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Design, Management and Efficiency of Community Based Electric Fencing in Mitigating Human-wildlife Conflict

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Abstract

Low cost electric fencing called Fabricated Electric Fence System is widely used to manage human-wildlife conflict in Bhutan. It is promoted through Community Based Electric Fencing (CBEF); however its technical design, management and efficacy in the field are not properly studied. Therefore, this study assessed the fence design, voltage, maintenance system and effectiveness of seven CBEFs in Wangduephodrang district. The technicalities of CBEFs were evaluated based on technical manual of electric fence of Bhutan and effectiveness through farmers' interview. The IEC-60335-2-76 certified Polar Lanstar energizers were found vulnerable to lightning damage and had insufficient solar power to recharge battery during cloudy weather condition. Two out of seven CBEFs assessed had guard power supply below minimum standard voltage of 3 kV. The length of fence given to an energizer (58%) and number of short circuit along the fence perimeter (36%) accounted the variation on fence voltage. The entire five strand wired CBEFs with the mean spacing of 30.3 cm (*SD* = ±10), 40.5 cm (*SD* = ±8.4), 70.4 cm (*SD* = ±13), 115 cm (*SD* = ±13) and 160 cm (*SD* = ±14.4) from the ground level proved effective against most of the animals except porcupine and monkeys. Although, all CBEFs had their management plans and by-laws enacted, only 50% of the respondents mentioned that it is effectively implemented. However, CBEFs were able to reduce crop loss per season compared to past as follows: rice from 35.4% to 3.6%, potato from 33.1% to 1.4%, maize from 40.9% to 7.9%, wheat from 30.7% to 1.7% and significantly reduce crop guarding time. Despite shortcomings in the management systems, crops saved and reduction in crop guarding time was considerable.

Keywords: Community Based Electric Fencing, design, efficacy, human wildlife conflict

Introduction

In Bhutan, Human Wildlife Conflict (HWC) is one of the main factors challenging achievement of food self-sufficiency by exacerbating poverty, increasing rural-urban migration and increasing fallow agricultural lands in rural areas (Tobgay, 2005; Penjor *et al.*, 2014). Amongst the various mitigation measures tested and promoted, Fabricated Electric Fencing system (FEF) is increasingly being used. After the official approval for its use by Bhutan Electricity Authority (BEA) and Bhutan Power Cooperation (BPC) in 2013, more than 4,000 km of FEF had been established across the country protecting about 40,000 acres of agricultural land benefiting more than 10,000 rural households (NPPC, 2017). Since then, standard guidelines were developed and electric fencing projects were up-scaled through Community Based Electric Fence

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(CBEF) approach. However, its effectiveness under community management and their technical design in the field are yet to be demonstrated and documented.

Over the years, the CBEF approach has been debated in the country several times. While there are media reports, studies and farmers appreciating its effectiveness, there are also cases where CBEFs are ineffective and unsuccessful. For instance, solar fencing at Tashicholing Geog in Samtshe Dzongkhag has completely failed (Lhamo, 2015) and CBEF at Dhukti at Yalang Geog in Trashiyangtshe was reported to be dysfunctional (Wangdi, 2016). Whilst such cases are yet to be determined, studies conducted across the country indicated that the electric fencing is effective both in terms of deterring crop raids by animals (Chettri *et al*., 2013) and reducing costs (Penjor *et al*., 2014). However, most of the studies were designed to assess the impact of CBEF through farmers' interview mostly based on socio-economic indicators. There is no study investigating how the fencings are technically designed and managed in the field to identify and rectify errors.

According to the literatures on the use of electric fencings, a number of factors including fence design, voltage, maintenance, wildlife pressure and animal behaviour influence the success of the fencings (Garai and Carr, 2001; Hoare, 2003). Although, voltage does not indicate the energy available to deliver an effective shock, it should be maintained above 3 kV and the fence design depends on the size and agility of the animal species to be managed (McKillop *et al.,* 2003). Another important aspect of electric fencing is the maintenance system. According to Taylor (1999), in countries where wildlife management schemes operate at a local level, the effectiveness of electric fencings is disappointing mainly due to maintenance deficiencies.

Therefore, this study assessed (i) the voltage and technical design of electric fencing in the field, (ii) implementation approach and management systems of CBEFs, and (iii) effectiveness of electric fencings in terms of crops and guarding time saved in seven CBEFs of Wangduephodrang Dzongkhag. The overall design of the CBEFs was evaluated in accordance with the technical reference manual for installation and maintenance of electric fence of Bhutan. Similarly, the efficacy of CBEFs was determined through farmers' interview following the installations of the CBEFs.

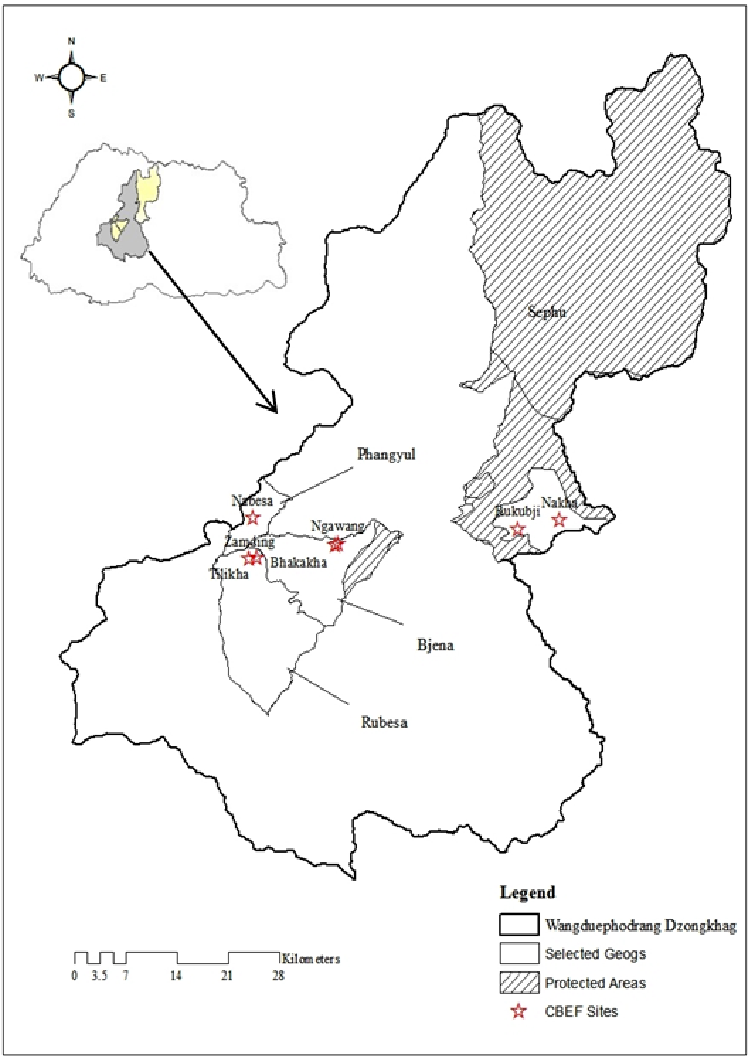

Figure 1: Map showing study area

Materials and Method

Study sites

Wangduephodrang Dzongkhag was selected for this study as it is considered as one of the HWC hotspots in western Bhutan (NPPC and WWF-Bhutan, 2016). Mostly established in between the year 2014 and 2016, Wangduephodrang Dzongkhag has 98.46 km of electric fencing covering 940.04 acres of agricultural land benefiting 395 households (NPPC, 2016). However, in order to same resources, only the CBEFs that had benefited at-least one cropping season during the time of the study were considered. Hence, Bhakakha and Ngawang CBEFs from Bjena Geog; Nabesa CBEF of Phangyul Geog; Tilikha and Zamding CBEFs of Rubesa; and Nakha and Rukubji CBEFs from Sephu Geog of Wangduephodrang Dzongkhag were considered for this study (Figure 1).

The CBEFs were established to protect crop depredation by wild animals such as wild boar, sambar, deer and monkeys. In CBEF of Bhakakha, Ngawang, Nabesa and Zamding, paddy and potato are the main crops grown by the farmers. Farmers of Nakha and Rukubji of Sephu Geog grow potato. The community of Tilikha practice maize based farming system. The CBEFs are repaired and maintained according to the management plans and by-laws of the respective sites.

Assessment of management systems and efficacy of CBEFs

As shown in the Table 1, 100% of farmers from Bhakakha, Nabesa, Tilikha, Zamding and 71% from Ngawang and 65% from Rukubji were randomly selected for face to face interview to obtain information on effectiveness and management systems of electric fencings. However, none of the beneficiary farmers from Nakha could be sampled as they could not provide information from the past on the electric fencings.

A pre-tested semi-structured questionnaire consisting of three broad sections was employed. First section of the questionnaire was intended to collect information on inception, planning, and installation processes of CBEFs. The other two sections collected information on implementation of management plans in repairing and maintenance of CBEFs and HWC situation before and after the establishment of CBEFs.

Assessment of electric fence components and design

The appropriateness of the overall set up of the electric fences was evaluated based on the "technical reference manual for installation and maintenance for Bhutan" produced by ARDC Wengkhar (2015). The data were collected from December 2016 to February 2017. The energizers used in the electric fencings were assessed for their brand, capacity and power source for

Table 1: Description of selected CBEFs and number of beneficiary farmers interviewed

Geog	Name of CBEF	Fence length (km)	Beneficiary farmers (no.)	Area covered (acres)	Year of establishment	Funding Agency	Farmers interviewed (no.)
Bjena	Bhakakha	2.71	12	42.5	2015	GDG	12
	Ngwang	3.63	35	75.0	2015	GDG	25
Phangyul	Nabesa	1.61	9	16.4	2014	SNV	9
Rubesa	Tilikha	2.66	7	20.0	2015	UNDP	7
	Zamding	3.14	17	45.0	2015	UNDP	17
Sephu	Nakha	1.90	11	20.1	2015	NPPC	0
	Rukubji	1.98	31	32.0	2016	NPPC	20
Total		**17.63**	**122**	**251**			**90**

operation. In case of the solar powered energizers, watt of solar panel, voltage output of the battery and specification of charge controller were evaluated.

At every 100 m along the fence perimeter, the number of wire strands were counted and the spacing in-between the wires were measured using measuring tape. Number of incidences of current leakage was spotted by visual observation and locating clicking sound along the fence perimeter of an energizer. The causes of current leakages were categorized as uncut vegetation, insulator defects, post defects, uneven ground level and wire tension. At the end of the fence perimeter of an energizer, the voltage of the fence wires was measured in kV using Lanstar Voltmeter model LX-CLB.

Data analysis

The data were analyzed using Microsoft Office Excel spreadsheet and Statistical Package for the Social Sciences (SPSS). A simple linear regression analysis was performed to study the effect of fence length per energizer and number of incidences of current leakages over fence voltage. The farmers opinions on the effect of CBEFs in terms of percentage of crop saved, crop guarding time, and other socio-economic information were assessed by comparing post and prior CBEF establishment scenario using paired samples *t*-test. Unless otherwise stated, 95% significance level was used to accept or reject null hypotheses.

Results and Discussion

Fence design and components

The details of energizers used for respective study areas are given in Table 2. The study noted that all CBEFs used two joule Chinese made fence energizer Polar Lanstar S2 which can be either used with solar power or hydroelectricity. Out of the seven CBEFs inspected, six CBEFs used hydroelectricity and one of the two at Rukubji CBEF used solar power. Initially, both the energizers of Rukubji CBEF were powered by 30 watt solar panel circuited through 12 volt lead acid battery and 12/10 ampere charge controller. However, one of the energizer was damaged by lightning and is now replaced with hydroelectric power. The community has plans to switch the one with the solar power energizer to electricity as the solar is not able to charge the battery sufficiently when the weather is cloudy.

Energizer damage by lightning during monsoon is seen as one of the common problem which was also observed in the case of Ngawang CBEF where two energizers out of four were damaged by lightning. The CBEF also fails when the hydro-power electricity is cut off. This issue was raised by the community of Nakha CBEF in Sephu Geog where power cut off can last for several months. The representatives from the community suggested that solar panel could be installed as alternative source of power in the event of electricity black out.

As shown in Table 2, the CBEF with longer fence length used higher number of energizers. Also, the division of fence length to each energizer was not equal. As the fence perimeter covered by an energizers increase, the output voltage tends to drop. This situation was observed in the case of Nakha CBEF. An energizer connected to 1.9 km fence perimeter had an output voltage of 1.7 kV only.

Fence voltage

As per the electric fence manual developed by WWF (1999), the guard voltage above 5 kV is rated as a good fence, 3-5 kV as reasonable fence and below 3 kV as poor fence. Following this guideline, majority of the CBEFs inspected had very good voltage but the energizers of Bhakakha and Nakha was very poor (Table 2). It was not possible to assess the reason for the low voltage at Bhakakha. In case of Nakha, low voltage could be attributed to the length covered by the energizer. Only a single energizer was connected to about 2 km of 5 strand wires, whereas the energizers of the other fencing sites carried a maximum of 1.5 km only.

However, despite having low voltage of 1.7 kV in the CBEFs, the beneficiary farmers were satisfied that not a single animal broke through

Table 2: Details of energizers used in each CBEF sites

CBEF	Fence length (km)	No. of energizer	Energizer ID	Power source	Length/ energizer (km)	No. of wire strand	Fence voltage (kV)
Bhakakha	2.71	2	Energizer 1	hydro	1.30	4	3.0
			Energizer 2	hydro	1.41	4	2.5
Ngawang	3.63	4	Energizer 1	hydro	0.86	5	5.8
			Energizer 2	hydro	0.87	5	5.3
			Energizer 3	hydro	0.74	5	6.1
			Energizer 4	hydro	1.16	5	4.3
Nabesa	1.61	2	Energizer 1	hydro	0.87	5	5.2
			Energizer 2	hydro	0.74	5	5.6
Tilikha	2.66	2	Energizer 1	hydro	1.27	6	4.3
			Energizer 2	hydro	1.39	6	4.8
Zamding	3.14	3	Energizer 1	hydro	0.60	6	7.0
			Energizer 2	hydro	1.28	6	4.1
			Energizer 3	hydro	1.17	6	5.1
Nakha	1.90	1	Energizer 1	hydro	1.90	5	1.7
Rukubji	1.98	2	Energizer 1	hydro	0.90	5	8.2
			Energizer 2	solar	0.82	5	6.8

the fence. This situation confirms to the finding of Brown (1996) that a minimal voltage of as low as 1 kV would be effective to control wild pigs. Another reason for low voltage might be because of voltage leakage through the barbed wire that the farmers have installed in the lower part of the fence. Farmers have also fixed two additional strands of barbed wire at the lower part of the fence, which contradict the norms of electric fencing.

Effect of fence length on voltage

Actual length covered by each energizer was calculated to one strand of wire to obtain uniformity. A simple linear regression was calculated to predict the output voltage of the fence based upon the length covered by each energizer keeping other factors constant. A significant association was found between the length and the voltage output; $F_{(1, 14)} = 18.96$, $p = .001$; $r^2 = 0.575$ (Figure 2).

The predicted fence voltage is ˉy = -.598x + 8.53 when the fence length covered by an energizer is measured in km. The output voltage on the fence decreased by 8.53 kV for e km of fence load given to the energizers. Therefore, since the use of higher capacity of energizer is not allowed as per the electric fence standards of Bhutan, another option is to reduce fence perimeter for an energizer.

Number of wire strand and spacing

The five strand wires of the fences had the above ground mean spacing of30.3 cm (*SD* = ±10), 40.5 cm (*SD* = ±8.4), 70.4 cm (*SD* = ±13), 115 and 160 cm (*SD* = ±14.4)]. None of the

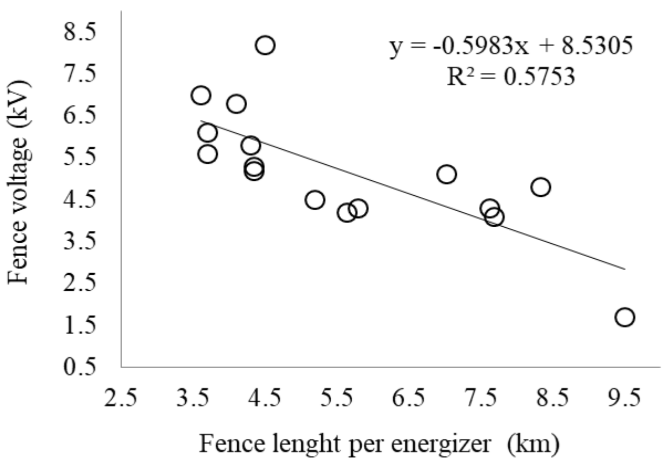

Figure 2: Association between fence length and voltage output

CBEF however was effective against porcupine and monkey. As per ARDC Wengkhar (2015) if porcupine is a problem, the first wire should be at 15 to 16 cm from the ground level. In all the CBEFs, the first wire from the ground level was at 30.3 cm (*SD* = ±10). However, at Rukubji, farmers have fixed wooden planks in-between ground and the first wire to control such species. Though, crop raid by porcupine was common amongst all the CBEFs, crop damage was comparatively lower than that by animals such as wild pigs and sambar. Beneficiary farmers expressed that the lower most wire was purposefully kept higher so that the vegetation does not touch the wire in a short time and space is adequate for cleaning.

The spacing in-between the rest of the wire strands were standard in preventing damages by animals such as stray cattle, wild pig, sambar and barking deer. Since the occurrence of monkey at Tilikha and Zamding was higher, six strands of wires were used in these sites.

Number of incidences of short circuit

In all the CBEFs, short circuits because of over grown grasses were the highest cause of electric fence failure followed by insulator defects, pole defects; uneven grounds and inadequate wire tension (Table 3). Hence, farmers must ensure timely maintenances of the electric fences. Short circuits at Nakha and Rukubji were comparatively less in the study areas. This is because these places are located at higher altitudes. Additionally, these places have less slope gradients making the maintenance works easier.

Effect of current leakage on fence voltage

According to Hoare (2003) any instance of insulated fence wire coming in contact with earth, stone, fencing post causes power leakages and vegetation over growth conceals the fence from being a barrier to the targeted animals. Keeping vegetation growth under control along the fence line in the growing season is a challenge in electric fence management (Hoare, 2003). As similar incidences of current leakage were found from the study areas (Table 2), the effect of leakage on output voltage was performed using a simple linear regression. Using the output voltage as a dependent variable to number of incidences of short

Table 3: Number of incidences of current leakage and its causes

CBEF	Energizer ID	Vegetation not cleared	Insulator defect	Pole defect	Ground level	Wire tension	Total
Bhakakha	Energizer 1	21	7	5	3	3	39
	Energizer 2	16	6	9	6	4	41
Ngawang	Energizer 1	9	5	3	3	2	22
	Energizer 2	12	5	2	3	2	24
	Energizer 3	12	4	2	1	2	21
	Energizer 4	13	6	6	4	1	30
Nabesa	Energizer 1	11	6	3	1	1	22
	Energizer 2	9	4	3	4	2	22
Tilikha	Energizer 1	10	5	5	3	4	27
	Energizer 2	9	8	5	4	2	28
Zamding	Energizer 1	5	2	1	1	1	10
	Energizer 2	9	4	3	2	2	20
	Energizer 3	10	5	2	2	1	20
Nakha	Energizer 1	2	3	4	1	3	13
Rukubji	Energizer 1	3	3	2	1	1	10
	Energizer 2	2	6	4	2	1	15
Total		**153**	**79**	**59**	**41**	**32**	**364**

circuit, a model of $F_{(1, 14)} = 7.88$, $P = .014$ with an r^2 of .36 was found (Figure 3).

According to this analysis, 36% of the variation in fence voltage can be explained by the number of short circuit along the fence perimeter. Therefore, to keep fencing effective, proper monitoring mechanism to rectify such flaws should be adopted by beneficiary farmers.

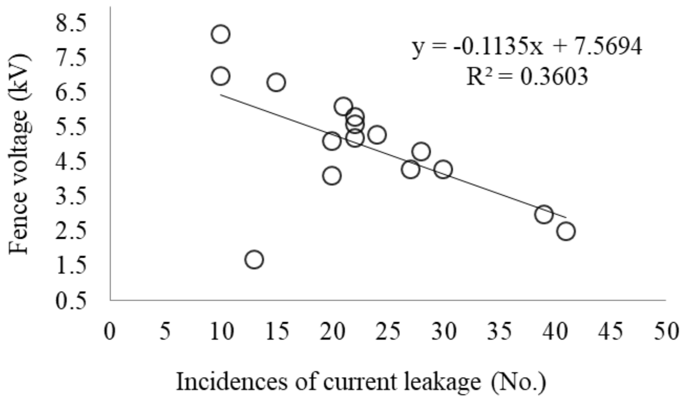

Figure 3: Association between number of current leakages and voltage

Planning and installation of CBEF

In the study areas, more than 70% of the beneficiary farmers proposed electric fencing except in Tilikha with 57%. While more than 70% of the respondents from all CBEFs were involved in planning, highest number of respondents who did not participated in planning was from Bhakakha (30%). It is important that all beneficiary farmers participate in planning so that the beneficiary farmers can determine the fencing line (ARDC Wengkhar, 2015). More than 90% of the farmers were also involved in installation and received training on making electric fence.

In order to manage electric fencing effectively, it is important for the beneficiary farmers to know basic management aspects of electric fencing (ARDC Wengkhar, 2015). More than 60% of the respondents knew the basic aspects of electric fencing (Table 4). However, farmers who knew how to install earthing were 36% and energizer was 16% only. The finding indicated that focus should be given to train farmers on installation of energizers and earthing so that they do not have to rely on experts from outside the group.

Table 4: Farmers knowledge on electric fencing

Knowledge on electric fence	% (*n* = 90)	
	No	Yes
Working principle of electric fence	31.1	68.1
Clearing vegetation	5.6	94.4
Preparing and fixing insulators	27.8	72.2
Earthing installation	64.4	35.6
Earthing should be kept moist	35.6	64.4
Installation of energizers	84.4	15.6
Testing current on fence	21.1	78.9

Challenges in planning and installation of CBEF

Unlike the formation of other self-help groups where membership can depend upon the interest of an individual farmer, the case of electric fencing seems different. Since the entire community had to be covered inside the fence, leaving some households outside the fence boundary is not sensible (ARDC Wengkhar, 2015). However, there were some community members who did not want to be in the group because of various reasons (Figure 4b). In all the sites, there were some households unwilling to join the group (Figure 4a).

Amongst various reasons, households located in the middle of the community who faced less pressure from wild animals were the largest group who were not willing to go for CBEF (44%). It was followed by farmers who had comparatively less land (39%) and argue that it is unfair for them to contribute equal labour and resources for construction and repair of electric fencing. Other community members unwilling to participate during the inception of CBEF were households with fewer household members and who lacked confidence on electric fencing. However, these issues were resolved through group discussions with the help of Geog administration or the technical agencies providing assistance to install the fences.

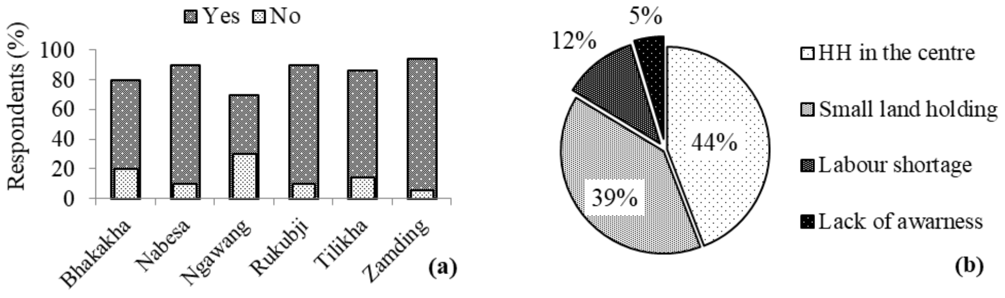

Figure 4: (a) Responses on whether all the community members were willing to participate in CBEF and (b) reasons for not willing to participate in CBEF

This study also explored existence of absentee households in the areas and their implication in planning, establishment and management of CBEF. From the respondents, 88% from Nabesa, 86% from Tilikha and 73% from Zamding expressed that the empty households are problematic. Generally, when such absentee households and their land are situated in the middle of the community; they had to be included inside the fence by default. In such a situation, the owners of the empty households should to be traced and made to contribute labour and resources.

Implementation of repair and management systems

According to Hoare (2003), electric fence is only as good as its maintenance, which has to be continual and meticulous. As per the finding of WWF (1998) in Africa, collective maintenance of an electric fence by a rural community has often failed because it involves a long chain of responsibility, which easily fails at the weakest link. Similarly, in this study, an attempt was made to explore how CBEFs are managed by the beneficiary farmers.

As shown in Table 5, 24% (n = 22) of the respondents out of 90 did not participate in making management plans and by-laws to manage CBEF. Ideally, every household should participate in such important discussion so that the outcome is agreed by every member (ARDC Wengkhar, 2015). Regarding strict enforcement of management plans by imposing fines and fees, the responses were almost 50% positive and 50% otherwise.

Table 5: Implementation of repair and maintenance systems

	Frequency (n = 90)	
	No	**Yes**
Were you involved in framing management plans and by-laws?	22	68
Were the management plans and by-laws strictly followed?	43	47
Did the Chairman and executives members fulfill all their duties?	46	44
Were the collection of fees and fines strictly followed?	48	42
Does poor repair and maintenance impact effectiveness of EF?	34	56

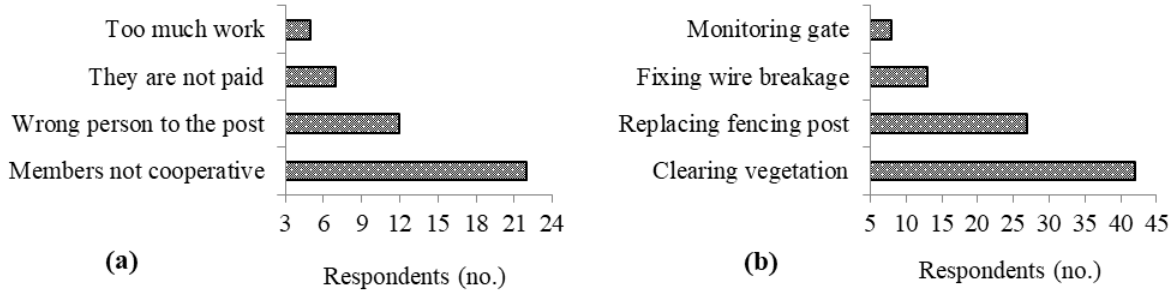

Figure 5: (a) Reason for chairperson and other executive members not being able to fulfill their roles and responsibilities and (b) most difficult part of maintaining electric fencing

About 50% (n = 46) of the respondents also revealed that chairperson and other committee members were not able to fulfill their responsibilities; highest reason being the beneficiary farmers not cooperative with the executive committee members (Figure 5a). Almost 50% out of 90 respondents experienced clearing vegetation as most difficult part of maintaining electric fencing (Figure 5b). Hoare (2003) also mentioned that keeping vigorous growth of vegetation clear of a fence line in the growing season is a perennial problem that characterizes the management of electric fences.

Mitigation of agricultural crop depredation

Mitigation of agricultural crop depredation by wild animals is the primary objective of establishing electric fencing in Bhutan. In this study, only the major crops grown by the farmers of respective CBEFs were taken into account. Following the control treatment concept, opinions of the beneficiary farmers on the crop loss in kg/acre per season to wild animals before (control) and after CBEF establishments (treatments) were assessed.

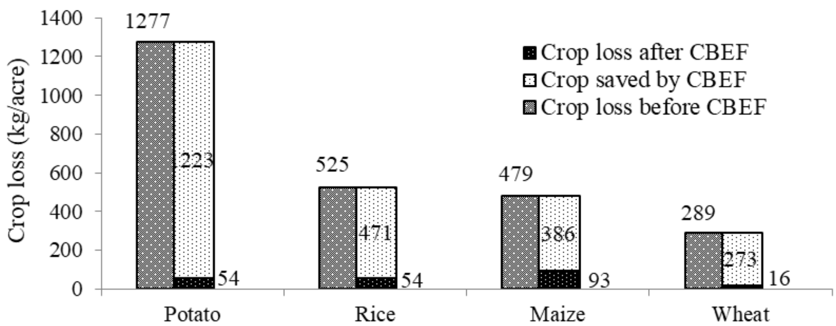

Figure 6: Crops loss before and after CBEF

From the mean potential yield of 1,482.2 kg/acre of rice (*SD* = ±220.4); 35.4% was lost to wild animals per season before and 3.6% after CBEF establishment. A paired-samples *t*-test conducted to compare rice loss before (*M*=524.8, *SD*= ±189.5) and after CBEF (*M*=53.6, *SD*= ±59.6) establishments showed significant difference; $t_{(62)} = 21.02$, $p = .000$.

In terms of quantity, electric fence was able to save 471.2 kg/acre (31.8%) of rice per season from the potential yield (Figure 6). The saved yield amounts to Nu. 28,270.8 (*SD* = ±10,675.1) per household per season when calculated at the rate of Nu. 60/kg following the RNR statistics of 2015.

Similarly, after establishment of CBEF, potato loss in kg/acre per season to wild animals reduced to 1.4% from 33.1% with a net saving of 31.7% in yield. A paired samples *t*-test of potato loss before (*M* = 1,277.1, *SD* = ±576.3) and after (*M* = 54.5, *SD*= ±94.3) establishment of CBEF showed significance difference; $t_{(71)} = 17.60$, $p = .000$. As shown in Figure 6, 1,223 kg/acre of potato was saved by electric fencing per season per household and the perceived saving in terms of monetary value was Nu. 30,565. Similar result was reported by WCD (2013) in Ura Geog where farmers reported increased yield by 1,417 kg/acre after establishment of electric fencing.

In case of maize,

Table 6: Man-days spent in guarding crops before and after CBEF establishment

Crops	*N*	Before CBEF establishment						
		Days		Nights		Total	Man-days in monetary value	
		Mean	*SD*	Mean	*SD*		Rate/man-day*	Amount (Nu.)
Paddy	58	14.4	±7.3	68.9	±24.7	83.3	215	17,909.5
Potato	70	19.2	±10.2	74.0	±34.0	93.2	215	20,038.0
Wheat	16	12.3	±19.9	61.59	±18.4	73.89	215	15,886.6
Maize	8	26.6	±14.1	64.3	±21.5	90.9	215	19,543.5
Total Nu.								**73,377.6**
		After CBEF establishment						
Paddy	58	0	0	11.8	±3.3	11.8	215	2,537.0
Potato	70	0	0	11.0	±5.7	11.0	215	2,365.0
Wheat	16	0	0	0	0	0	215	0.0
Maize	8	14.6	±7.1	16.0	±8.3	30.6	215	6,579.0
Total Nu.								11,481.0
Total perceived monetary value saved by CBEF (before minusafter)								**66,798.6**

*Minimum wage rate of Bhutan (MOLHR, 2016) is Nu. 215

40.9% of the yield from one acre was lost to wild animals, which reduced to 7.9% after the construction of CBEF. Compared to other crops, damage by wild animals on maize crop seems to be higher; possibly due to pressure from monkeys by day and by wild pig at night. Electric fencing is also said to be not effective against monkey. A paired-samples *t*-test on maize crop loss before (M = 478.6, SD = ±126.1) and after CBEF establishment (M = 93.1, SD= ±48.5) showed significant difference; $t_{(8)}$ = 10.45, p = .000. The electric fencing was able to save 385.7 kg/acre of maize worth Nu. 8,872 annually.

Though not grown extensively, farmers experienced wheat yield loss of 30.7% per acre. Electric fencing was able to save 273.4 kg/acre of wheat (SD = ±118.1) worth Nu.6,016.4 (SD = ±2,598.6) accounting to 29% annually. Similar to other crops, a paired samples *t*-test conducted to compare wheat loss before (M= 289.3, SD= ±110.4) and after CBEF (M= 15.9, SD= ±26.6); t (15) showed significant difference; $t_{(15)}$ = 9.26, p = .000.

Majority of the framers who reported crop loss after CBEF were from Ngawang. They attributed the crop loss after CBEF establishment to breakdown of energizers by lightning strikes. Otherwise, effectiveness of CBEF in mitigating agricultural crop loss would have been even higher.

Reduction in crop guarding time

Reduction in crop guarding time was another major impact of electric fencing. As shown in Table 6, the average days spent on crop guarding for various crops reduced to zero except for maize. Farmers continue to spend few weeks in guarding maize crop during day time as electric fence is not 100% effective against monkeys. The time spent on wheat guarding reduced by 100% after CBEF establishment, prior to which the farmers spent about 74 man-days. In terms of monetary value calculated using minimum wage rate of Bhutan (Ministry of Labour and Human Resources [MOLHR, 2016]), the time spent on wheat crop guarding translates to Nu. 15,886.6 annually.

In all the study areas, irrespective of crop types, farmers had to guard their crops from wild animals. As most farmers grew summer and winter crops, farmers had to be on guard round the year. On average, 83 days and nights were spent for guarding paddy, 93 for potato, 74 for wheat and 91 for maize (Table 6).

Before CBEF establishment the total man-days spent for crop guarding summed up to a year amounting to Nu. 73,377.6 per household.

After CBEF establishment, the man-days spent reduced to worth of Nu. 11,481. Therefore, CBEF was able to save Nu. 66,798 per household annually (Table 6).

Conclusions

All the investigated CBEF sites used two joule Chinese made fence energizer Polar Lanstar S2 which can be either used with solar power or hydroelectricity. Main challenges associated with the CBEFs included damage of energizers by lightning and, inability of solar power to charge battery during gloomy weather.

In some CBEFs, despite sufficient numbers of energizer used, the distribution of fence length amongst energizers was not even. In few cases, the length of fence was longer than an energizer could effectively cover. Excessive length of fence covered by an energizer, higher number of wire strands and more incidences of short circuit along the fence perimeter resulted in low fence voltage. Short circuits due to leakages through overgrowth vegetation along the fence perimeter were prevalent in all the CBEFs. The design of the fence in-terms of the number of wire strands and wire spacing in between the wire strands was fairly appropriate for larger animals such as wild pig, sambar and barking deer. However, none of the CBEFs had appropriate design to deter porcupine and monkeys. All energizers had an earthing each, which were installed in dry locations and were hardly watered, so were ineffective.

Presence of absentee households and lack of cooperation from households located at the centre of the community and owning small land holdings were the main obstacles in smooth planning, establishment and maintenance of CBEFs. Significant numbers of farmers had basic knowledge on maintenance of electric fencing however farmers who knew how to install energizers and earthing were not significant. Clearing vegetation along the fence perimeter was the most tedious task in repairing and maintaining electric fencing. Despite shortcomings in management system, the amount of crops saved and reduction in crop guarding time were worth investigating.

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