, benefits and costs are expressed in monetary terms, then adjusted for the time value of money so that all flows of benefits and flows of project costs over time (which tend to occur at different points in time) are expressed on a common basis in terms of their net present value.

To derive the **Net Present Value (NPV)** of a given land use system, for each year, costs are subtracted from benefits and discounted using the interest rate of r to reflect the net-benefits in present value terms. These are then summed up to derive a NPV for the total time horizon (T) that is being evaluated (Equation 1).

In general, policy initiatives with positive NPV should be considered: the greater the NPV, the more justifiable the initiative.

The **benefit cost ratio (BCR)** is another convenient criterion that can be used to judge the relative of interest in one land use or policy scenario vis-à-vis the other. It is the ratio of the benefits of a project, expressed in discounted present values, relative to its costs, also expressed in discounted present values (Equation 2), where r is the interest rate.

The Expected Annual Net Benefit (EANB) also known as the annuity value, is equivalent to the present value the average annual additional income or welfare benefit generated over the 10-year accounting period. It has the same NPV as the project itself. The EANB of a project is computed by dividing the NPV by the appropriate annuity factor, atr according to Equation 3.

Where the annuity factor is the present value of an annuity of GEL 1 for the life of the project (10 years), and r = interest rate used to compute the NPV.

The **Internal Rate of Return (IRR)** on an investment or project is the rate of return that makes the NPV of land use cash flows equal to zero. It is the discount rate at which an investment breaks even, that is, the rate at which present value of all future revenues is equal to the initial investment. In this report, the IRR is only used in the financial analysis of the pellet producing facility.

For further background on ecosystem service valuation methodology please see the user-guide developed by the Economics of Land Degradation (ELD) Initiative (2015).

EQUATION 1

$$NVP = \sum_{t=0}^{T} (B_t - C_t) / (1+r)^t$$

EQUATION 2

$$BCR = \sum_{t=0}^{T} \frac{Benefits_t / (1+r)^t}{Costs_t / (1+r)^t}$$

EQUATION 3

$$EANB = \frac{NVP}{a^t{}_r}$$

2.2 The discount rate

The discount rate is a critical parameter in cost benefit analysis whenever costs and benefits differ in their distribution over time, especially when they occur over a long time period. In selecting the discount rate, we have used a so-called descriptive approach, based on the opportunity cost of drawing funds from the private or the public sector.

Accordingly, the cost of investing a Georgian Lari (GEL) in land management systems without burning today is the value that each Lari would have produced in its alternative use. Therefore, for no-burn to be worthwhile at the societal level, the invested capital should grow more than if the "Lari" had been invested elsewhere. This expectation is reflected through the use of positive interest rates when evaluating NPV and BCRs.

The real rate of interest is equal to the nominal lending interest rate adjusted for inflation. The real rate of interest is the appropriate discount rate for cost benefit analysis. Most variations in nominal rates are due to changes in inflationary expectations since the rate of return on capital (e.g. factories, equipment) is fairly stable over time.

Currently, the actual inflation rate in Georgia is 3.5 per cent and the nominal interest rate is 7.5 per cent. The real interest rate approximate is thus 4 per cent. The inflation rate has ranged between 3–5 per cent since July 2014[4] and was approximately 4 per cent during most of 2015. The National Bank of Georgia kept its refinancing rate unchanged for the third consecutive time at 8 per cent in April 2016. Tight monetary policy has helped to stabilise national currency and inflation expectations have eased. 4 per cent is therefore considered a stable benchmark to use for the costs and benefit calculated throughout this paper. The sensitivity of results to changes in the discount rates is also estimated in Chapter 5.

2.3 The accounting period

A 10-year time horizon has been chosen for the valuation study. Even though the ending of burning will have very long-lasting consequences, it was considered that national decision-makers and farmers alike are most concerned about the immediate future. We have therefore opted for a relatively short time horizon of 10 years.

2.4 Scenarios

In terms of how future land use and burning practices may evolve, we assess two different possible scenarios. Either there is 'no change' relative to today (BAU – "business as usual"), that is, farmers continue to burn if and when they would like to without any legal consequences. Under the BAU, individual farmers may also voluntarily decide to stop burning residues and integrate and/or collect straw residues. But voluntary action does not guarantee a farmer from not being affected by the fires of neighbouring farmers. In the alternative scenario, the government enacts a law to ban crop residue burning. In that case, farmers can decide to integrate leftover crop residues in the ground, collect and sell them or do a combination of the two. It is also possible that alternative uses, such as fuel pellets can be made from the straw residues that are collected provided adequate investments into pellet producing facilities (see Chapter 5). On this basis, the valuation study considers two different valuation scenarios, namely:

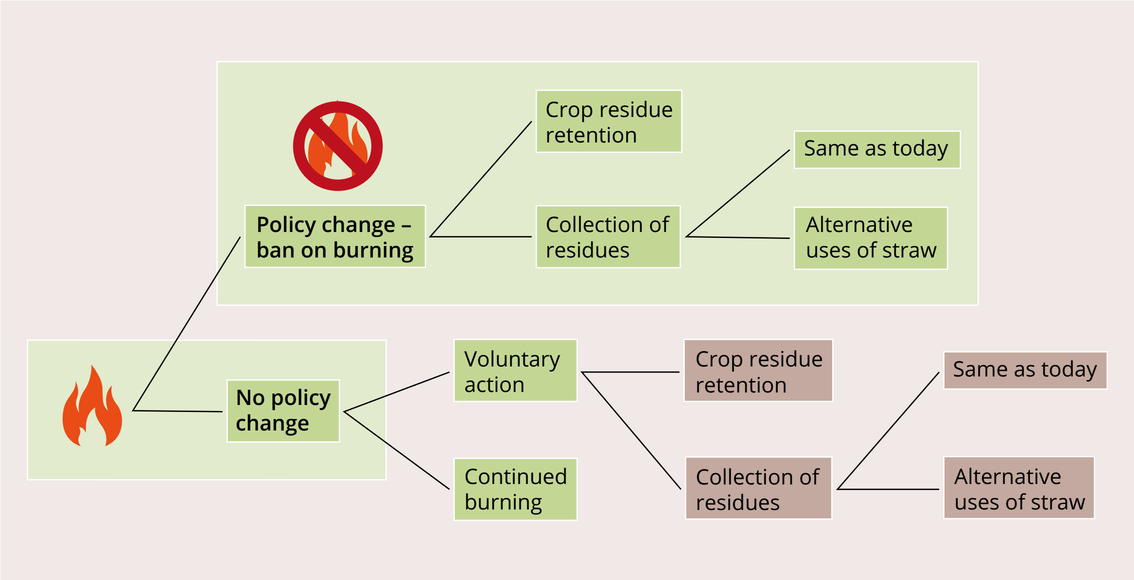
- **BAU scenario:** No change, a simple continuation of the BAU;
- **Ban on burning scenario:** A legal action to prohibit crop residue burning. Small and large farmers stop burning and decide to integrate residues in the soil, and/or collect, compress and sell straw bales depending on the benefits and costs of each activity.

The latter scenario is valued relative to the former BAU. The valuation scenarios are illustrated in Figure 3.

[4] *IIECONOMICS.com/Georgia-inflation-rate-forecast.*

FIGURE 3

The policy scenarios under consideration



2.5 Ecosystem services and social impacts being valued

Agricultural fires have many direct and indirect impacts on ecosystems, biodiversity and people's livelihoods. It is beyond the scope of any CBA to account for all occurring impacts. The first part of the study therefore served to define which crucial goods and services were to be valued. That was done during a workshop with both national and local decision makers (see Appendix 2 for further details). Following these workshops it was decided that the following elements should be assessed:

- The value of protecting remaining windbreaks from fires;
- The benefits and costs to farmers associated with shredding, integrating and/or collecting and selling residues as opposed to burning them;
- The impact on carbon emissions from a prohibition of crop residue burning;
- The economic feasibility of developing alternative uses of straw;
- Farmers' true preferences over residue management and how much they would need to be compensated or would be willing to pay to forego the burning of crop residues.

2.6 Questionnaire design and data collection

In order to value the abovementioned ecosystem services and livelihood aspects, a detailed valuation survey was implemented with 300 randomly selected farmers in Dedoplistskaro Municipality between March and April 2016.[5] The survey had several aims:

- First, to have an understanding of the characteristics of the farms within Shiraki valley;
- Secondly, to understand the economic values associated with restoring windbreaks; and
- Thirdly, to assess the welfare economic impacts of implementing a policy that prohibits the burning of crop residues.

Data collection was undertaken using face-to-face interviews conducted on the farms. Each interview lasted on average 45 minutes. The population from which the sample was selected included farmers cultivating more than 0.5 ha of land and living within the Dedoplistskaro municipality, approximately 4,820 farmers. Descriptive statistics of the households are provided in Appendix 3. The study involved interviewing 300 randomly sampled farmers so as to achieve 95 per cent confidence level for sample statistics. In collecting a sample that reaches a desired level of statistical precision,

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[5] *Dedoplistskaro municipality and the villages: Arboshiki, Mirzaani, Samtatskaro, Zemo Qedi, Arkhiloskalo, Qvemo Qedi, Samreklo, Sabatlo, Gamarjveba, Khornabuji, Pirosmani, Zemo Machkhaani.*

[6] *Using formulae developed by United Nations Statistical Division (2008) that allows for the estimation of a target sample size for purposes of collecting data on a population with a desired level of statistical precision. The size of the target population relative to the total survey population plays a crucial role in the choice of a sample size.*

TABLE 1

Valuation methods and data types associated with benefits and costs used in this study

Benefits and costs of ending fires	Valuation method	Data
Protection of remaining windbreaks	Stated Preference	Remote sensing and valuation survey
Welfare impacts of burning on livelihoods	Stated Preference	Valuation survey
Changes in yields	Productivity change	Field study and lab experiments, and valuation survey
Changes in carbon emissions	Avoided costs	Remote sensing, valuation survey data and secondary data
Collection and sale of straw	Market prices	Valuation survey
Costs associated with the disposing of residues by other means than burning	Market prices	Valuation survey

Neuman (1991) suggests a ratio of 30 per cent for small populations (those under 1000); 10 per cent for moderately large populations (those of, say, 10,000) and 1 per cent for large populations (those over 150,000). But smaller samples can be justified when the underlying population is homogeneous (e.g. mainly agrarian), as is in the case of the Shiraki valley. For example, if the target population of agricultural households is believed to be 90 per cent of rural households, then the appropriate sample size to reach a 95 per cent confidence level for sample statistics would be approximately 300 (UNSD 2008).[6]

Statistical representation of our data is confirmed by holding up data from the household survey with census data. For example, 85 per cent of farmers in our sample own less than four hectares of land, which is similar to the proportion (83 per cent) found in Geostat census data from Dedoplistskaro (Geostat Census 2014). In our sample, we also find that 50 per cent of farmers cultivate five hectares or less, and 50 per cent cultivate more than five hectares, which also corresponds to the information provided by the mayor of Dedoplistskaro (Table A4.7, Appendix 4).

The first section of the questionnaire served to reveal information about the socio-demographic and economic characteristics of the farm households. The second part consisted of stated preference valuation exercises known as choice experiments and the third part sought to reveal more about farmers' land use practices and their attitudes about the burning of agricultural residues.

2.7 Data sources and valuation methods

The valuation study is largely informed by the household questionnaire. The data from the survey has been combined with data from secondary literature, satellite imagery and field and lab experiments. The marketable and non-marketable goods and services that we value in the following are shown in Table 1, including the valuation method that was used to value it and where the data inputs have come from.

CHAPTER

03

Biophysical changes associated with ending crop residue burning

This chapter focuses on assessing the biophysical and agronomic impacts of ending crop residue burning. This assessment then enables us in Chapter 4 to assess the economic implications of these impacts.

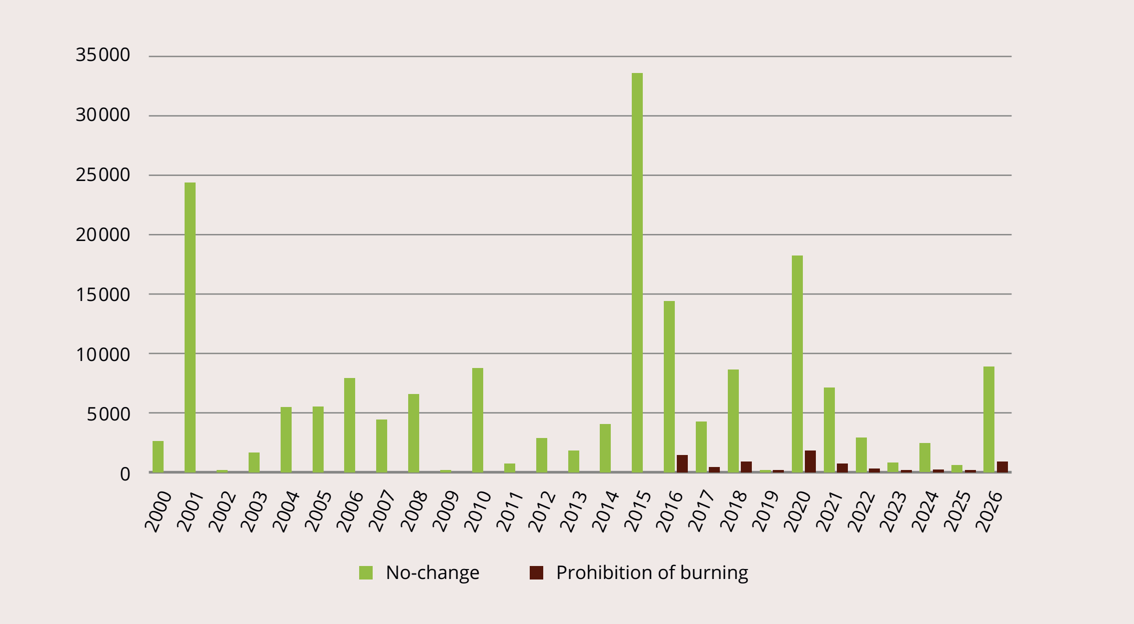
3.1 What ‘banning of fire’ implies for windbreaks

In order to project the possible incidence of fire hazards from 2017 to 2026 under a ‘no-change’ and ‘ban of burning scenario’, normally distributed random numbers were drawn from a distribution characterised by the same mean (6,917 ha) and standard deviation (8,990 ha) of observed fire events in Dedoplistskaro from 2000 to 2015 (Costa 2016; see Appendix 1). This method was used because past climatic data, agricultural yields and fire events did not allow us to establish any statistically significant and robust leading variables that we could use to predict future fire hazards. It was also not possible to infer a trend in wildfire events over the last 20 years (Costa 2016; see Appendix 1). The resulting distribution of the random draws is shown in Figure 4.

It should also be highlighted that even if burning is banned, it is unrealistic to assume that a ban of burning would lead to a complete termination of fires (Costa 2016, personal communication). In any one year, there may be non-intentional fires or farmers who ignore legislation. In the ‘ban of burning’ scenario it is therefore assumed that at least 10 per cent of the fires seen under a no-change scenario remain (Costa 2016).

FIGURE 4

Historical record of cropland burned in Shiraki valley and possible wildfire projection



EQUATION 4

$$\text{Windbreaks burned per ha cropland burned}_{2015} = \frac{55\,300\,\text{m of windbreak}}{33\,490\,\text{ha of wildfire}} = 1.65\ \frac{\text{m windbreak}}{\text{ha of cropland burned}}$$

EQUATION 5

$$\text{Remaining windbreaks}_{s,t} = \text{remaining windbreaks}_{s,t-1} - 1.65 * \text{ha of burned cropland}_{t}$$

3.2 Predicting the extent of windbreaks in the 'business as usual' and ban on burning scenario

The degradation of windbreaks started after the fall of the Soviet Union when the population of Dedoplistskaro began to cut trees to meet demand for fuel. Even though the pressure from the local population decreased as the people mostly buy fuel wood from the forest through local wood sellers (Helbig 2016), the windbreaks still continued to deteriorate because of the yearly agricultural burnings. Efforts were made to restore the windbreaks in the frame of the GIZ programme "Sustainable Management of Biodiversity, South Caucasus" with support of the Austrian Development Agency (ADA). The fires of 2015 severely damaged remaining windbreaks and restoration efforts by GIZ.

Windbreaks consist of rows of trees and shrubs planted along the edges of agricultural fields to protect crops and soil from strong winds (GIZ 2014). They improve the climate for crops growing in their shelter and provide nesting sites for birds that support natural pest control.

Prior to the collapse of the Soviet Union, there were 1,800 km of tree windbreaks in Shiraki valley (NFA). After the collapse of the Soviet Union, gas supplies were cut and the institutions that used to govern windbreaks broke down. Windbreaks thus belonged to the commons and as a result degraded quickly as households were cutting trees for heating. In 1999, there were 614 km of field windbreaks remaining, according to a map prepared by GIZ based on ortho-photos from 1999.[7]

The fires of summer 2015 had a particularly large toll on windbreaks. An area of more than 33,490 hectares of arable land burned. The wildfires were so large that fire trenches, roads and other infrastructures that normally protect windbreaks were ineffective. Field studies by GIZ revealed that out of the 68 km of windbreaks planted by GIZ, 55.5 km[8] or 83 per cent were destroyed (Klein 2015).

If there is no change in fire and land use management practices, with the current trend, the remaining windbreaks will soon be lost as well. This was also highlighted by local farmers during the stakeholder consultation in January 2016 (see Annex 5 with outcome of inception workshop). A ban of crop residue burning will help protect the existing windbreaks. In order to test that hypothesis, we used the wildfire scenarios (section above) to infer what will happen to windbreaks in a BAU scenario versus 'ban of burning' scenario.

According to a windbreak inventory by GIZ in Georgia, only 50 km of windbreaks remain in Shiraki valley (Weigel 2016). Detailed data from the windbreak inventory of the replanted windbreaks from 2015 is used to establish causality between wildfires and windbreak mortality (Klein 2015). From this data, it can be deduced (using Equation 3) that for every hectare of cropland burned, 1.65 m of windbreaks were destroyed. In that case, the extent of windbreaks that remain in year t, for the BAU and ban on burning policy scenarios can be estimated using Equation 4. Consulting the results in Table 2, it can be seen that if there is a BAU fire management regime, all windbreaks will have been destroyed within less than ten years. In the case that burning is prohibited however, even after ten years, 90 per cent of windbreaks will remain. To simplify the analysis, we have abstained from other factors that may influence the windbreaks, such as deliberate felling of trees. This is because we are essentially interested in valuing the changes resulting from reduced burning.

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[7] *Lasha khizanishvili.*

[8] *or 55 ha, as windbreaks restored by GIZ were 10 metres broad.*

TABLE 2

Lifeline of the remaining windbreaks in the baseline scenario and the 'no burn' scenario

	Hectares of burned cropland		Meters of remaining windbreaks	
Year	**BAU scenario**	**Ban on burning scenario**	**BAU scenario**[9]	**Ban on burning scenario**
2016	14,505	1,451.5	50,000	50,000
2017	4,221	422.1	40,425	49,042
2018	8,804	880.4	36,171	48,617
2019	25	2.5	29,546	47,955
2020	18,275	1,827.5	27,463	47,746
2021	7,290	729.0	15,937	46,594
2022	2,882	288.2	10,095	46,010
2023	791	79.1	6,534	45,653
2024	2,416	241.6	4,055	45,405
2025	604	60.4	735	45,074
2026	9,022	902.2	0	44,835
Average	**5,981 ha**	**591 ha**		

3.3 Avoided Greenhouse Gas emissions

Climate change poses a major risk for irreversible impacts on ecosystems and economic activity. Changing food production systems, rising sea levels, more incidences of droughts, floods, storms as well as biodiversity and species loss are the main expected direct impacts of climate change (Stern 2007). There is growing evidence of the scale and severity of the business-as-usual path of greenhouse gas (GHG) emissions. This evidence base provides the rationale for structural integration of climate change mitigation opportunities in project and policy design, including the question of whether or not the burning of crop residues should be allowed.

To assess how GHG emission levels may change as a result of invigorating a ban on burning the FAO EX ACT tool was used. EX-ACT is a land-based accounting system that relates activity data from Agriculture, Forestry and Other Land Use (AFOLU) sectors to estimated values of the five carbon pools: above ground biomass, below ground biomass, dead wood, litter and soil organic carbon. This way, EX-ACT derives values of carbon stocks, stock changes and emissions of CH_4, N_2O and CO_2. EX-ACT has been developed using mostly IPCC 2006 Guidelines for National Greenhouse Gas Inventories (IPCC) that furnish EX-ACT with recognised default values for emission factors and carbon values, the so-called Tier 1 level of precision (Smith et al. 2007). FAO's ex-ante carbon balance tool 'EX-ACT' measures GHG impacts per unit of land, expressed in tonnes of CO_2-equivalent emissions per hectare and year. It is able to account for changes in deforestation, afforestation and reforestation, land use change and conservation, land degradation, annual crop production and sustainable land management practices.

[9] *We assumed that windbreaks are on average of 15 m broad, especially those along the roads. In that case, 1 km of windbreak = 1.5 ha of windbreak. This relation is used to estimate avoided GHG emissions from the deforestation and burning of windbreaks.*

FIGURE 5A

Share of farmers who burn, burn occasionally and do not burn

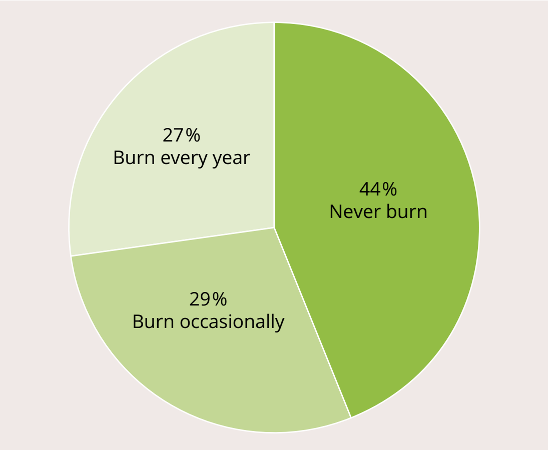
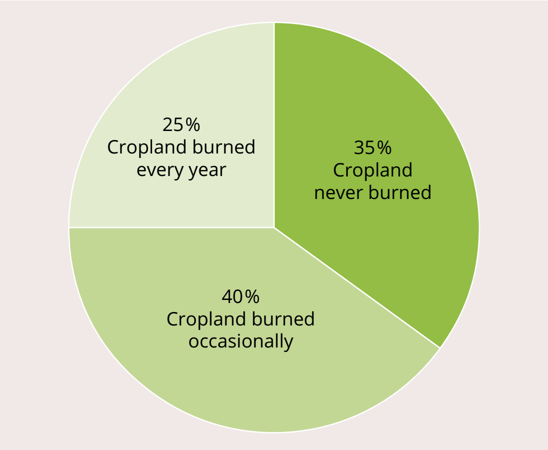


FIGURE 5B

Approximate share of farmland burned annual, occasionally and never



3.4 Extent of burning of crop residues on farmland

Data from the valuation survey was used to assess the prevalence of residue burning in Shiraki valley. From Figure 5a, it can be seen that 27 per cent of farmers burn every year, 29 per cent burn occasionally (every 2–3 years) and another 44 per cent never burn. For each of these farmer groups, we have studied the area of cereal land that is under their control to make an approximation about how much land that is burned occasionally, burned every year and never burned.

On this basis, we may infer that 25 per cent of farmland is burned every year, 40 per cent of the farmland is burned regularly (every 2–3 years) and 35 per cent is never burned by the farmer. Additionally, 25 per cent of farmers claim to be affected every year by the fires caused by neighbouring farmers (Figure 5b).

Using these statistics, it is fair to assume that at least 50 per cent of all cropland is burned in any one year when there are no 'extreme/uncontrolled' fire events like the 2015 event. That corresponds to about 10,000 ha since approximately 20,000 ha of

FIGURE 6

GHG emissions in the EX-Ante annual systems module

All GHG in tCO_2eq	Gross fluxes			Share per GHG of the Balance			
Components of the project	**BAU**	**No-burn**	**Balance**	**CO_2**		**N2O**	**CH4**
Land use changes				**Biomass**	**Soil**		
Deforestation	22,399	1,792	-20,607	-15,027	-5313	-120	-147
Agriculture – Annuals	31,300	3,130	-28,170	0	0	-7,797	-20,373
Total	53,699	4,922	-48,778	-15,027	-5,313	-7,917	-20,520
Per hectare	2.6	0.2	-2.4	-0.7	-0.3	-0.4	-1.0
Per hectare per year	0.3	0.0	-0.2	-0.1	0.0	0.0	-0.1

**Positive = source / negative = sink*

[10] *On average 5,981 ha per year derived from Table 2 plus an additional 4,000 ha, so as to arrive at 10,000 ha, which is the total estimated area of farmland that is burned every year on the basis of the farmer's own revealed practices.*

arable land is used for barley and wheat cropping (see Table A4.7, Appendix 4).

This is different to what is captured by MODIS satellite data (Appendix 1), indicating that an average of 6,000 ha is burned per year. This is also the data upon which future wildfire incidences are predicted (in Table 2). The discrepancy between what farmers reveal themselves and what is captured by satellite imagery can be explained by the fact that only fires larger than 2.5 km^2 are detected with MODIS satellite data which has a 500 m x 500 m resolution. In order to have a more realistic estimate to total cropland area burned, we have therefore upward adjusted by 4,000 ha the predicted extent of fire hazard on cropland.

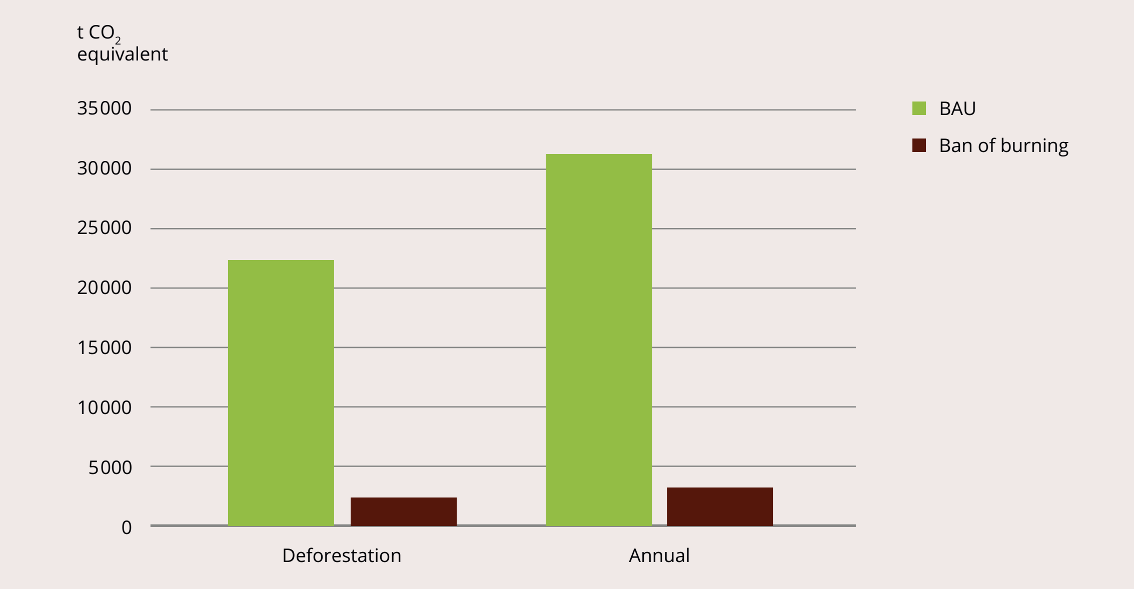
GHG emissions from the burning of crop residues consist of methane and nitrous oxide gases. Burning one hectare of crop residues generate on average 0.31 t CO_2-equivalent emissions. This estimate and those that follow have been computed within EX-ante's annual systems module (Figure 7) using IPCC Tier 1 Guidelines for National GHG Inventories (IPCC 2006).

In the BAU scenario, an average of 10,000 ha[10] of cropland is burned per year compared to only 10% if burning is banned. As a consequence, over an accounting period of 10 years, an estimated 28,200 t CO_2-eq emissions will be avoided per year (Figure 6). Figure 7 illustrates the CO_2-eq GHG emissions produced in ban of burning and BAU scenarios from annual crops (residues) and deforestation (windbreaks).

Fire induced deforestation release 303 t CO_2-eq per hectare of windbreak burned. Over an accounting period of 10 years, a total of approximately 20,000 t CO_2-eq emissions are avoided by protecting remaining windbreaks (Figure 8). Reduced emissions from avoided deforestation and residue burning will together result in the avoidance of approximately 49,000 t CO_2-eq emissions. The difference between emissions in the BAU and the ban on burning scenario are illustrated in Figure 8.

FIGURE 7

GHG emissions associated with deforestation of windbreaks and burning of residues in BAU and ban of burning scenario



[11] *This section draws heavily on Giorgi Ghambashidze (2016) with some modifications.*

3.5 Biophysical impact of fires on soil and agricultural yields

Fire significantly affects the physical, chemical and biological properties of soils and therefore also the yields and the livelihoods of those cultivating the soil.[11] The degree of alteration caused by fires depends on fire intensity and duration, which in turn depend on factors such as amount and type of fuels, air temperature and humidity, wind, topography; soil properties of moisture content, texture and organic matter content and properties of above ground biomass (DeBano et al. 1998). Effects of fire on soil include a loss of soil organic matter (SOM) (Albalasmeh et al. 2013), the altering and removal of above-ground vegetation and topsoil biomass, and increasing erodibility of soil (Carroll et al. 2007), which leads to subsequent shifts in plant and microbial populations (Janzen & Tobin-Janzen 2008).

The aim of the agronomic study (see Giorgi Ghambashidze 2016 for detailed analysis) was to assess possible changes in soil properties, particularly changes in soil organic matter and water retention capacity of soils resulting from the termination of crop residue burning.

3.5.1 Study-site selection and data collection

Site selection for soil sampling was based on differences in agricultural practices established by farmers. Three different types of management practices were selected: 1) annual burn of crops residues; 2) no burning of crop residues; and 3) no burning of crop residues, but burned occasionally or accidently, e.g. due to intensive fires in 2015. A total of nine different plots were sampled that had these characteristics. A description of the nine sites and the results of the laboratory analysis are provided in Appendix 5.

In all cases, soil sampling was conducted at two depths: 0-5 cm and 0-20 cm. Sampling of the 5 cm soil was based on the assumption that it is the soil depth which is most affected during fire. Sampling at 0-20 cm is used to assess general soil properties and its fertility level, as it represents basic plough depth in the study area.

The selection of soil parameters to be analysed was based on existing research describing impacts of fire on certain soil properties, such as organic matter, bulk density, nitrogen, phosphorus and potassium. In addition, the parameters that may not be easily changed, like particle size distribution, cation exchange capacity, pH and calcium carbonate were also determined to obtain general

FIGURE 8

GHG emissions in BAU and ban of burning scenario and net-sequestration in case residue burning is prohibited (T=10)

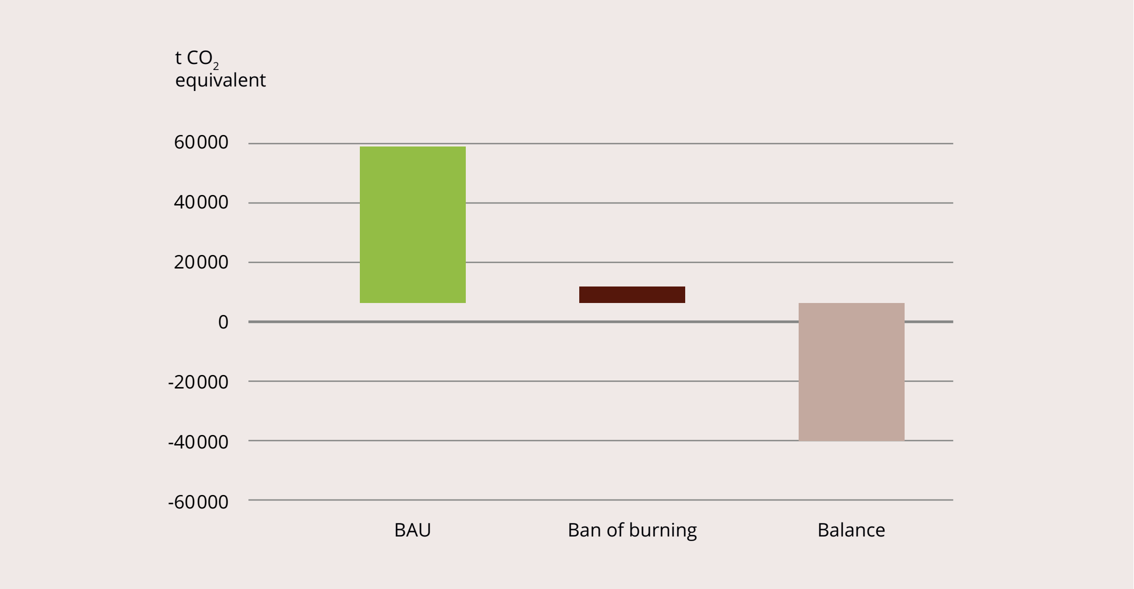


TABLE 3

Results of the one-way ANOVA test

Organic matter

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.516	1	.516	8.356	.034*
Within Groups	.309	5	.062		
Total	.825	6			

**Significant at the 95% level of confidence*

Bulk Density

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.018	1	.018	3.978	.103
Within Groups	.023	5	.005		
Total	.041	6			

Nitrogen

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.000	1	.000	.097	.769
Within Groups	.002	5	.000		
Total	.002	6			

Phosphorus

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.001	1	.001	1.499	.275
Within Groups	.005	5	.001		
Total	.006	6			

Potassium

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.000	1	.000	.000	.986
Within Groups	.081	5	.016		
Total	.081	6			

main soil properties, which help in identification of any substantial differences between soils. These parameters can be also affected by long lasting high temperature fires in places where fuel load are much higher than on agricultural lands, such as in forests or within windbreaks.

A comparison of the sampling sites was done based on changes in organic matter content, and soil bulk density, which can be altered as a result of organic matter reduction. Concentrations of the plant macro nutrients like nitrogen, phosphorus and potassium were also compared. The comparison shows the main differences between fire affected and non-affected soil in organic matter and bulk density.

In order to evaluate the statistical significance of observed changes, one-way ANOVA (analysis of variance) test were applied using SPSS software. The nine sites were divided into two groups: burned and non-burned sites. Burned sites unite the plots, which burn regularly and those burn occasionally or accidentally, as it is difficult to assess the severity of each fire event. Sites studied under windbreaks (Site 3 and Site 5) were excluded from statistical tests as they serve as "natural reference" and cannot be compared to arable lands, which experience permanent anthropogenic impact.

The results of statistical analysis in Table 3 shows that only changes in organic matter content is statistically significant. Soil bulk density indicates on substantial differences between sites, but it is statistically non-significant at the 90 per cent level of confidence. Existing differences in macro-nutrients (N, P, K) contents are statistically negligible and thus are not directly correlated to burn or no-burn practices.

3.5.2 Comparative soil analysis between burned and non-burned sites

Among the nine plots that were sampled, two plots (Site 1 and Site 2) located side by side offer a good basis for comparison, because of similar agro-ecological characteristics but opposing management characteristics on the plots.

On site 1, crop residues are integrated into the soil through shredding using a combi-harvester (grain harvesting machine) followed by use of a disc-cultivator to allow for better incorporation of residues into the soil.[12] Site 1 has not been affected by fire during the last three years – even during the massive 2015 fires. No mineral fertilisers have been applied during the last three years except 100 kg nitrogen fertilisers in the form of ammonium nitrate (≈34 kg N per hectare) to support decomposition of shredded straw and followed by rotary cultivator for better incorporation into soil.

Site 2 was burned during the three years prior to the field sampling and the owner of the site burns the entire amount of straw after grain harvest. The farmer furthermore applies NPK fertilisers regularly.

A comparison of the physical and chemical properties of the soil for the two comparable sites described above indicate significant improvements in soil parameters when burning is not undertaken. These improvements include:

- An increase in soil organic matter content by 18 per cent;
- Reduced soil bulk density by 10 per cent;
- Reduced fuel consumption used by agricultural machinery during soil cultivation as a result of reduced bulk density;
- An equal water infiltration rate on the entire plot where burning has not been undertaken (Site 1), equivalent to 480 mm/day. Repeated measurements on "Site 2" showed a lower and a significantly different water infiltration rate within the plot, which may also be caused by the use of heavy agricultural machinery.
- The incorporation of straw and shallow tillage of soil prevents crust formation and cracking of soil and reduces water evaporation;
- Regular addition of fresh organic matter in the form of crop residues to soil and increased maintenance of moisture creates favourable

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[12] *Farmers who burn crops also use a rotary cultivator after burning to prepare for the planting season (revealed in the valuation survey). So the rotary cultivator does not lead to increased costs for the farmer who decides not to burn.*

conditions for soil organisms. The presence of earthworms observed during soil sampling on “Site 1” is a good indicator of this. No earthworms were found on “Site 2”.

- Finally, due to higher organic matter content, the soil on “Site 1” can hold about 145 t more water per ha in the top 20 cm of the soil.

All of these improvements in soil properties have direct or indirect impact on soil productivity and yield formation. The differences found between the neighbouring plots clearly indicate the importance of proper soil management and avoided burning.

The characteristics of the remaining sites (3–9) which cannot be directly compared are explained in Appendix 5.

3.5.3 Water balance under different soil management regimes

AquaCrop (ver. 5.0) model simulation

Adequate supply of water is crucial to allowing cereal crops to realise their growth potential. Moreover, because Dedoplistskaro municipality is characterised by rain-fed agriculture, water management is a key determinant for agricultural productivity with increasing importance as climate change becomes more pronounced. Moreover, because of year-to-year changes in available precipitation within the growing season in Dedoplistskaro, yields may vary greatly from one year to another. Therefore, the only way to improve and stabilise agricultural production is to establish better agricultural practices in which proper soil management plays a crucial role.

In order to assess how different soil management practices actually affect agricultural yields in Dedoplistskaro, we have used a water-balance crop model known as ‘AquaCrop’ to isolate the impact of fires on yields. The Food and Agricultural Organization (FAO) developed the AquaCrop model in 2009 (Jin et al. 2014). The model was first built on “yield response to water” data of Doorenbos and Kassam (1979) and further developed to a normalized crop water productivity (NCWP) concept (Steduto et al. 2009). Compared with other models, AquaCrop is relatively simple to operate and allows for simulation of crop performance in multiple scenarios. AquaCrop is also capable of predicting crop productivity, water requirements, and water use efficiency under limited water conditions. To date, this model has been successfully tested for cotton, maize, wheat, sugar beet, sunflower, groundnut, potato, quinoa, barley, green onion and tomato under a wide-range of environments.

3.5.4 AquaCrop data inputs and calibration process

In addition to offering a high level of accuracy, the AquaCrop model requires a limited set of input parameters, most of which are relatively easy to acquire. Input consists of weather data, crop and soil characteristics, and management practices that define the environment in which the crop will develop. Weather data is typically collected from agro-meteorological stations and include minimum and maximum air temperature, ETo (evapotranspiration) and rainfall. Climatic data for the model developed in this study was provided by the Ministry of Environment and Natural Resource Protection of Georgia.

Crop data is taken from calibrated and validated crop characteristics from the data bank of AquaCrop software. Soil physical characteristics are adjusted based on field observations and texture class determined based on laboratory tests. The AquaCrop model furthermore takes into account field management practices such as soil fertility level and practices that affect the soil water balance. The simulation was done for winter wheat, the main crop in Shiraki valley. Average yield information was taken from local farmers in order to validate the results of the AquaCrop simulation.[13]

The assumptions underlying the AquaCrop model and the sequence of calculations made to arrive at the main results (Table 4) are as follows:

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[13] *As farmers typically report yields in fresh mass, fresh yield estimates have been converted to dry yields.*

TABLE 4

Yield simulation by the AquaCrop model for year 2015

Management regime	Grain Yield t/ha Dry Mass	Grain Yield t/ha Fresh Mass	Water productivity (yield per cubic meter of water)	% Increase in fresh yield from a transition to no-burning*
Annual consistent burning of residue	3.21	3.67	0.68 kg / m^3 of water	**23%**
Occasional burning of residues	3.60	4.14	0.75 kg / m^3 of water	**11%**
No burning of soil	3.94	4.53	0.82 kg / m^3 of water	

These differences in yields are realised as of year 3, after the farmer stops burning residues.

1. **Soil water balance:** The amount of water stored in the root zone is simulated by accounting for the incoming and outgoing water fluxes at its boundaries.
2. **Crop development:** In the simulation of crop development, the canopy expansion is separated from the expansion of the root zone. AquaCrop uses canopy cover to describe crop development and the interdependence between shoot and root is indirectly accounted for via water stress.
3. **Crop transpiration (Tr):** Crop transpiration is obtained by multiplying the evaporating power of the atmosphere with a crop coefficient. The crop coefficient (Kcb) is proportional to CC and hence continuously adjusted. The evaporating power is expressed by the reference grass evapotranspiration (ETo) as determined by the FAO Penman-Monteith equation.
4. **Above ground biomass (B):** The cumulative amount of water transpired (Tr) translates into a proportional amount of biomass produced through the biomass water productivity.
5. **Partitioning of biomass into yield (Y).** Given the simulated above ground biomass (B), crop yield is obtained using a Harvest Index (HI) (Yield = HI*B). In response to water and / or temperature stresses, HI is continuously altered during yield formation.

The core equation of the AquaCrop growth engine is shown in Equation 6:

EQUATION 6

$$B = WP * \sum Tr$$

where B is the cumulative aboveground biomass production (kg/m^2), Tr is the crop transpiration (in mm/day) and WP* is the normalised crop water productivity (kg of biomass per m^2 and per mm of cumulated water transpired over the time period in which the biomass is produced) (AquaCrop, Reference manual, 2011). WP is normalised for CO_2 and local climate (i.e. expressed by ETo).

Based on the results of soil analysis presented above, three different levels of soil fertility were selected to demonstrate potential grain yields under climate conditions similar to those of 2015. “Site 1” was taken as a reference plot with non-limiting soil fertility, which valued as 100 per cent fertility in the AquaCrop model. The sites affected by occasional or accidental fires were compared to the reference plot.

The results of the AquaCrop simuations in Table 4 shows considerable differences in agricultural yields under the three different crop and fire management regimes. A farmer, who burns his crop residues every year in the Shiraki valley, can expect to have a fresh yield of 3.67 ton/ha under 2015 climate conditions, while farmers who burn occasionally and never may expect fresh yields of respectively 4.14 ton/ha and

4.53 ton/ha, corresponding to 11 to 23 per cent higher yields compared to the farmers burning residues. The differences are attributed to the fact that crops on fields that are not burned make more effective use of water. However, these benefits are not immediate. Discussions with farmers that represent each of these sites indicate that the soil fertility improvement presented here materialises three years after the farmer stops burning. This information is used when calculating the NPV of integrating straw residues (Section 4.3, Equation 13).

Discussion of results

The findings from the AquaCrop simulations are consistent with other findings from the literature on soil management. For example, Steiner (1989) and Li et al. (1992) showed that wheat straw mulching is regarded as one of the best ways of retaining more water in the soil and decreasing water evaporation. Certain types of soil organic matter can hold up to 20 times their weight in water (Reicosky 2005). On the converse, it has been shown that fire has a direct impact on the physical properties of soil, decreasing soil porosity, increasing bulk density (Alauzis et al. 2004; Stoof et al. 2010, 2015) and decreasing the retention of water in the soil (Stoof et al. 2010, 2015; Shakesby 2011) and water infiltration (Martin and Moody 2001; García-Corona et al. 2004; Stoof et al. 2015). Moreover, burnt organic matter (OM) and ash may form a hydrophobic coating on soil surface (DeBano 2000; González-Pelayo et al. 2010; Stoof et al. 2015), which reduces infiltration, increases runoff and soil erodibility (Nunes et al. 2005; Moody and Ebel 2014; Stoof et al. 2015). Consequently, there is no doubt neither in Dedoplistskaro nor elsewhere that continuous burning of crop residues negatively affects soil parameters that are critical in ensuring resilient and high-yielding agricultural farm systems.

Valuation of the biophysical and social impacts of terminating crop residue burning

In this chapter, the biophysical changes that are induced from a termination of burning are valued using productivity change, avoided damages, stated preference, market prices and avoided cost valuation approaches.

These changes are calculated for farmers with 5 hectares or more (large farmers) as well as farmers that cultivate less than 5 hectares of land (small farmers).

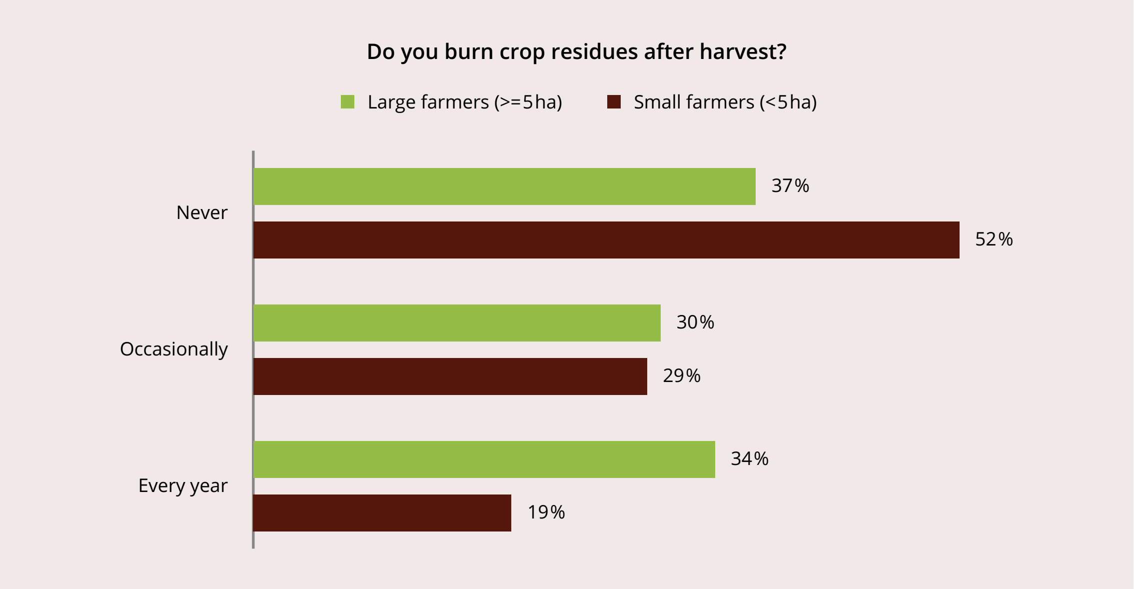
The segregation between small and large farmers has been done because the analysis of the household data has revealed that 5 hectares is a critical cutting point allowing to detect significantly different price structures with respect to rental cost of combi-harvesters and straw collection machines as well as straw prices. Furthermore, as revealed in the next section, small and large farm also have different farming practices.

4.1 Small versus large farmers

Figure 9 shows that 50 per cent of all small farmers never burn their crop residues, whereas only 37 per cent of large farmers claim never to burn crop residues. Consistent with these finding, Figure 10 shows that a greater proportion of small farmers believe that burning is bad for soil fertility. Finally, in terms of who are affected by the burning of neighbouring farmers it can be seen that large farmers are relatively more exposed with 34 per cent claiming that they are affected every year by burning from other farmers (Figure 11).

FIGURE 9

Prevalence of burning among small and large farmers



4.2 Societal benefit of prohibiting burning and protecting remaining windbreaks

To assess farmers' actual preferences for burning agricultural residues, a stated preference valuation study was undertaken as part of the valuation survey. The stated preference study employed a choice experiment (CE) method. In CEs, a number of respondents are asked in a questionnaire to select their preferred option from a range of potential management alternatives, usually including a status quo alternative. Discrete choices are described in a utility maximising framework and are determined by the utility that is derived from the attributes of a particular good or situation. It is based on

FIGURE 10

Beliefs about the impact of burning among small and large farmers

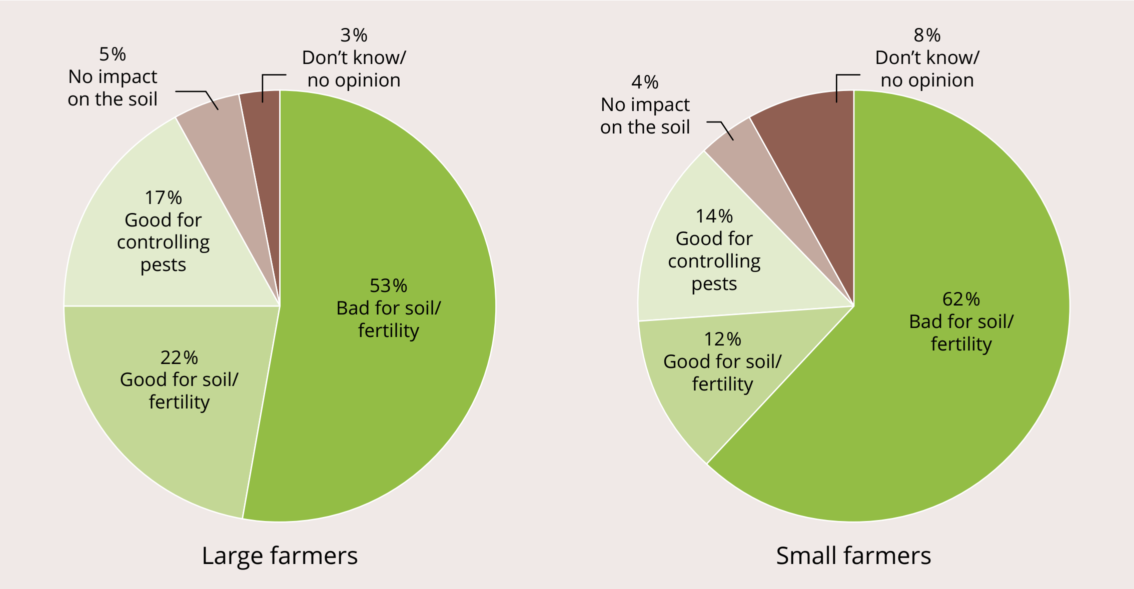
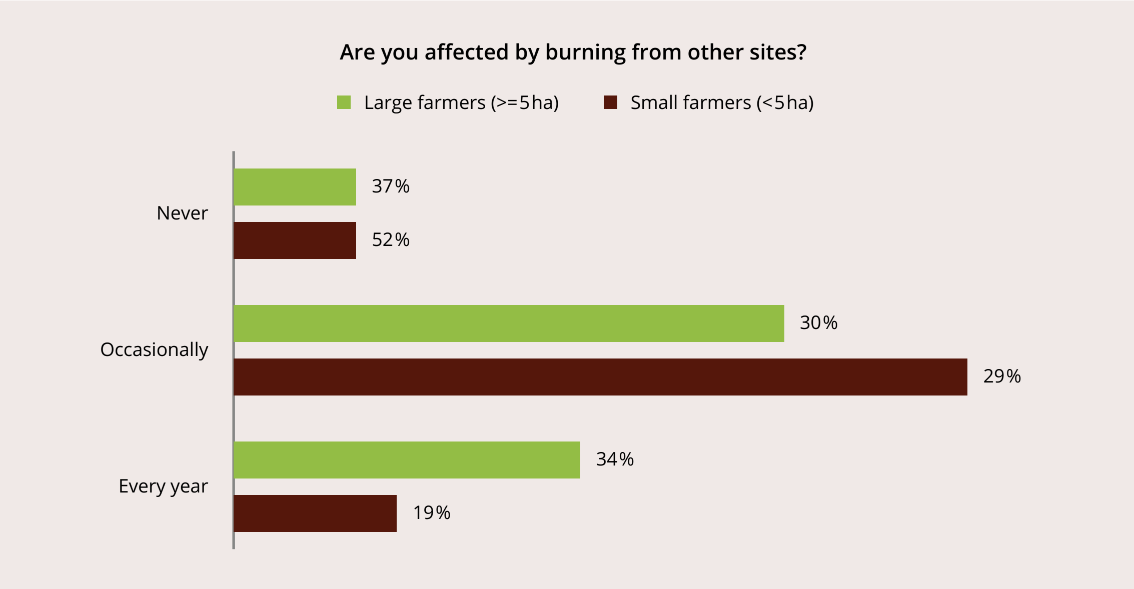


FIGURE 11

The extent to which small and large farmers are affected by the burning of neighbouring farmers



the behavioural framework of random utility theory (Manski 1977) and Lancaster's theory of demand (Lancaster 1966). As a hypothetical market, CE can be used ex-ante to estimate marketable and non-marketable values for any environmental resource, and in particular the implicit economic value of its specific attributes and their internal ranking (Louviere et al. 2000; Birol et al. 2006). Choice modelling is regarded as the most suitable method for estimating consumers' willingness to pay (WTP) for quality improvements with multiple dimensions.[14]

Farmers were asked to evaluate eight choice sets and to choose between three landscape scenarios: a continuation of the present landscape, and two future scenarios involving a ban of burning and/or a change in extent of windbreaks relative to the current situation. Each scenario was associated with annual cost, above and below what they currently pay for the land registration fee. The farmers were asked to choose their preferred scenario and identify if either of the two future scenarios were too expensive to pay or unfavourable. In that case, they should choose the present situation. Visual aids were used to depict the policy attributes (Figure 12). Out of the 300 households, there were 12 protest bidders who were eliminated from the sample.[15] With 288 households each evaluating eight choice sets, a total of 2,304 (8 x 288) choices were observed (representing 3 x 8 x 288 trade-offs).

FIGURE 12

Example of one out of 8 choice sets from choice experiment

Choice set 1 (Block 2)	Status Quo	Future Alternative 1	Future Alternative 2
Windbreaks	20 % windbreaks 	100 % windbreaks 	50 % windbreaks 
Crop residue management	Fire allowed 🔥	Fire banned 🚫	Fire allowed 🔥
Land registration fee Relative to what you pay today	**87 Lari / ha** 0 Lari / ha	**110 Lari / ha** +22 Lari / ha	**95 Lari / ha** +7 Lari / ha
Your choice			

[14] CIE (2001) Review of willingness-to-pay methodologies. Centre for International Economics

[15] Farmers who stated they were not able to pay more in land registration fee, but nevertheless chose scenarios involving a significant increase in the land registration fee. A source of strategic bias.

4.2.1 Econometric Estimation

To describe discrete choices in a utility maximising framework, the CE employs the behavioural framework of random utility theory (RUT). In RUT, the individual *i*'s utility *U* from alternative *j* is specified as:

EQUATION 7

$$U_{i,j} = V_{n,j} + \varepsilon_{i,j}$$

where *Vij* is the systematic and observable component of the latent utility and ε is a random or "unexplained" component that is assumed to be independently and identically distributed (IDD) (Louviere et al., 2000).

The utility function used to generate the core results for this study is specified to be linear in the parameters. Observed preference heterogeneity associated with differences in farm sizes is incorporated into the deterministic part of the utility function by interacting respondent characteristics with the management attributes.[16]

Where β_{ASC} is the parameter for the alternative specific constant (ASC), which accounts for variations in choices that are not explained by the attributes or socio-economic variables. The vector of coefficients $\beta_{1\ldots}\ \beta_K$ and δ_1 is attached to a vector of attributes (X) and farm size characteristics (S) that influence utility.

EQUATION 8

$$V_{i,j} = \beta_{ASC} + \beta_1 X_{no\_windbreaks} + \beta_2 X_{50\%\_windbreaks} + \beta_3 X_{100\%\_windbreaks} + \beta_4 X_{Ban\_on\_burning} + \beta_4 X_{tax}$$
$$+ \delta_1 (X_{Ban\_on\_burning} * S_{<3ha\ farmers}) + \delta_2 (X_{Fire\_Ban} * S_{3\text{-}4.9ha\ farmers}) + 1(X_{Ban\_of\_burning} * S_{5ha\ or\ larger\ farmers})\,\delta_3$$

TABLE 5

Basic conditional logit model

Parameter	Estimate	Std Error	P>z	WTP/WTA	WTA-WTP Confidence interval
Alternative specific constant	20.2	510.4	0.98	820.3	
Loss of remaining windbreaks	-0.25	0.10	***	-10.0	-17; -2
Moderate rehabilitation of windbreaks (20% to 50%)	0.89	0.08	***	36.1	28; 43
Large-scale rehab of windbreaks (50% to 100%)	1.49	0.09	***	60.3	52; 67
Ban of burning, farmers with less than 3 ha	0.57	0.06	***	23.2	12; 33
Ban of burning, farmers with 3 ha – 4.9 ha	0.93	0.18	***	60.7^A	35; 86
Ban of burning, farmers with > 5 ha	0.4	0.17	***	39.2^A	15; 63
Price	-0.024	0.001	***		

A Calculated as shown in equation 10.

**** Denotes significance at 1% level. Obs=6912, LR=2096, Pseodo R2=0.27, Log likelihood=- -2840.3.*

The WTP is calculated using Equation 9, whereby the policy attribute β_k is divided by the price attribute β_{tax}.

EQUATION 9

$$WTP_k = -(\beta_k / \beta_{tax})$$

Given the presence of interactions between the 'ban on burning' parameter and farm-sizes of the respondents, we also adjust the WTP estimation to take into account this heterogeneity in the underlying sample. For example, using Equation 10, WTP for a ban on burning amongst farmers with 5 hectares or more land is calculated as follows:

EQUATION 10

$$WTP_{Ban\_on\_burning \geq 5ha} = -(\beta_4 + \delta_1 / \beta_{tax})$$

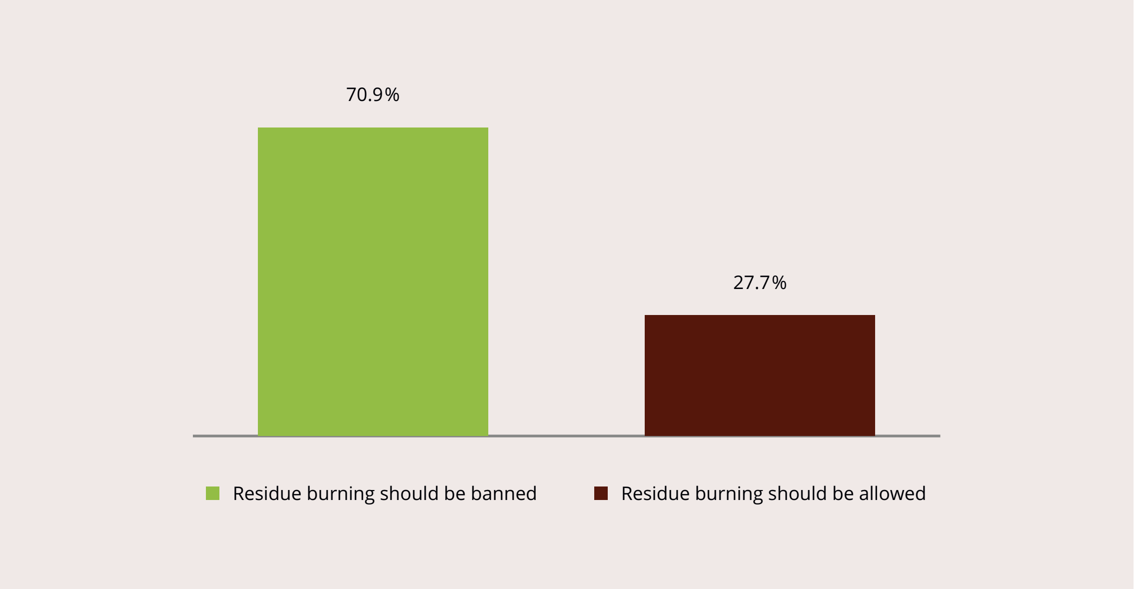
All models are estimated using STATA 13 software. The parametric models are specified so that the probability of selecting a particular management scenario is a function of the attributes of that scenario and of the alternative specific constant (ASC). The ASC variable is specified to equal 0 when either of the future policy and landscape management scenarios are chosen and 1 when the status quo option is chosen. Different model specifications including a basic conditional logit model (CLM) and CLM with socio demographic and economic interactions (CLM-interactions) are presented in the following. The purpose of the latter model (Equation 6) was to understand differences in farmer's preferences towards the ban of residue burning and the value of protecting existing windbreaks. The results of the basic CLM are presented in the next section. The CLM with interactions is included in Appendix 3 (Table A3.1).

4.2.2 Basic conditional logit model

In the basic CLM model, windbreak protection and restoration and a legal ban of crop residue burning are significant factors in the choice of a future management scenario. All the attributes are significant at 99 per cent level of confidence, implying that the farmers understood very well the exercise. Signs are as expected and the overall fit of the model, as measured by the adjusted Pseodu ρ^2 of 0.27, is very good by conventional standards used to describe probabilistic discrete choice models (Louviere et al. 2000).

FIGURE 13

Farmers preferences regarding residue burning (n=300)



4.2.3 Results – Benefits of protecting existing windbreaks

The choice experiment results reveal that the average farmer would experience a loss equal to GEL 10 per hectare (he cultivates) if remaining windbreaks would be lost. In theoretical terms, the farmer requires a compensation of GEL 10 per ha to be equally well off as without the windbreaks. The compensation demand does not vary between small and large farmers.

Interestingly, the model with the socio-demographic interactions (in Appendix 2) demonstrates that farmers that have some remaining windbreaks (28 per cent of the sample) experience a higher loss, equivalent to 26 GEL per ha. When including this interaction in the estimation, compensation demand for those farmers without windbreaks is zero. This implies that windbreaks are essentially valued (by farmers) for their contribution to the individual farm's productivity and not so much for their broader societal amenity benefits.

It is worth noting that the most important policy attribute is the large-scale restoration of windbreaks. Considering that the current land registration fee (of GEL 87 per ha) is expensive to most farmers, it is remarkable that the average farmer reveal on an additional willing to pay of GEL 60 per ha for a large-scale restoration of windbreaks. It should be said however, that stated preference studies are sometimes subject to hypothetical biases, which inflate WTP estimates (Murphy et al. 2005). This is further discussed within the section on the limitations of this study (Section 6.1).

4.2.4 Results: Benefit of banning crop residue burning

Farmers that cultivate less than 5 hectares of land are WTP an average of GEL 41 GEL per ha[17] to ensure the implementation and enforcement of a policy that bans crop residue burning, while farmer with 5 hectares or more are WTP an additional GEL 39 GEL per ha in land registration fee.[18]

With an effective prohibition of burning, farmers will be better protected from unpredictable fires that originate from neighbouring farms. If farmers unilaterally decide to stop burning, they cannot avoid the externalities imposed by other farmers burning. In light of this, it is not surprising that farmers as a whole demonstrate significant WTP to enforce a ban on burning. Although it is individually rational for farmers to continue to burn if they ignore the fertility improving effects of retaining crop residue it is collectively rational to stop burning. It should also be mentioned that the theoretical underpinnings of the choice experiment ensure independent estimation of attributes, implying that farmers WTP for banning of burning does not include the perceived benefit of protecting remaining windbreaks. So, there is no double-counting when adding the benefits of protecting remaining hedges and banning crop residue burning

Finally, consistent with the choice experiment findings, Figure 13 shows that the overwhelming majority of valuation survey respondents think that residue burning should be banned.

TABLE 6

WTP for a ban on burning for small and large farmers

Interaction variables	% of population	WTP	EANB per ha (GEL/year)	NPV per ha cultivated
Farmers with less than 5 ha	46%	41	38	306
Farmers with 5 hectare or more	54%	39	36	295

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[17] *There is an additional statistically significant split in WTP, within the small farmer group – notably amongst farmer with less than 3 hectares and farmers with 3 to 5 hectare. We have averaged across these two groups to derive a WTP figure for farmers with less than 5 hectares.*

[18] *?????????????*

4.2.5 Aggregate societal benefits from the choice experiment results

In estimating the benefits of banning burning and protecting remaining windbreaks to farmers over a 10-year time horizon, we use farmers' own elicited preferences on how much they would need to be compensated in the case of loss of existing windbreaks.

With regards to the protection of windbreaks, it was shown in Chapter 3 that if business as usual (BAU) continues, remaining windbreaks would be lost within less than 10 years. On the contrary, if a policy is enforced to ban residue burning, windbreaks are likely to remain within the time horizon of this study and beyond. Table 5 shows that farmers would need to be compensated (to be equally well off as today) if remaining windbreaks were to disappear. Thus, the benefit of implementing a law to ban burning is the avoided 'welfare loss' (negative of WTA compensation) associated with losing windbreaks in the BAU scenario (Equation 8). The BAU scenario involves a continuous and incremental degradation of remaining windbreaks. Protecting them therefore requires an immediate policy response. The avoided loss to farmers is estimated as of year 4 (t=3), when more than 50 per cent of remaining windbreaks risk being lost according to predicted wildfire hazards (see Table 2). The expected annual net benefit of preventing this loss is calculated as shown in Equation 11.

EQUATION 11

$$NVP_{\text{protection of windbreaks}} = \sum_{t=3}^{9} \frac{-WTA\ per\ ha_t}{(1+r)^t}$$

Where:
t=3, fourth year
WTA/ha=-10
r=4%

An effective ban of residue burning could be implemented almost immediately. The benefits from banning burning (Equation 11) are therefore estimated for almost the full accounting period (t=1 to t=9). The benefit of banning crop residue burning is calculated as shown in Equation 12. The aggregated benefits of banning crop residue burning and protecting remaining windbreaks are shown in Table 7.

EQUATION 12

$$NVP_{\text{banning of burning}} = \sum_{t=1}^{9} \frac{WTA\ per\ ha_t}{(1+r)^t}$$

Where:
t=1, second year
r=4%

TABLE 7

Soil enhancing benefits from left-over residues 3 years after burning stops

PRACTICE		BAU	IF BURNING STOPS	
Cereal yields		**Average farmer**	**Farmers otherwise burning occasionally**	**Farmers otherwise burning every year**
Farmers with less than 5 ha	t/ha	1.8	2.0	2.3
Farmers with 5 ha or more	t/ha	2.5	2.7	3.0

TABLE 8

Additional costs associated with shredding residues

Cost of machine rental		Traditional Harvester	Min – max	Combi harvester with residue integration	Min – max	Additional cost
Farmers with less than 5 ha	**GEL/ha**	**70**	40–125	**110**	50–130	40
Farmers with 5 ha or more	**GEL/ha**	**70**	30–120	**100**	50–120	30

4.3 Benefits from enhanced yields from crop residue integration

In deciding not to burn, farmers have two choices as to what to do with the straw residues: Either collect and use or sell the straw residues; or shred them during crop harvest using a combi-harvester[19] and subsequently be integrated into the soil through use of a disc cultivator to allow for better incorporation of residues into the soil.[20]

Crop growth simulations from Section 3.5.2 show that the termination of crop residue burning and the subsequent integration of residues into the soil will enhance cereal yields, benefiting farmers by increasing the amount of cereal crop they can sell at any given year.

As shown in Table 4 above, pronounced yield increases will manifest themselves three years after farmers stop burning. Yields can be expected to increase by 11 per cent for farmers who otherwise burn occasionally; and by 23 per cent on land that otherwise was burned annually. The actual expected impact on yields for small and large farmers (using data from the valuation survey) are shown in Table 7.

Whilst the yields will increase, the farmer will incur an additional cost associated with renting a combi-harvester as opposed to a traditional harvester. Combi-harvesters ensure that residues are shredded simultaneously with harvesting, allowing for easy integration of the residues into the soil.

TABLE 9

Benefits and costs to the farmer of integrating crop residues

		Unit	Small farmer (range)	Large farmer (range)
Wheat prices (2016)		GEL/ton	440	440
Occasional burning ➔ no burn	Yield (from year 3)	t/ha/yr	0.2	0.3
	EANB	GEL/ha/year	52	60
Annual burning ➔ no burn	Yield (from year 3)	t/ha/yr	0.4	0.6
	EANB	GEL/ha/year	117	145
Burning ➔ No burn *Adjusted according to the frequency of burning amongst small and large farmers*	**EANB**	**GEL/ha/year**	**78**	**105**
	Net Present Value	**GEL/ha**	**632** (580-680)	**854** (815-893)
	BCR	**GEL/ha**	**3.7**	**5.2**

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[19] *Combined grain-harvesting and residue shredding machine*

[20] *Farmers who burn crops also use a rotary cultivator after burning to prepare for the planting season (revealed in the valuation survey). So the rotary cultivator does not lead to increased costs for the farmer who decides not to burn.*

As shown in Table 8, combi-harvesters are more expensive than traditional Soviet harvesters. Furthermore, the valuation survey revealed that small farmers (<5 ha) pay on average GEL 10 more per hectare for the rental of a combi-harvester relative to large farmers (≥ than 5 ha). Since most farmers rent a tillage machine after harvest to prepare the soil for a new cropping season, the actual integration of residues into the soil does not represent an additional cost nor additional time (and opportunity costs) to the farmer.

4.3.1 Net-benefits associated with shredding and integrating residues

The benefits of yield increases to farmers are valued using farmgate market prices for wheat. Yield increases are not to be expected before year 3, whereas the additional costs of renting appropriate machinery are incurred as of the first year. The additional costs of integrating crop residues are subtracted from the additional revenue to derive the Net Present Value per hectare of integrating residues for small and large farmers using Equation 13.

EQUATION 13

$$NPV_{crop\ residue\ integration} = -C_0 - C_1 + \sum_{t=2}^{9} \frac{\Delta Y_t * P_t - C_t}{(1+r)^t}$$

Where:
C_t *is the additional cost in year t of renting a harvester that can chop residues simultaneously to harvesting*
ΔYt is the additional yield in year t to farmers that stop burning and integrate residues instead (from t=2 to t=9)
P_t *is farmgate market price of wheat 440 GEL/ton*
r is the real interest rate of 4%

Since small and large farmers burn with different frequencies – some occasionally, others every year – the average per hectare NPV benefit of ending burning is furthermore calculated for the two farmer segments using Equation 14.

EQUATION 14

$$NPV_{adjusted} = NPV_{annual} * P_b + NPV_{occasional}\, P_{oc}$$

Where:
P_b *is the proportion of farmers that burn residues annually and* P_{oc} *is proportion of farmers that burn occasionally. For small farmers* $P_b=0.4$ *and* $P_{oc}=0.6$*. For large farmers* $P_b=0.54$ *and* $P_{oc}=0.46$*.*

Table 9 demonstrates that there are significant net-benefits associated with retaining straw in the soil as opposed to burning it. Small farmers can expect a Net Present Value benefit of GEL 632 per ha, equivalent to an expected net annual benefit of GEL 78 per ha per year.[21] This implies that for every additional 1 GEL they invest in integrating straw residues, they can expect 3.7 GEL of benefits. The benefit cost ratio for large farmers is even greater (GEL 5.2 of benefits for every GEL 1 invested) since they face lower crop residue integration costs and higher yields.

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[21] *Also called the annuity value, equivalent to the present value the average annual additional income generated over the 10-year accounting period.*

4.3.2 Marketable benefits from collecting and selling straw

Unprocessed crop residues or straw have productive uses for animal bedding or supplementary forage, but whether it makes sense for farmers to collect straw or not depends on the cost of collecting and storing straw and the price at which straw can be sold or would otherwise need to be bought.

The costs associated with collecting straw and compressing it into bales are also shown in Table 10. These include, per hectare rental costs of machinery and the opportunity cost of time that could be spent on other productive activities during the harvesting season. Machinery rental costs are significantly different for small and large farmers. Furthermore, small farmers face significantly lower farmgate market prices for straw bales. This can possibly be explained by the absence of access to storage space and/or lower negotiation power.

It should also be highlighted that the farmgate price for straw is variable from year to year. In years with good rain and decent temperatures, crop, straw, hay and forage yields are high. Under these circumstances, straw becomes less valuable and the price at which it can sell is low. With an increasing incidence of dry-spells or uptake of straw residue integration, the supply of straw is likely to become more restricted in years to come. In 2015, straw prices were high directly after the burning season because of the uncontrolled fires that made straw low in supply. Therefore, in evaluating the benefit of collecting and selling straw we used the ‘lower range’ of 2015 farm gate market straw prices, with a mean selling price of GEL 0.6 per bale for small farmers and GEL 1 per bale for large farmers (Table 10). These prices are consistent with those of previous years according to the Georgian GIZ field officer (Amiran Kodiashvili, personal communication, 2016).

Given straw yields (Qt), straw prices and straw collection costs, we are able to calculate the per hectare net present value benefits of not burning and producing straw bales in Dedoplistskaro as shown in Equation 15.

EQUATION 15

$$NPV_{straw} = \sum_{t=0}^{9} \frac{Q_t * P_t - C_t}{(1+r)^t}$$

Where:

Q_t is the quantity of straw that may be collected per hectare in year t

C_t is the per hectare cost of renting the straw collection and baling machine and compressing the bales in year t.

P_t is the farmgate price at which straw sells

r is the real interest rate of 4%

T=10 years (t=0 to t=9)

TABLE 10

Benefits of collecting and selling straw

Variable	Unit	Small farmers	Large farmers
Yield of straw per ha*	tons/ha	2.8	3.7
Effective collection of straw per ha**	tons/ha	1.9	2.8
Price per bale (2015 farm gate prices, lower range)	GEL/bale	0.6	1
Price per ton (approx. 80 bales in 1 ton)	GEL/ton	48	80
Machine rental cost associated with collecting and compressing bales	GEL/ha	100	80
Expected net annual benefit (EANB)	**GEL/ha**	**-5**	**147**
Net Present Value (NPV)	**GEL/ha**	**N/A**	**1196**
Benefit Cost Ratio (BCR)	**GEL/ha**	**0.9**	**2.4**

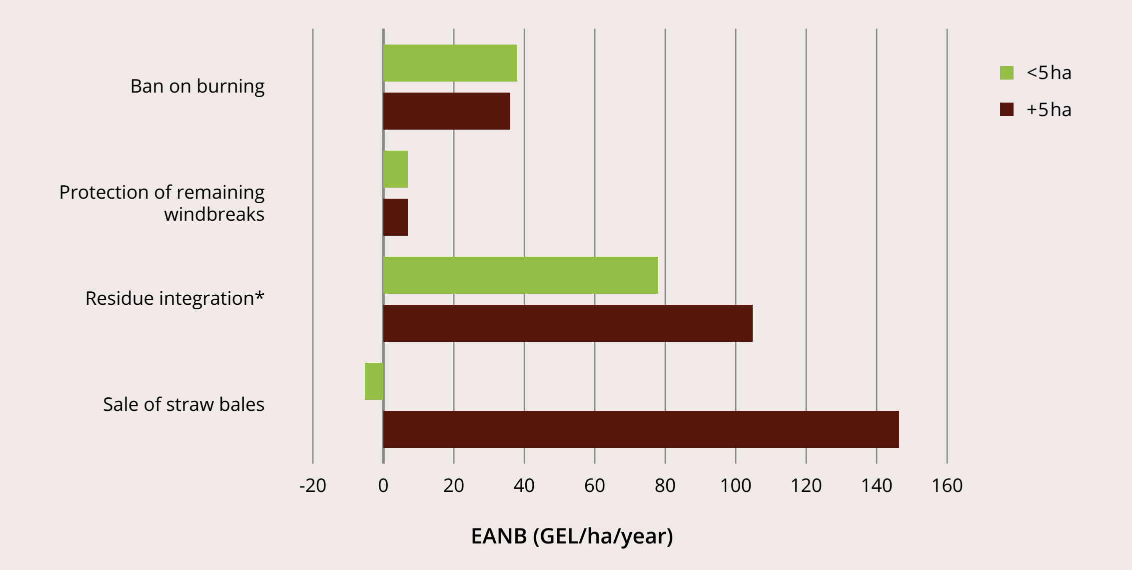
As shown in Table 10, the expected net annual benefit of collecting and selling straw for the large farmer is in the order of GEL 147 per ha per year over 10 years using a 4 per cent discount rate. Small farmers, however, face higher straw collection prices and lower yields relative to large farmers, which makes it uneconomical for them to collect and sell straw bales. The benefit cost ratio of 0.9 reveal that at current farm gate market prices and machine rental costs, the average small farmer would lose GEL 0.1 for every GEL spent. Of course, if small farmers were able to improve their agricultural yields and negotiate prices differently, they could earn positive net-benefits from straw collection and sale.

4.4 Farm level net-benefits

The expected annual net benefits per hectare from the valued ecosystem services and policy options analysed above are shown in Figure 14. The figure highlights that if a ban on burning were to be implemented, it would be most rational for small farmers to integrate all straw into to the soil. Large farmers could choose to do a mixture of straw residue integration and straw collection to diversify income sources.

FIGURE 14

Expected annual net benefit per hectare of 'not burning' for small and large farmers



Averaged for farmers burning yearly and occasionally

TABLE 11

Estimates of the social cost of carbon

Study	SCC per ton CO_2
Nordhaus (2008)	$6(a)
Anthoff et al. (2011)	$8 (b)
Stern (2007)	$85 (a)
Hope (2013)	$106 (b)
Moore et al (2015)	$202 (b)
EPA (2015)	$37 (c)
Van den Bergh and Botzen (2014)	$125 (b)

4.5 Societal level benefits and cost

4.5.1 Benefits of reduced greenhouse gas emissions

GHG emissions from wildfires generate a global externality, since the climate changes caused by them have worldwide economic and societal consequences. The benefits from reduced emissions associated with the prohibition of burning in Dedoplistskaro municipality are therefore not specific to Georgia, but rather global. The benefits of reduced emissions are valued using the Social Cost of Carbon (SCC).

The SCC is often used to evaluate regulatory policies affecting GHG emissions. The SCC estimates the discounted value of the damage associated with climate change impacts that would be avoided by reducing carbon dioxide (CO_2) emissions by one metric ton in a given year (Anthoff et al. 2009). SCC estimates are calculated using Integrated Assessment Models (IAMs) of climate and the economy, which estimate the damage resulting from greenhouse gas emissions over a period of 100 or 200 years or longer. The damages include decreased agricultural productivity, damage from rising sea levels and harm to human health.

There are a number of different Integrated Assessment Models. In these models, the SCC depends on expectations of future economic growth and ethical viewpoints about weighting welfare levels between different generations, amongst other issues. Moreover, the SCC is sensitive to the categories of monetary and non-monetary climate change effects that are being considered in IAMs, and to assumptions made about uncertainties and extreme scenarios of climate change (Montenegro et al. 2007). As a result, different SCC estimates are found in the scientific literature. Some of the most known studies are shown in Table 11. In this report we employ one of the more conservative estimates (USD 37/ton[22]). This estimate is used by the US EPA (EPA 2015) and has been devised by the American interagency working group (White House 2013). It combines the three most common IAM models (DICE, FUND and PAGE).

On the basis of carbon balance estimates presented in Section 3.4 we estimate the Present Value benefits of implementing a ban of burning using Equation 13. The present value benefit represents the avoided global damage costs over 10 years (2017–2026). Using Equation 16, these amounts to GEL 4.4 million.

EQUATION 16

$$PV_{\text{benefit of avoided emissions}} = \sum_{t=0}^{9} [(CO_2e_{BAU_t} - CO_2e_{\text{ban on burning}_t}) * SCC_t / (1+r)^t]$$

Where:

CO_2e_{BAU} = Tons of CO_2 equivalent emissions year by year in the BAU scenario

Where CO_2e policy = Tons of CO_2 equivalent emissions year by year in the ban-of burning scenario

r=4%, the real Georgian interest rate.

SCC= 94 GEL/t CO_2e eq[23] in the first year and gradually rising up to 116 GEL/t CO_2e in 2026.

[22] *Equivalent to 94 GEL in 2016. Calculated using an inflation factor of 1.15 (USD 2007 to USD 2016) and an exchange rate of 1 USD=2.2 GEL in 2016.*

[23] *USD 37 in 2007 dollars amounts to GEL 94 in 2016. We have used the official inflation factor of 1.15 to convert USD 2007 to USD 2016 values. We subsequently applied the 2016 commercial exchange rate of 1 USD=2.2 GEL to convert USD to GEL.*

4.5.2 Costs of implementing a policy to ban crop residue burning

There will be costs involved in implementing a law that prohibits burning of crop residues. At the very minimum, public authorities would need to finance awareness-raising campaigns including the distribution of leaflets, newsletters and broadcasting across radio and television networks. The Georgian Ministry of Environment has provided a detailed breakdown of expected expenses shown in Table 12 (Weigel 2016).

Within the first two years after the ban has been implemented, fire patrolling would also be necessary. Fire patrollers should also be given the legal mandate to fine arson and conduct forensic wildfire investigations. The costs of these services are estimated on the basis of GIZ’s prior fire patrolling experience and shown in Table 13. Taken together, these awareness-raising and enforcement costs sum up to approximately GEL 95,000 in present value terms over the 10-year accounting period for Dedoplistskaro municipality alone.

Lastly, one could also foresee the possibility that these services are complemented with extension services to facilitate the farmer’s ability to transition away from crop residue burning towards more sustainable land management practices. A minimal level of enforcement costs after the first two years is probably also advisable, especially during the harvesting season. Farmers themselves, however, claim that the openness of the valley makes it virtually impossible for any farmer to hide arson. Though this claim hold less true during night. In either way, a fair air degree of collective self-enforcement of the law is foreseeable in the case that most farmers understand and uphold an interesting in avoiding fires.

TABLE 12

Avoided damage from the SCC (r=4%)

Year	Tonnes of CO_2 equivalent emissions from deforestation of windbreaks and crop residue burning			SCC GEL per CO_2eq 1 USD=2.2 GEL	Total avoided damage cost SCC GEL
	BAU	Ban on burning	Difference		
2017	8,706.4	870.6	5,222.9	94	855,740
2018	3,867.9	386.8	2,320.3	96	375,427
2019	6,024.1	602.4	3,613.8	99	577,025
2020	1,893.7	189.4	1,136.0	101	178,886
2021	10,480.1	1,048.0	6,286.9	104	975,706
2022	5,311.8	531.2	3,186.5	106	487,110
2023	3,237.9	323.8	1,942.4	109	292,303
2024	2,254.1	225.4	1,352.2	111	200,215
2025	3,018.6	301.9	1,810.9	114	263,670
2026	1,666.7	216.6	1,299.4	116	185,970
Total	46,461	4,646	28,171		**GEL 4,392,054**
EANB					**GEL 541,487**

TABLE 13

Implementation and enforcement costs

Lower-bound implementation and enforcement costs for Dedoplistskaro		Year	Cost (GEL)
Awareness and information raising costs in the first year incurred by MoE	10,000 brochures	1	2,000
	Information desks and banners	1	2,000
	Logistics, including transportation of banners and all other materials	1	1,000
	Rent for the meeting spaces for two meetings per district	1	500
	Graphic informative clip for TV and other social media resources	1	6,000
	Newspaper with comprehensive information, to be released over several editions in the summer.	1	500
	SUB-TOTAL	1	12,000
Fire patrolling and fining	700 GEL/month/person for 6 months (May–October). Two patrols	1 – 2	8,400 per year
4x4 Vehicle	Suitable for off-road	1	48,000 (one-off)
Fire patrolling Fuel cost	Patrolling of 2000-3000 km per month (for 6 months)	1 – 2	9,000 per year
Lower bound discounted cost		**1-2**	**95,650 GEL**

Upper-bound implementation and enforcement costs		Year	Cost (GEL)
Extended fire patrolling	2 patrols for one month per year (700 GEL/year each)	3 - 10	1,400 per year
Fire patrolling fuel cost	Patrolling of 2000-3000 km per month (11 month)	3-10	1,000 per year
Extension services in SLM	Workshops and individual farm-level support. Two extension service provider 4 months per year (700 GEL/month)	1 - 3	5,600 per year
Sub-total discounted cost		1-10	26,310
Upper bound discounted cost			**122,200**

TABLE 14

Present value implementation and enforcement cost

Parameter	Present Value (GEL)
PV implementation and enforcement costs (min)	95,650
PV implementation and enforcement costs (max)	122,000
Maximum Expected Annual Net Cost (EANC)	**15,040**

Accounting for these additional costs, the Maximum Present Value costs of implementing and enforcing the policy to ban crop residue burning amount to GEL 122,200 using Equation 17 and information in Table 13.

EQUATION 17

$$PV_{Public\ Costs} = \sum_{t=0}^{9} [Implementation\ and\ Enforcement\ Costs / (1+r)^t]$$

Where: $r=4\%$

4.6 Making alternative uses of Straw: Pellet producing facility

Straw pellets are widely used in daily life, for animal bedding, feed for animals and fuel for heating homes and industry use. Turning raw straw or straw bales into pellets offers great opportunities for easily transporting and using pellets in households and industrial appliances. In its 'unprocessed state' one m^3 of raw straw weighs 50 kg. In contrast, pellets are very dense, offering 800 kg of straw material per m^3 (Figure 15). In this light, it is of interest to analyse the scope for developing an economically viable straw pellet production facility in Dedoplistskaro.

4.6.1 Straw for animal fodder

Straw is a low quality feedstuff but it can be utilised as an alternative to hay if properly supplemented with minerals, vitamins and grain (Rossi 2009; Hall 2009). In order to infer the potential value at which straw pellets for fodder can sell in Dedoplistskaro, we have compared the protein content of straw with that of hay – a major feed-source in Dedoplistskaro. This is because protein is a major determinant of feed prices (Rossi 2009), explaining for example the high prices on soybean (43 per cent protein content), currently selling on international markets for 100 USD/t (Ragan 2016). Thus, on the basis of the protein content of straw and sale price of hay, we have inferred the possible selling price of straw pellets.

With a protein content of only 3.6 per cent, it can be seen from Table 15 that the sale price of straw as a source of feed is not economically viable.

FIGURE 15

Density of raw straw, straw bales and straw pellets

TABLE 15

Hypothetical price of straw on the basis of protein content

	Protein	Hay	Straw
Dry matter in 1 ton		900 kg	900 kg
Total digestible nutrients in 1 ton		550 kg	430 kg
Crude Protein in 1 ton		170 kg	36 kg
Price per bale (in 2015)		1.8 (1.3)	1.3[24]
Price per ton (in 2015)		145 GEL/ton	104 GEL/ton
Inferred feed price on the basis of protein content in Hay (146 GEL/170 kg)	0.85 GEL/kg	145 GEL/kg[25]	30 GEL/ton

[24] *A price range of 0.9 GEL/ton and a higher price range of 1.6 GEL/ton (from GIZ valuation survey 2016)*

[25] *Weigh per bale (10–15 kg)*

Straw bales currently sell for more than their ‘feed equivalent’ content. Clearly, straw is valued for animal bedding or something else than fodder in Dedoplistskaro. There is no viable business model in converting straw into straw pellets for feedstock.

4.6.2 Using straw for fuel pellets

Straw pellets can be used as fuels burning in pellet boilers, pellet stoves and other pellet appliance in households. Straw pellets are also used in central power plants to co-fire with traditional fuels, such as coals, oil and others.

There is significant demand for fuelwood in the Dedoplistskaro district. According to Helbig (2016), the mean consumption of firewood is 9 m^3/household/year in the Dedoplistskaro municipality, resulting in a total annual demand of 51,000 m^3/year in Dedoplistskaro. The majority of households spend between GEL 350 and GEL 700 per year for firewood, which corresponds to 1–2 months of the average household income (GEL 350).

A lot of the fuelwood is illegally sourced and as restrictions on supply are enforced, the price of fuelwood might rise. But with a higher price premium, the incentive to continue unsustainable sourcing of fuelwood will persist. At the same time, it is the principal means for heating of households in Dedoplistskaro. In this context, it is relevant to analyse the case for substituting fuelwood with pellets from straw. Such a scenario, however, would require investments into a pellet producing facility and households would need to buy stoves suited for pellets, so as to maximise the benefits of pellet burning. Because of the fuel’s consistency and the combustion mechanics of new pellet stoves, they burn more efficiently[26] and more cleanly than wood – giving off 80% less particulates relative to woodstoves, improving indoor climates.[27] Pellet burning stoves can also burn in normal fuelwood, but creates a lot of ash that way.[28]

The following section focuses on analysing the economic feasibility of installing a large-scale fuel pellet production facility. Data sources and references underlying the analyses are found in Appendix 4. In undertaking a feasibility study, we have considered:

- **The demand side:** What is the annual demand for fuelwood in Dedoplistskaro district and at what price are consumers purchasing this fuel?
- **The supply side:** What is the magnitude of wheat and straw produced in the Shiraki valley and at what price are farmers currently selling straw?
- **The production side:** What is the capital and operating costs of the facility? At what price would fuel-pellets need to be sold for the production facility to be economically viable?

Demand side

The maximum current sale price of pellets on the basis of its energetic equivalent value is 109 GEL/t (Table 16). This was calculated using local fuelwood prices from Dedoplistskaro (RECC 2016; Helbig 2016) and secondary data on energy content of fuelwood and straw. Data sources underlying the analysis are shown in Appendix 6.

TABLE 16

Calculation of the energy equivalent value of a ton of straw pellets

Price (GEL) per m^3 fuelwood	Mega Jules (MJ) per m^3 fuelwood	Price per Mega Jules (GEL/ MJ)	MJ/ ton of straw	MJ equivalent value of ton of straw
63	9360	0.0067	16,200	GEL 109

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[26] *Pellet stoves are very efficient -75 percent to 90 percent overall efficiency - and have a BTU output content four to five times higher than cord wood or wood chips. Pellet stoves can be vented through a small hole in the wall, rather than a whole chimney. www.hometips.com/buying-guides/pellet-stove-advantages.html*

[27] *http://www.treehugger.com/clean-technology/pellet-stoves-vs-wood-stoves-which-is-greener.html*

[28] *In order to help households finance the purchase of a pellet stove, intelligent arrangements can be made, whereby the pellet producing facility would sell stoves to households at discounted prices, zero-interest loans or in return for straw.*

TABLE 17

Assumptions underlying the cash-flow analysis

	Low price (GEL/ton)	High Price (GEL/ton)	Frequency of price hikes	Tonnes of straw processed per year	Capacity utilisation of the pellet machine
BAU	75	100	1 year out of 3	37600	70%
Prohibition of burning	70	100	1 year out of 4	43700	80%

Supply side

On the supply side, the estimated annual production of straw in Shiraki valley is 82,000 t. In 2015, straw was sold for an average of between GEL 75 per ton (lower range price equivalent to GEL 0.9 per bale) and GEL 136 per ton (upper range equivalent to GEL 1.7 per bale). The prices were particularly high in 2015 because of low supply of straw.

If crop residue **burning continues to be allowed** and is coupled with an increasing prevalence dry-spells due to changing climates, the price of straw is likely to reach regular price hikes above 75 GEL/t.

For the financial feasibility analysis we have developed two scenarios. Under the **BAU scenario**, we assume there are price hikes from GEL 75 per ton to GEL 100 per ton every one in three years (due to fires or droughts coupled with low supply of straw).

If residue **burning were to be prohibited**, straw will be in more abundant supply. In this case, input prices of GEL 70 per ton is likely to be guaranteed in most years. We have therefore assumed a price hike of 100 GEL/ha only one in five years.

In both scenarios, it is assumed that the sale price for straw pellets increases from GEL 80 per ton to GEL 110 per ton within four years after start of operations.

In the BAU scenario, we assume that the that the facility operates at 70 per cent capacity utilisation (37,600 t/year) and at 80 per cent (43,700 t/year) in the ‘ban on burning’ scenario, because there is a greater likelihood of a stable supply of straw if burning is prohibited.

Assuming average annual wheat yields of two tons per hectare, the Shiraki valley produces an estimated 80,000 tons of straw per year. Ensuring a steady supply of straw for the facility throughout the year would require good storage facilities. These assumptions are outlined in table 17.

Production side

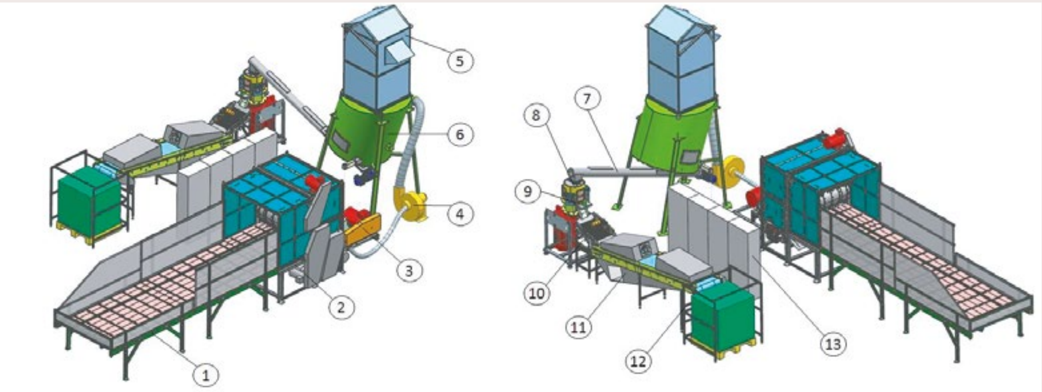
The costs of installing a facility that match the straw that can be supplied in Dedoplistskaro have been sourced from a detailed offer from a reliable German company, MÜNCH Edelstahl GmbH.[29] The straw pelleting production line includes:

1. Material receiving, bale shredding;
2. Milling, intermediate storing;
3. Humidity regulation, pelletizing, cooling, screening;
4. Bagging, storing;
5. Control system, electrical equipment, automation.

[29] *MUNCH webpage: http://www.muench-edelstahl-gmbh.de/index.html*

FIGURE 16

Components of pellet production facility



1. Input conveyor
2. Separator
3. Grinder
4. Fan for air transporter
5. Dust filtration
6. Buffer silo
7. Dispensing equipment to press
8. Press
9. Vapor and dust extraction fan
10. Separating vibratory conveyor
11. Cooling conveyor
12. Holder for big-bag
13. Main electrical panel
    Control panel

Figure 16 provides a more detailed breakdown of the components of a pellet production facility. The total cost of these production elements, including the building of a storage facility and the purchase of a vehicle, amounts to 3.6 million GEL as shown in Appendix 8 featuring the cash flow. The lifetime of the machinery is more than 20 years if well maintained. We have assumed a 20-year lifetime of the machine, although according to an interview with the CEO of MÜNCH (the supplier of the machinery), the lifetime of the machine could be much longer if well maintained. As it was not possible to obtain estimates of maintenance costs, these have not been integrated in the cash-flow analysis and as a consequence we have maintained a hypothesis of a 20-year lifetime of the machinery. The machinery has a total production capacity of 7.5 tons per hour, or 52,000 t of pellets per year assuming it is in operation 80 per cent of the time.

4.6.3 Results

Under the BAU scenario, where use of fire is allowed, investing in the pellet producing facility would be risky. With an insecure supply of straw at varying prices, the business would only just make break-even. According, to the feasibility and assuming an interest rate of 4 per cent and over 20 year timeline the BCR is 1.02 and the NPV is GEL 800,000. The internal rate of return is 7 per cent.

In case that the burning of straw is prohibited, input prices are likely to be more stable. In this case, a net present value benefit of GEL 6.4 million can be realised if straw pellets are sold approximately 35 per cent above the price at which straw is bought from the farmer. If there would be regular and consistent demand for straw, it is likely that prices lower than GEL 70 per ton of straw can be negotiated with farmers, especially amongst the larger once which have lower straw collection costs and higher yields, relative to the small farmers.

In that case, the profitability of the pellet producing enterprise could be higher. The present value outflows and inflows for the two scenarios are demonstrated in Figure 17 and 18.

TABLE 18

Main results from financial feasibility analysis of the pellet producing facility (r=4%, t=20 years)

	Reliable supply of straw (when burning is banned)	Unpredictable supply of Straw (BAU)
Net Present Value	GEL 6,400,000	GEL 800,000
BCR	1.11	1.0
IRR	17%	7%

FIGURE 17

Cash-flow of pellet producing machine under 'ban on burning'

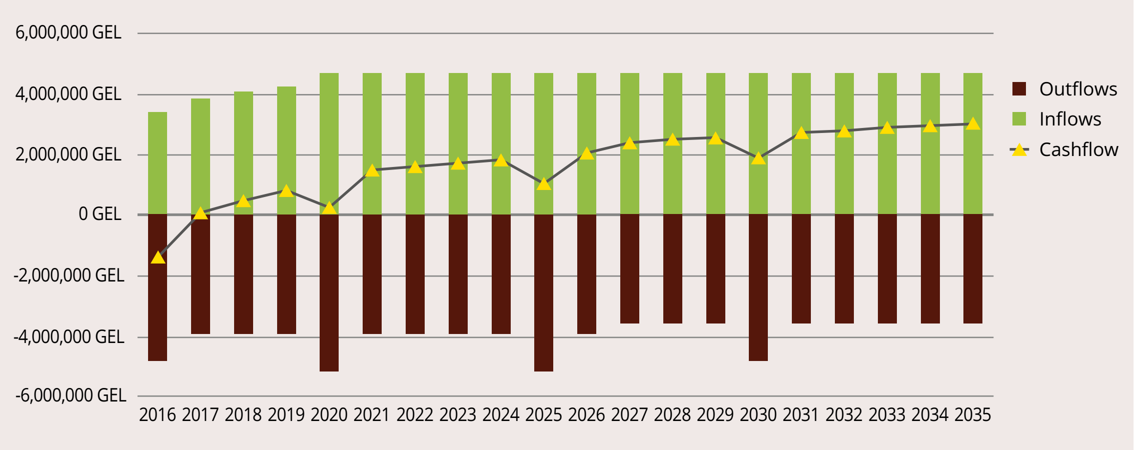
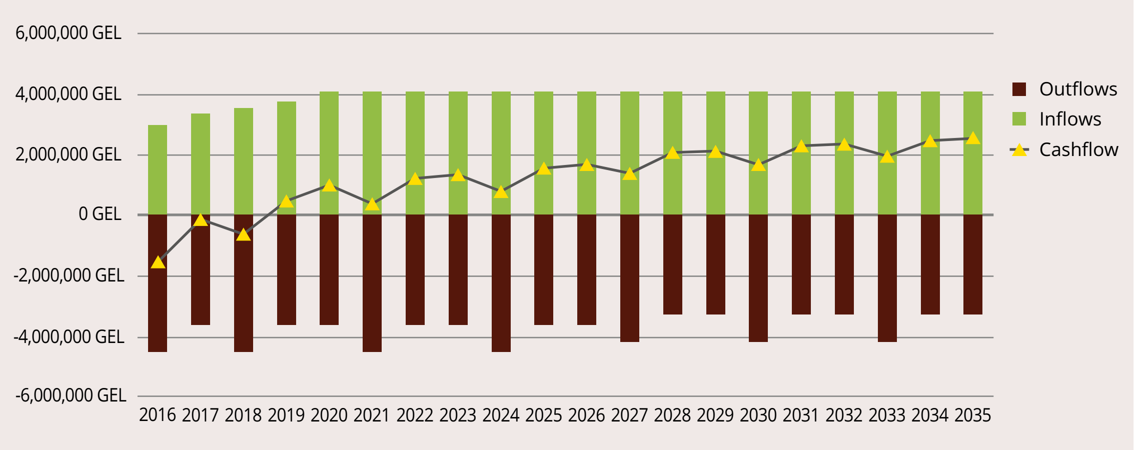


FIGURE 18

Cash-flow of pellet producing facility under 'BAU'



05 Aggregate cost benefit results

5.1 Assumptions and land use context

This chapter draws together all of the results presented in previous chapters to understand the overall societal and farm-level impact of ending crop residue burning. In order to do so, we first consider the share of the land within Shiraki valley that is cultivated by large and small farmers. Using the results from the valuation survey, we find that the 141 small farmers cultivate a total of 367 hectares. In contrast the large farmers cultivate 4,509 hectares in total (excluding one farmer with 2,500 hectares of land who is not representative for the general large farmer population). From this data, it may be deduced that large farmers cultivate approximately 92 per cent of the 20,000 hectares of cropland dedicated to cereal crops. We have confidence in this estimate since the share of large and small farmers (at 5 ha split) within our survey is consistent with official statistics from the Dedoplistskaro municipality.

Secondly, we have estimated the net-benefits and benefit cost ratios for small and large farmers (Tables 20a and 20b) in Dedoplistskaro under the **ban on burning scenario**, relative to a simple continuation of BAU. In doing so, we have assumed that burning in the farming sector is prohibited by law and that the law is effectively implemented and enforced. The resulting benefits include the protection of remaining windbreaks, avoided damages from carbon emissions, welfare benefits from a comprehensive ban on burning, enhanced yields from crop residue integration and marketable benefits from selling straw, minus the costs of doing so to farmers and the costs to public authorities for enforcing the law. Given the relative proportion of land cultivated by small and large farmers (from Table 19), per hectare estimates are scaled to Dedoplistskaro municipality in Table 21 for a 10-year period using the Georgian real discount rate of 4 per cent.

TABLE 19

Proportion of land cultivated by small and large farmers in the Dedoplistskaro district

Typology	Farmers with	Number of farms	Total farmland area	Proportion of farmland
Small farmers	Less than 5 ha	141	367	**8%**
Large farmers	5 ha and more	149	4,509[30]	**92%**

[30] *This figure excludes one large farmer with 2,500 hectares of land. There are a total of 4,820 farmers in Dedoplistskaro municipality, amongst which there are 3 very large farmers as known to the GIZ project with 2,500 ha of land. Since one of these three farmers, is represented in the sample of with only 300 households, we believe there is reason to think that this super-large farmer type is overrepresented within the sample. In order for our sample to be representative of super-large farmers in the valley, there would need to be 4820/300 = 16 of them in the valley. That is not realistic, since they alone would be cultivating near 34,000 ha of land. Hence, in calculating the proportion of land cultivated by respective small and large farmers, we have excluded one very large farmer.*

5.2 Results

Tables 20a and 20b show the impact of a ban on burning on small and large farmers respectively. As can be seen, under current machine rental prices, it is significantly more advantageous for small farmers to shred and integrate straw[31] during harvest using combi-harvesters (NPV of GEL 630 per ha) compared to collecting, using and selling straw bales (NPV of GEL -40 per ha).

It is thus rational for small farmers to integrate straw into the soil provided they are aware of the long term benefits of doing so. For large farmers, the collection and sale of straw is highly worthwhile. However, if all large farmers would collect

TABLE 20A

EANB (GEL), NPV (GEL) and Benefit-Cost Ratios (BCR) for small farmers under a ban on burning scenario (T=10 years, r=4%, cereal cultivation=20,000 ha, land burned=10,000 ha)

Small farmers	EANB/ha	NPV/ha	NPV district wide	BCR
Ecosystem service benefits from not burning				
Residue retention and integration in soil (100%)	78	632	0.8 million	3.7
Collection and sale of straw residues (100%)	- 5	-40	- 32’000	0.9
Welfare economic impacts from a ban of burning				
Welfare benefit from ban of residue burning	38	306	489600	N/A*
Protection of remaining hedges	6.8	56	89600	N/A*
Aggregate net-benefits				
Burning banned and all residues are integrated in the soil	**123**	**994**	**1.1 million**	**5.2**

***Assuming that government authorities bear the costs of enforcing a ban on burning, there is no cost involved for farmers.*

TABLE 20B

EANB (GEL), NPV (GEL) and Benefit-Cost Ratios (BCR) for large farmers under a ban on burning scenario (T=10 years, r=4%, cereal cultivation=20,000 ha, land burned=10,000 ha)

Large farmers	EANB/ha	NPV/ha	NPV district wide	BCR
Ecosystem service benefits from not burning				
Residue retention and integration in soil** (100%)	105	855	7.8 million	5.2
Collection and sale of straw residues (100%)	147	1196	11.0 million	2.4
Welfare economic impacts from a ban of burning				
Welfare benefit from ban of residue burning	36	295	5.4 million	N/A**
Protection of remaining hedges	6.8	56	1.0 million	N/A**
Aggregate net-benefits				
Burning banned and all residues are integrated in the soil	**148**	**1206**	**15.8 million**	**6.9**
Burning banned and all straw collected and sold	**190**	**1547**	**17.4 million**	**2.9**

**Averaged across farmers that burn residue on an occasional and a yearly basis.*

***Assuming that government authorities bear the costs of enforcing a ban on burning, there is no cost involved for farmers.*

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[31] *When straw has been shredded it can easily be integrated into the soil when ploughing the soil.*

straw bales this would likely put a downward pressure on prices. Moreover, the price of straw bales varies according to supply and demand conditions inducing a risk to farmers. To mitigate this, it is worthwhile for large farmers to also integrate the residues in the soil, so as to reap the ecosystem service benefits of enhanced soil fertility and soil moisture.

By integrating straw in the soil, **large farmers** may expect an additional GEL 5.2 in revenues for every GEL 1 spent on required farm machinery (notably, combi harvesters). **Small farmers**, may earn an additional GEL 3.7 for every additional 1 GEL spent (Table 20a)

When accounting for the welfare benefit of ensuring a legally enforced ban on burning, the benefits to farmers and society alike are even more pronounced. The stated preference results from the choice experiment exercise shows that farmers would be willing to pay a higher land registration fee to ensure that burning is effectively prohibited. Over a 10-year period, the NPV amounts to approximately GEL 300 per hectare for both small and large farmers. This implies that farmers overall have a preference for using cohesion to enforce an ending of crop residue burning, as opposed to leaving it up to farmers own voluntary decisions. Voluntary action does not protect the individual farmer against the negative externalities associated with neighbouring farmers burning their fields. As mentioned in Section 6.1, however, there is reason to interpret Willingness to Pay results for such policy-oriented questions with some caution.

The choice experiment also revealed that farmers would also suffer a welfare loss with the disappearance of remaining windbreaks. The NPV welfare benefit of protecting remaining windbreaks over the 10-year period is GEL 56 per hectare for both large and small farmers.

Accounting for the benefits of integrating straw and selling in addition to farmers' own stated preferences for a ban on burning and the avoided destruction of remaining windbreaks – the total NPV benefits to small farmers in the Dedoplistskaro district is GEL 0.8 million and between GEL 16 and GEL 17.5 million for large farmers over a 10-year period. Overall, small farmers can expect GEL 5 of benefits for every GEL 1 they spend, and large farmers can expect between GEL 3 and GEL 7 of benefits for every GEL 1 they spend, depending on what they do with the straw residues. It is reasonable to expect that large farmers will eventually do a mixture of residue integration and straw collection to minimise risks.

TABLE 21

Societal estimates for EANB (GEL), ENAC (GEL), NPV (GEL) and Benefit-Cost Ratios (BCR) for farmers, the Georgian and global society. (T=10 years, r=4%, cereal cultivation=20,000 ha, land burned=10,000 ha)

Global benefits	**EANB district-wide**		**NPV district-wide**	
Avoided damages from enhanced carbon sequestration	541,500		4,390,000	
Cost to public authorities	**ENAC district-wide**		**NPV cost district-wide**	
Enforcement and Implementation Costs	15,050		122,000	
Aggregate societal net-benefits	**EANB/ha**	**NPV/ha**	**NPV district wide**	**BCR**
Farmers as a whole	**166**	**1343**	**16.9 million**	**3.8**
Georgian society			**16.8 million**	**4.4**
Global society, including carbon sequestration			**21.2 million**	**5.3**

Assuming that: 8% and 92% of land in Dedoplistskaro district is cultivated respectively by small and large farmers (as revealed by the household survey undertaken for this study), and that large farmers adopt a mixed strategy of collecting half the straw and integrating the other half.

In that case, the NPV benefit of implementing a ban on burning in the Dedoplistskaro distrist, amount to GEL 16.8 million for the Georgian society over a 10-year period. It is assumed that law enforcement costs of GEL 120,000 are borne by Georgian authorities. Accounting furthermore for the benefits of enhanced carbon sequestration, global net benefits are in the order of GEL 21 million.

5.3 District-wide present value benefits and costs from ban on burning

Figure 20 shows **aggregate** present value benefits and costs for all farmers associated with a ban on burning in the Dedoplistskaro district over a 10-year accounting period with a 4 per cent discount rate. As can be seen, the benefits associated with integrating residues (GEL 9.2 million) in the soil and collecting and selling straw bales (GEL 5.5 million) are significantly larger than the present value costs associated with doing so (between GEL 1.1 and 3.7 million).

There are not many windbreaks left in Dedoplistskaro. Remaining windbreaks protect only some 5 per cent of farmland (derived from the basis of farmers' own estimates, Table A4.4, Appendix 4). With few windbreaks left to protect, the present value benefit of protecting these is rather low, equivalent to a present value benefit of GEL 1.1 million. Finally, the legal enforcement and implementation costs (GEL 0.1 million) are minimal compared to the benefits generated to the farming population from invigorating a 'ban on burning' (GEL 16.9 million) and avoided carbon emissions (GEL 4.4 million).

FIGURE 19

Aggregate PV benefit and PV costs in million GEL from a legally enforced ban of crop residue burning (r=4%)

CHAPTER

06

Discussion

The results presented in Tables 20a and 20b lend themselves to the conclusion that crop residues should be used productively and integrated into the soil, as cash-constrained farmers can earn a good return on every Georgian Lari invested in crop retention. However, if crop residue burning was to be prohibited by law and effectively implemented, the final strategy adopted by farmers would most likely be a mixture of crop residue integration into the soil and collection of straw. If farmers realise that significant benefits can be made by integrating residue into the ground at little additional cost, most farmers will choose that strategy. As that happens and supply of straw is reduced, the farmgate market price for straw will increase and more farmers may decide to collect straw as opposed to integrate it. Thus, over time and provided perfect knowledge amongst farmers regarding the benefits of integrating residues, it can be expected that the net benefits from either of these strategies will converge. This will of course also depend on the evolution of the livestock sector in Dedoplistskaro and the potential demand for straw from other industries, e.g. for pellet production.

One may also question why farmers do not voluntary decide to integrate residues, or sell the straw, if the outcome of doing so is as beneficial as our results demonstrate? Aside from prevailing misperceptions about fires controlling pests and fires being good for the ground, there is a crucial issue of timing and acess to capital that intervenes. Currently when farmers harvest, their financial resources are scarce because they have not yet sold their crop harvests. It is therefore difficult for a small, cash constrained farmer to legitimise the additional costs associated with hiring a combi-harvester and in particular a machine to collect and compress straw into straw bales. This obstacle could be overcome if rural financial markets were well established or if there were effective cooperatives that could pool resources for the purchase of farm machinery.

Additionally, there is significant scope for improving farmers' knowledge about sustainable land management practices. Mono-cropping and zero-rotation is common amongst farmers. Cultivating the same crops year after year results in a higher prevalence of pests and diseases and rapid spread where a uniform crop is susceptible to a pathogen. Mono-cropping also adversely affects overall soil fertility. Thus, other measures – in addition to prohibiting burning – including integrated pest management, conservation or no-tillage and frequent crop rotations may be adopted to improve soil fertility levels.

Indeed, lack of extension services and in particular information about the long term negative repercussions on farm systems from burning is hindering progress on uptake of SLM approaches in Georgia. Furthermore, many farmers do not have long-term tenure security to their land, as they are renting from other farmers. This reduces their incentives to invest into soil fertility over the long term.

Despite these challenges, the valuation survey in Dedoplistskaro has revealed that the fires of 2015 have created understanding and urgency around the dangers of fires, especially with regards to their impacts on windbreaks. It is an opportune moment for Georgian society to create further awareness about risks of burning (whether to clear land for weeds or residues) as well as the impacts of burning and the economic benefits that straw can bring.

6.1 Limitations of the study

The stated preference results assessed in Section 4 should be interpreted with some caution. The potential presence of hypothetical bias is known to lead to overstatements of true WTP in stated preference methods and will potentially lead to the overestimation of welfare measures for the specific scenarios (Harrison and Rutström 2008). There are different sources of hypothetical bias but considering the relatively high WTP estimates for a ban on burning in this study, it is possible that the estimate is a reflection of farmers interest in influencing political outcome (i.e. strategic bias), as opposed to their true Willingess to Pay for a ban on burning. Meta-analysis conducted by List and Gallet (2001) and by Murphy et al. (2005) suggests that mean hypothetical values can be about 2 to 3 times greater than actual cash payments. In this study, we have no proof of whether political or strategic bias has been a source of inflated willingness to pay for a ban on burning. Independently of that, the net benefits of integrating crop residues and collecting and selling straw (aggregate NPV of GEL 10 million from Tables 20a and 20b) provides a safe lower bound estimate of the benefits of banning burning to farmers.

But these results should nevertheless be treated as lower bound estimates of the true benefits of prohibiting fires. We have not valued the additional benefits, accruing to:

- health benefits from improved air quality;
- the protection of biological pest control functions that windbreaks offer;
- the likely reduced fire suppression costs to public authorities; and
- the enhanced protection of perennial farm systems such as vineyards.

These benefits are likely to be significant. Furthermore, there are uncertainties regarding how some of the parameters used in the analysis will evolve in the future, for example the prices for straw. We have therefore used conservative estimates where possible so as to produce lower bound benefit estimates.

CHAPTER

07

Conclusion

Crop residue burning has proven to be an inexpensive and convenient way of managing excess straw. But the significant energy embedded in straw can profitably be exploited for fuel instead of going up in smoke. Alternatively, if left in the ground, crop residue can provide a protective layer for soil erosion by wind or water, increase the organic matter and water holding capacity of the soil, and provide 'feed and forage' for earth worms. When crop residue is burned all of those benefits are lost and other damages, e.g. to perennial farm systems and windbreaks are done. Moreover, without residue on the soil surface, the ground is susceptible to erosion and the depletion of organic matter (Fasching 2001). Thus, although there may be some short-term cost savings to crop residue burning there is a slow, steady and sure reduction in soil health including microbial activity, carbon and nitrogen pools and moisture content, that will eventually result in reductions in productivity that cannot be overcome with increased additions of mineral fertilisers.

The agronomic and economic results from this study confirm these findings and clearly demonstrate that there are multiple long-term economic and social benefits associated with ending crop residue burning once and for all within the Dedoplistskaro district. Moreover, the farming population itself demonstrates significant welfare benefits from and preferences for a ban of burning. Because fires easily spread across fields, their impacts cannot be effectively mitigated if farmers unilaterally decide not to burn. It is a collective action problem that has to be dealt with by leveraging effective institutional powers.

Finally, in the context of an increasingly imminent climate crisis there are reasons to prioritise changes to how we manage land. The agricultural sector is characterised by a large technical carbon mitigation potential, offering comparably more cost effective mitigation options than other sectors of the economy (FAO 2013). When adequately targeted, GHG mitigation in agriculture is closely linked to benefits for climate change adaptation and food security (as shown above). Georgia would hereby make a serious contribution towards the achievement of UN Sustainable Development Goal 15 – Life on Land, carbon emissions reductions through the UNFCCC process and goals in the Convention on Biological Diversity.

References

Anthoff, D., Tol, R.S.J., (2010). Climate policy under fat-tailed risk: an application of FUND. Working Paper No. 348, June 2010. The Economic and Social Research Institute (ESRI), Dublin

Birol, E., Karousakis, K., Koundouri., (2006). Using a choice experiment to estimate the non-use values of wetlands: The case of Cheimaditida wetland in Greece, Ecological Economics 60 (1), 145-156.

Camacho, A., Oberthür, F., Waldmüller., L (2015). Sustainable Management of Biodiversity, South Caucasus. Recommendations on Sustainable Agriculture Promotion and Agrobiodiversity for the Program on Sustainable Management of Biodiversity in Georgia

Rossi, J., (2009). Feeding Straw to Beef Cattle. The University of Georgia, College of Agricultural and Environmental Sciences. Available from URL *www.caes.uga.edu/commodities/fieldcrops/forages/newinfo/ADS/feeding%20straw%20to%20beef%20cattle.pdf*

Chidumayo, E. N. (1987), A shifting cultivation land use system under population pressure in Zambia, Agrofor. Syst., 5, 15–25.

CIA, The World Factbook: Georgia, (2011). *https://www.cia.gov/library/publications/the-world-factbook/geos/gg.html*

DeBano, L.F., Neary, D.G., Ffolliot, P.F., (1998). Fire's Effects on Ecosystems, first ed. Hoboken, New Jersey.

Ekboir, J., (2002). World Wheat Overview and Outlook: Developing No-Till Packages for Small-Scale Farmers, 74 pp., Int. Maize and Wheat Improve. Cent. (CIMMYT), Mexico City, Mexico.

ELD Initiative (2015). ELD Initiative User Guide: A 6+1 step approach to assess the economics of land management. GIZ: Bonn, Germany.

EPA (2015). Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 (May 2013, Revised July 2015). *https://www3.epa.gov/*

Fasching, R.A., 2001. Burning-Effects on Soil Quality. Agronomy Technical Note No. 150.16. USDA NRCS, October.

FAO (2013). User Manual for Estimating GHG in Agriculture with EX-ACT. Estimating and Targeting Greenhouse Gas Mitigation in Agriculture, Livestock, Forestry and Land Use Projects

- Free Tool Access: *www.fao.org/tc/exact/carbon-balance-tool-ex-act*
- EX-ACT User Manual & EX-ACT Quick Guidance: *www.fao.org/tc/exact/user-guidelines*

FAO and Georgia Ministry of Agriculture (2011). Georgia: Agriculture Sector Bulletin. *www.fao.org/fileadmin/templates/tc/tce/pdf/Georgia_Ag_Sector_Bulletin_Winter_2011.pdf*

GFMC (2015) Wildfires in Dedoplistskaro Municipality Shiraki Valley, Georgia. Rationale and Proposal for a Fire Management Concept. Report by the Global Fire Monitoring Center (GFMC). Working Paper 70/2015. Available from URL: *http://www.fire.uni-freiburg.de/GlobalNetworks/SEEurope/Fire-Management-Concept-Dedoplistskaro-Georgia-GFMC-GIZ-WP-70-ENG.pdf*

GIZ (2014). BioFacts. Dedoplistskaro district Windbreaks. May 2014.

Harrison, G.W., Rutström, E.E., 2008. Experimental Evidence on the Existence of Hypothetical Bias in Value Elicitation Methods. In: Plott C, Smith VL (eds) Handbook of Experimental Economics Results. Elsevier Science, New York, 752-767.

Hall, J.B., Seay, W., (2009). Nutrition and Feeding of the Cow-Calf Herd: Essential Nutrients, Feed Classification and Nutrient Content of Feeds.

Helbig, F., (2016). Energy demand assessment in the municipalities of Dedoplistskaro and Akhmeta. Sustainable Management of Biodiversity, South Caucasus

Heard, J., Cavers, C. and Adrian, G. (2006). Up in Smoke --Nutrient Loss with Straw Burning. Better Crops, Vol 90 (2006, No 3.).

Holmgren, L., Cardon, G., and Clint Hill (2014) Economic and Soil Quality Impacts from Crop/Rangeland Residue Burning. AG/Forages/2014-02pr. Extension Utah State Uniersity.

Hope, C., (2013). Critical issues for the calculation of the social cost of CO_2: why the estimates from PAGE09 are higher than those from PAGE2002. Clim. Chang. 117, 531–543.

Hope, C., (2006). The marginal impact of CO_2 from PAGE2002: an integrated assessment model incorporating the IPCC's five reasons for concern. Integr. Assess. J. 6 (1), 19–56. Hope, C., 2008. Discount rates, equity weights and the social cost of carbon. Energy Econ. 30, 1011–1019.

IPCC (2006) IPCC Guidelines for National Greenhouse Gas Inventories. Agriculture, Forestry and Other Land Use. Volume 4. Available from URL: *http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html*

Korontzi, S., McCarty, J., Loboda, T., Kumar, S., Justice, C.O. Global Distribution of Agricultural Fires from Three Years of MODIS Data; Global Biogeochem. Cy. 2006, 20, 2021; doi: 10.1029/2005GB002529. *http://onlinelibrary.wiley.com/doi/10.1029/2005GB002529/full*

Lancaster, K. J., (1966). A New Approach to Consumer Theory. Journal of Political Economy 74 (2), 132- 157.

Li S., Xiao L. (1992). Distribution and management of drylands in the People’s Republic of China. Advances in Soil Science, 18: 148–293

List, J.A., Gallet, C.A., 2001. What experimental protocol influence disparities between actual and hypothetical stated values. Environmental and Resource Economics 20 (3), 241-254.

Louviere, J., Hensher, D.A., Swait, J., (2000). Stated choice methods: Analysis and application. University Press, Cambridge, England.

Manski, C., (1977). The structure of random utility models. Theory and Decision 8, 229-254.

McVay, K.A. (2003). Value of Crop Residue, Kansas State University Department of Agronomy. MF-2604.

Montenegro A, Brovkin V, Eby M, Archer D, Weaver A.J., (2007). Long term fate of anthropogenic carbon. Geophys Res Lett 34:L19707. doi:10.1029/2007GL030905

Murphy, J., Stevens, T., Allen, P., & Weatherhead, D. (2005). A meta- Harrison, G.W., Rutström, E.E., 2008. Experimental Evidence on the Existence of Hypothetical Bias in Value Elicitation Methods. In: Plott C, Smith VL (eds) Handbook of Experimental Economics Results. Elsevier Science, New York, 752-767.

analysis of hypothetical bias in stated preference valuation. Environmental and Resource Economics, 30(3), 313-325.

Russell M.A., Robles Gil R. R., Hoffman, M., Pilgrim, J., Brooks T., Mittermeier, C.G., John Lamoreux, J., Gustavo A.B., (2005). Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions, Conservation International, The University of Chicago Press, 392 p. *http://www.biodiversityhotspots.org*

Neuman, W. L. (1991). Social Research Methods, Qualitative and Quantitative Approaches, Allyn and Bacon, Boston, MA

Nunes, M.C.S., Vasconcelos, M.J., Pereira, J.M.C., Dasgupta, N., Alldredge, R.J., Rego, F.C., (2005). Land cover type and fire in Portugal: do fires burn land cover selectively? Landsc. Ecol. 20 (6), 661–673;

Skidmore, E.L., Layton, J.B., Armbrust, D.V., Hooker M.L., (1986). Soil Physical Properties as Influenced by Cropping and Residue Management. Soil Science Society of America Journal, Vol 50, No. 2, March – April.

Smith, P., Martino, Cai, Z., Gwary, D., Janzen, P. H., Kumar, B., McCarl, S. Ogle, F., Rice, B. Scholes, Sirotenko. O., (2007). Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Stoof, C.R., Wesseling, J.G., Ritsema, C.J., (2010). Effects of fire and ash on soil water retention. Geoderma 159 (4), 276–285.

Fasching, R.A., (2001). Burning-Effects on Soil Quality. Agronomy Technical Note No. 150.16. USDA NRCS, October.

Moore, F., Diaz, D., (2015). Temperature impacts on economic growth warrant stringent mitigation policy, Nature Climate Change 5, 127–131.

National Statistics Office of Georgia (2014). Data provided by I. Kochlamazashvili, ISET Policy Institute www.iset-pi.ge. *https://pubs.ext.vt.edu/400/400-011/400-011_pdf.pdf Publication 400-011*

Nordhaus, W.D., (2008). A Question of Balance: Weighting the Options of Global Warming Policies. Yale University Press, New Haven

Nordhaus, W.D., (2011). Estimates of the social cost of carbon: background and results from the RICE-2011 model. *http://www.econ.yale.edu/~nordhaus/homepage/ documents/CFDP1826.pdf*

NBSAP-2. Second Biodiversity Strategy and Action Plan of Georgia (2012-2013). Draft version submitted to MoENPR.

UNEP (2012). Pan-European 2020 Strategy For Biodiversity

UNSD (2008). Designing household survey samples: Practical guidelines', Studies in Methods Series F, No 98, Department of Economic and Social Affairs, Statistics Division, United Nations, New York

Steduto P., Hsiao TC., Raes, D., Fereres, E., (2009) AquaCrop-The FAO crop model to simulate yield response to water. I. Concepts. Agronomy Journal. 101: 426–437. doi: 10.2134/agronj2008.0139s

Steiner J.L. (1989). Tillage and surface residue effects on evaporation from soils. Soil Science Society of America Journal, 53: 911–916.

Stoof, C.R., Ferreira, A.J.D., Mol, W., Van den Berg, J., De Kort, A., Drooger, S., Slingerland, E.C., Mansholt, A.U., Ferreira, C.S.S., Ritsema, C.J., (2015). Soil surface changes increase runoff and erosion risk after a low–moderate severity fire. Geoderma 239–240 (0), 58–67

Van den Bergh, J.C.J.M., Botzen, W.J.W., (2014). A lower bound to the social cost of CO_2 emissions. Nat. Clim. Chang. 4, 253–258 (April).

White House, (2013). Technical update of the social cost of carbon for regulatory impact analysis. Retrieved on [04/20/2015] from *www.whitehouse.gov/sites/default/ files/omb/inforeg/social_cost_of_carbon_for_ria_2013_ update.pdf*

World Bank (2007). Integrating Environment into Agriculture and Forestry, Progress and Prospects in Eastern Europe and Central Asia: Volume II, Georgia Country Review.

List of figures

List of tables

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