The porter problem in ecological economics

Solar battery recycling in rural electrification

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Abstract

This paper introduces an incentive incompatibility problem that causes dramatic damage to delicate ecosystems. The aim is to rethink policies that facilitate the introduction of aggressive solid waste in markets with an imperfect infrastructure and in the absence of a secondary market for the solid waste. We sketch a case study in Nepal, where rural electrification through solar systems leads to the dumping of used batteries. We label the puzzle 'the porter problem', referring to the porters who are the most popular transportation medium in the Himalayas.

Key words: Solid waste, incentive incompatibility problem, renewable energy, reverse logistics.

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1 Introduction

Ever since 'biodiversity hotspots' have been introduced into the literature (e.g. Myers et al. (2000), Myers (1988)) much research has been conducted on the options to conserve these hotspots and the causes underlying their threats. Many scholars have investigated the relationship between poverty and biodiveristy (e.g. Fisher and Christopher (2007), Adams et al. (2004), Brockington and Schmidt-Soltau (2004), Cincotta et al. (2000)). Though we acknowledge poverty alleviation may impose a threat to biodiversity due to a depletion of natural resources, we argue that it is the poor physical and institutional infrastructure endemic to poverty which forms an enormous threat to our natural environment. For people living in scarcely populated areas, the absence of paved roads hinders the recycling of inorganic solid waste (Van Beukering and Bouman (2001)). That notion does not necessarily relate to the economic aspects of poverty of an individual. Poverty imposes a cap on the buying power of individuals and increases the individual's utility discount rate (Becker and Mulligan (1997), Ogaki and Atkeson (1997), Lawrance (1991)). As a consequence, short-run economic value may supersede long-term value, and people may, for example, (be forced to) buy products and services with a short expected useful life, or they may not internalise the long-run economic costs associated with the externalities of the depletion of natural resources. Particularly for poor people, recycling waste or reusing (parts of) goods is commonplace, though often driven by a necessity. After all, for many millennia indigenous people have fostered their natural habitats though minimising waste disposal. With the introduction of modern industrial products into remote rural areas, however, people are no longer able to recycle or reuse their solid waste. Here, the economic status of these individual is not necessarily the cause of an environmental problem, but rather the lack of infrastructure (cf. Satterthwaite (2003)). That infrastructure may both be institutional or physical (Barrett and Swallow (2006)). In rural areas in developing countries, many roads are unpaved. In mountainous areas, transport and trade are often facilitated by porters. In this paper we argue that the pricing of the transportation medium cannot be made incentive-compatible. In the next section we develop a simple economic model that helps to identify the nature of that incentive incompatibility. We illustrate the nature of the problem by means of a case study, for which we sketch three potential policy scenarios. First, however, we illustrate the severity of the problem by introducing the theme.

Solar systems are commonly used for rural electrification in developing countries. These target areas often lack any sorts of physical infrastructure such as fresh water, sanitation, energy grids, or paved roads. In these settings, solar home systems (SHSs) are becoming increasingly popular as an affordable means of electrification. The delivery of (SHSs) to households either occurs in a self-organised fashion (a household buys an SHS at a retailer), or occurs through a project organisation (a utility company arranges the delivery, after-sales support, and often the financing). After approximately 2-4 years, the batteries of the SHS have to be replaced. In most cases, a smooth business infrastructure is lacking since both project organisations and retailers target at higher-end systems with minimum quality standards and with large volume transactions (Van der Vleuten et al. (2007)). As a consequence of failing reverse logistics, the net environmental benefits of renewable energy for rural electrification through SHSs may be nil. As an illustration, in January 2007, the Dutch Minister for Development Aid submitted a report to Parliament in which a specific development aid programme was evaluated. [1] Of all projects evaluated, the Bolivia rural electrification project stood out in terms of environmental impact:

'[...] The high expectations of the environmental benefits of solar energy in Bolivia were never met. From an environmental perspective, solar energy has advantages if and when the solar system batteries are being recycled (or the energy [systems installed do] not require batteries). Although in Bolivia the use of NiCd batteries was reduced by 10 percent, the solar batteries were never recycled, and the overall environmental gains were negligible.' (p.52)

The target area of our paper readily overlaps with the biodiversity hotspots as introduced by Myers et al. (2000). For these areas, Fisher and Christopher (2007) argue poverty can be a significant constraint to conservation. In our paper, we acknowledge poverty may form a major restriction in preventing large damage to delicate ecosystems indeed, but the lack of an incentive-compatible pricing scheme for the transportation medium is an untouched theme in the literature so far.

[1] ORET/MILIEV Evaluation 1999-2004: Final Report, November 2006.

2 Model

We assume that there are two types of porters: Those who face a high opportunity cost $\overline{C}$ (due to travelling long distances or a difficult road, $\overline{\lambda}$), and those who travel a short or easy road $\underline{\lambda}$ and face a low opportunity cost $\underline{C}$. Even in a highly competitive market with unlimited supplies of labour, the opportunity cost of each type must be positive because the gains of the trip (reflected in unit price p) must at least compensate for nutritional needs and for the depreciation of shoes and apparel. The reward for hired porters consists of a combination of distance λ travelled and weight q carried.[2] The environmental impact (being a cost to the principal) is denoted as $\Theta(q)$.[3] We analyse four dimensions of our problem:

(1) Symmetric information, equal environmental impact in all areas;
(2) Symmetric information, unequal environmental impact in some areas;
(3) Asymmetric information, equal environmental impact in all areas;
(4) Asymmetric information, unequal environmental impact in some areas.

It should be noted that the agent's opportunity cost $C(q, \lambda)$ depends on the weight carried and the distance travelled. Together, q and λ determine the travel time needed, and effort spent for the agent. Cf. Imperial (1999) or even Burnside and Dollar (2000), both the quality of the social or institutional infrastructure affect λ, but of course also the presence of a sound physical infrastructure (Jimenez (1995)). The physical infrastructure clearly affects the speed of travelling and the necessary effort, whereas the institutional infrastructure determines the dispersion of the recycling stations across a country and hence the distance that must be travelled. Let $\underline{C}(q, \underline{\lambda})$ denote a low opportunity cost for the agent, e.g. due to a good physical infrastructure. If the roads are poor, the agent has a higher opportunity cost $\overline{C}(q, \overline{\lambda})$ for carrying the same weight q for the same distance λ.

2.1 Symmetric information, equal environmental impact

A first-best contract in its simplest form may exist if the principal has full information on the route travelled by the porter. In addition, we assume here that the toxic solid waste has the same negative environmental impact, independent of where it is dumped. The principal's utility maximisation problem

[2] In general terms, the higher the capacity of a PV system's battery, the higher its weight.

[3] We assume the dumping of the toxic solid waste need not (immediately) be internalised by the agent. For example, for people living at a cliff, dumping waste causes an environmental damage outside their direct habitat.

may be written as a cost minimisation problem:

$$\min_{\{(\overline{p},q);(\underline{p},q)\}} \quad \Theta(q) - \left(\overline{p}\overline{\lambda} + \underline{p}\underline{\lambda}\right) q \tag{1}$$

subject to the agent's participation constraints:

$$\underline{p} - \underline{C}(q,\underline{\lambda}) \geq 0, \tag{a}$$
$$\underline{p} - \overline{C}(q,\underline{\lambda}) \geq 0, \tag{b}$$
$$\overline{p} - \underline{C}(q,\overline{\lambda}) \geq 0, \tag{c}$$
$$\overline{p} - \overline{C}(q,\overline{\lambda}) \geq 0, \tag{d}$$

and subject to the incentive compatibility constraints: [4]

$$\overline{p} - \overline{C}(q,\overline{\lambda}) \geq \underline{p} - \overline{C}(q,\underline{\lambda}), \tag{e}$$
$$\overline{p} - \overline{C}(q,\overline{\lambda}) \geq \overline{p} - \underline{C}(q,\overline{\lambda}), \tag{f}$$

If we want agents to return remote batteries at all (restriction (e)), the principal must be able to discriminate between remote batteries and batteries that have travelled a short distance $\underline{\lambda}$. If that condition is not met, it is impossible to write an incentive-compatible contract in this simple setting. If we want agents to travel difficult paths at all, then restriction (f) reads there should be some (additional) compensation in $\overline{p}$. If restriction (f) is not met, then agents have the incentive to travel paved roads only. Restriction (e) is the most binding restriction. In fact, it is virtually impossible to satisfy restriction (e) in an unregulated setting of full information.

2.2 Symmetric information, unequal environmental impact

Let us allow for the fact that some areas are more vulnerable than others (e.g., due to differences in biodiversity). More specifically, let us define $\overline{\Theta}(q)$ as the quantity of toxic waste with a large environmental impact, and $\underline{\Theta}(q)$ as a quantity of waste with a lower environmental impact. The principal now cares more for $\overline{\Theta}(q)$ than for $\underline{\Theta}(q)$ even if the waste itself is identical. For the cost function of the agent, it is only the weight of q that matters and the distance λ

[4] In the incentive compatibility restrictions we ensure that contract $(\overline{p}, q)$ is weakly preferred to contract $(\underline{p}, q)$ by an agent who has travelled $\overline{\lambda}$, just as contract $(\underline{p}, q)$ is weakly preferred to contract $(\overline{p}, q)$ by an agent who has travelled $\underline{\lambda}$.

travelled—not the potential environmental impact. Though the agent should be indifferent whether he carries a battery causing $\overline{\Theta}(q)$ or $\underline{\Theta}(q)$, under full information symmetry he knows the principal values $\overline{\Theta}(q)$ more than $\underline{\Theta}(q)$. Yet, since the cost functions of the agent are not altered, we only modify the principal's goal function:

$$\min_{\{(\overline{p},q);(\underline{p},q)\}} \quad \left(\overline{\Theta}(q) + \underline{\Theta}(q)\right) - \left(\overline{p}\overline{\lambda} + \underline{p}\underline{\lambda}\right) \tag{2}$$

subject to restrictions (a) through (f). Three situations can be considered:

- *Environmental impact is positively correlated with travel distance* λ (remote areas being more vulnerable): Since there is full information symmetry, the principal may weigh her willingness to pay for avoiding environmental impact against the expense to compensate the agent. As a variation, the principal may compensate the agent for facing high opportunity costs $\overline{C}$ in the case of travelling harsh areas.
- *Environmental impact is negatively correlated with travel distance* λ (nearby areas being more vulnerable): The principal will now prefer to collect the waste with large environmental impact being located nearby a collection facility. Hence, if the principal faces very tight budget restrictions, or attributes a low priority to minimising environmental damage, this model serves well. We assume that nearby waste has such a short travel distance λ that difference in the agent's opportunity cost C are negligible.
- *Environmental impact is not correlated with travel distance* λ (any area may be more vulnerable): Though the information symmetry enhances the principal in her decision-making, the monitoring (and administrative) costs of this situation will be high for the principal. If the principal is tight on budget, she wishes to focus on cheap batteries with a large environmental impact first. Since, however, the supply of waste being handed in is stochastic, the principal cannot optimise her spending. Compensation for differences in the agent's opportunity costs due to poor roads is possible, but under budget a governmental constraint not very likely.

2.3 Asymmetric information, equal environmental impact

Imagine the principal does not know whether the porter has travelled a long or a short way. This represents the situation in which monitoring is either impossible (due to a limited capacity on behalf of the principal), or monitoring is too costly. In this situation, if a porter hands in a battery, then with probability μ this porter has travelled a long way, and with probability $(1-\mu)$

it was a short travel. Hence the cost function of the agent either is: [5]

$$C(q, \overline{\lambda}) = q\overline{\lambda} \qquad \text{with probability } \mu \tag{3}$$

or

$$C(q, \underline{\lambda}) = q\underline{\lambda} \qquad \text{with probability } (1-\mu) \tag{4}$$

Again taking $\overline{p}$ as the price paid for handing in a remote battery, and $\underline{p}$ the price in the case of a battery that travelled a short way, the agent's participation constraints (a) through (d) remain unchanged. The incentive compatibility constraint (e), however is now violated. As a consequence, there is no incentive for agents to return remote waste, since they may always claim nearby waste came from far. By introducing the condition of the physical infrastructure we may further distinguish any differences in the agent's opportunity cost $\underline{C}$ versus $\overline{C}$.

2.4 Asymmetric information, unequal environmental impact

Under asymmetric information the fact that the principal attributes a higher value to preventing environmental impact $\overline{\Theta}(q)$ than $\underline{\Theta}(q)$ encourages the agent to enter into a game. We assume the agent knows whether he has carried a $\overline{\Theta}(q)$ battery or a $\underline{\Theta}(q)$ one. The principal however must still find out. Again, three situations can be considered:

- *Environmental impact is positively correlated with travel distance* λ (remote areas being more vulnerable): A strong conflict arises between the principal's desire to collect remote waste first, and the agent's incentive constraints. In fact, following Guesnerie and Laffont (1984) and Laffont and Martimort (2002), this situation can be labelled 'nonresponsiveness'. Due to nonresponsiveness, it becomes impossible for the principal to use the information given by the agent.
- *Environmental impact is negatively correlated with travel distance* λ (nearby areas being more vulnerable): An extreme situation of the symmetric information case occurs, in which the principal has an even stronger incentive to focus on nearby waste.
- *Environmental impact is not correlated with travel distance* λ (any area may be more vulnerable): The problem becomes stochastic, and several maximisers may exist. The major problem with this mechanism is the verifiability of the principal's randomisation of contracts, cf. Laffont and Martimort (2002). Given that the principal has some (rough) estimate about the distribution

[5] We assume the agent only faces variable costs. Also, we ignore the condition of the physical infrastructure here since the focus is on 'distance travelled'.

of solar panels in a region, and given some administration of the collection of dead batteries, the principal may learn what the chances are that a dead battery comes from a very vulnerable or a less vulnerable area, and may make better bids. That learning process, however, takes a long time.

3 Analysis

We use one case study to illustrate our problem. Following an introduction into the product market and into the geographic setting, we sketch three logical policy scenarios a government can pursue. For each of these scenarios we describe how infrastructure may be a bottleneck, the expected environmental impact and economic cost, and the barriers towards designing an incentive-compatible contract with end-users.

Though we focus on the Himalayas as the geographic setting and on porters as the medium of transportation, the message of our paper may easily be extended to alternative settings. For example, consider a remote archipelago where ferries occasionally bring new equipment to the islands, but where litter is not returned to the mainland. Entire cars may be dumped at a coral reef, which in the absence of internalising environmental costs probably becomes the most economic way to get rid of it. In case of an archipelago the transportation medium is the ferry, or the skipper of a small private boat, instead of the porter that we use. The mechanisms, however, remain the same.

3.1 The Nepali market for solar home systems

Since the 1980s, solar panels have been considered a highly promising renewable energy source. With soaring prices of fossil energy, SHSs are becoming increasingly economically attractive, particularly in remote areas where no electricity grid is available. SHSs are mostly produced and sold by multinational companies. When these companies target developing countries, they first tend to focus on the more wealthy consumers (London and Hart (2004)). For as far as an institutional infrastructure for collecting the waste is built, the focus is put on large-scale facilities (cf. Hart (1997)). In case of solar systems, this is no different. Van der Vleuten et al. (2007), for example, criticise the reluctancy to build an organisational infrastructure for SHSs in developing countries: 'Solar companies "prefer to be sitting in the capital city, waiting for the next tender" rather than developing the networks to serve the needy clients in the distant rural area's'(quotes in original). This is in line with the conclusions of Van Beukering and Bouman (2001) who find lead scrap is hardly recycled in developing countries because of a lacking infrastructure. Hence, if SHSs are either sold in developing countries through retailers or through subsidised large-scale development projects, we may at best expect the latter to develop some organisational infrastructure for recycling the batteries. In a survey completed a decade ago in Kenya, it appeared that the expected lifespan of a system's battery was some 2-3 years (Van der Plas and Hankins (1998)). These data referred to locally produced batteries. Though battery technology has improved over time, we may readily assume a lifespan of up to some 4-5 years as being realistic. In Nepal, there is neither a domestic market for producing batteries nor for processing lead. Most batteries are imported from India and Indonesia. The absence of an aftermarket for the waste products takes away most of the economic incentives to care for the used batteries. For other products, people may come up with innovative practices to reuse or recycle waste, but for toxic solid waste such behaviour is definitely undesired (e.g., Goldman and Tran (2002)).

In Nepal, the Alternative Energy Promotion Centre (AEPC) of the Ministry of Science and Technology keeps track of the dissemination of SHSs. In the latest survey [6] on the status of SHSs in Nepal, the dispersion of SHSs across the country correlates with population density. Though the Nepalese government has kept track of most SHSs since the late 1980s, the surveys only occur at very discrete time intervals.

While the solar PV technology has become known as a sustainable and appropriate technology for elementary rural village electrification schemes to reach the uncountable remote and impoverished communities too far away for the grid, the solar PV market is often strongly centralized in the main capital. This is also the case in Nepal. The now almost 50 registered and AEPC approved solar PV companies have their main offices in Kathmandu, Nepal's capital. Residing in Kathmandu, some of the major PV suppliers have a loose network to a few other big urban centers around the country in the lower altitude flat parts, mainly in the form of sales offices. This kind of network is suitable for serving large-scale customers and projects, usually driven by large international donor organizations, but not for serving individual households. In particular SHSs, that aim at providing improved elementary (for the first time) electrical services (usually limited to basic indoor lighting) for a particular content and demand which require often a 'customised' kind of PV system. They need to be designed and installed according to the user's or owner's initial defined energy services and affordability. This approach is more time consuming as specialists to interview and interpret the user's defined needs are required. Such a 'customised' SHS is usually also more expensive, but typically this will distinguish it in regard to used components, size and installation from a SHS 'mass product' for big scale solar PV home system projects with a standard design, pre-defined system components and often lower quality benchmarks.

[6] See `http://www.aepcnepal.org/nircret/lnks.php?id=115`.

While the main parameters under a big SHS project are minimal cost, highest turnover and shortest installation time, the main focus on customized SHSs is on sustainability, appropriateness of the system for the user's context and identified needs, strong ownership feeling, training in operation and maintenance, follow-up visits as well as the establishment of a relationship between the user and the project implementer for long-term access to spare parts and eventual repair services.An SHS can not be compared with a DIY tool as the users can not be expected to understand the detail of a SHS, its need for proper professional installation and maintenance needs, however minimal they may be. Thus, independent the financing of the SHS (e.g., directly purchased from a solar PV firm, or acquired under a subsidised programme), a proper installation and user training are crucial success factors. The power generation of a poorly installed SHS can be significantly lower, thus not providing the expected daily energy services. Further, under such conditions it is likely that the batteries are not able to be charged properly, are discharged too highly on a daily basis and may even suffer from too low or too high temperatures as they have not been positioned and/or insulated according to the local climatic conditions. Such conditions can considerably reduce the life expectancy of the battery bank, as these are crucial parameters besides the more commonly known needs for periodical topping up of liquid acid batteries with distilled water.

3.2 A description of the Humla region

About 80-85% of Nepal's population lives in rural areas, whereas about half of the population lives in areas within a 2-16 days walking distance from the nearest road. Humla is one of the seventy-five districts of Nepal. Humla is remotely located in the far North-West of Nepal, bordering Tibet. Humla is elevated between 1,524-7,337 metres. Lack of roads and extremely difficult air access are perhaps the most important constraints to tourism development in the area.[7] Humla is not only rich in species biodiversity but also represents a broad range of habitat types. Subedi (1998) identifies a.o. a number of wild fauna including the following eight protected and endangered species in the Humal region: The snow leopard (Panthera uncia), the clouded leopard (Neofelis nebulosa), the musk deer (Moschus moschiferous), the gray wolf (Canis lupus), the leopard cat (Felis bengalensis), the wild yak (Bos mutus), as well as the impeyan pheasant (Lophophorus impejanus), and satyr pheasant (Tragopan satyra). In addition to the fauna, Humla alone has about 1,500 species of high altitude plants (see the survey by Burch et al. (2003)). Particularly the protection of medicinal plants are an issue of concern in Humla

[7] See `www.biodiversityhotspots.org` for a generic description of the biodiversity hotspot that applies to the Eastern Himalaya.

(see e.g. Kunwar et al. (2006)).

According to the 2007/2008 Human Development Report, the Nepalese per capita GDP was about USD1,550 in the year 2005, and the human development index (HDI) was 0.534. Within Nepal, the Humla region is amongst the poorest, with an HDI of about half the national figure.[8] Its literacy rate of 27.1% is also the lowest of the country.[9]

Humla is the most northern part of the Karnali Zone, which is in turn part of Nepal's mid-western development region. It lies in the middle of the vast Himalayan mountain range between 29°35' to 30°47' northern latitude and 81°18' to 82°10' eastern longitude. The upper Humla villages lie at altitudes between 2,500 - 4,000 m.a.s.l. (metres above sea level), while their picturesque surrounding sceneries and mountain ranges reach altitudes of up to 7,335 m.a.s.l. A harsh high altitude climate, with an average of 199 frost days a year,[10] prevails. Most of the 5,355 km^2 Humla region is either covered with rocky mountain ranges, snow covered mountains, forests or high altitude pastures. Only 50.2 km^2, or 0.89% of the whole district area is suitable for agricultural farming.[11] While wheat, barley, 'papper' (buck wheat), corn, potatoes, and kidney beans are grown as the staple food in single crops, apples, apricots and hard-walnuts are the major fruits produced in the district. Though rich in natural resources such as water, sunshine, medical and aromatic herbs, these resources are not tapped into in appropriate or sustainable ways, because of lack of awareness, education, conservation measurements, basic infrastructure or economic opportunities. Humla is known as a permanent food shortage area, and for most of the year food has to be flown in at soaring prices, due to an average food to transportation cost ratio of 1:4.[12] That is also reflected in the high rate of malnourished children <5 years of age, which is estimated to be 65%.[13] The educational level of the Humla people is also low. Each person

[8] In a 2002 survey, the HDI for Humla was estimated to be only 0.244.

[9] In 2001, the national literacy rate was estimated to be 54.5%, and for Humla only 27.1%.

[10] See NASA web site: `http://eosweb.larc.nasa.gov/` generated data in: Zahnd A., Case Study of a Solar Photovoltaic Elementary Lighting System for a Poor and Remote Mountain Village in Nepal, MSc in RE dissertation, Murdoch University WA, Kathmandu, Nepal, October 2004.

[11] District Profile of Humla 2004 (in Nepali language), Humla 2004, page 10.

[12] Periodic District Development Plan, Humla First Five Year Plan 2002/2003 - 2006/2007, District Development Committee, Humla, 2003, page 6. The air transport cost from Nepalgunj to Simikot (the only air route) is NRp75/kg (or about USD1.20/kg, April 2008), for each kg food or equipment item sent to Simikot, Humla's only, mud and stone, airstrip.

[13] Periodic District Development Plan, Humla First Five Year Plan 2002/2003 - 2006/2007, District Development Committee, Humla, 2003, page 27, and RIDS-Nepal nutrition base-line survey data.

averages only 0.88 years of school education and the literacy rate for Humla women is just 4.8%.[14] Thus it does not come as a surprise that Humla, out of Nepal's 75 districts, ranks second to last for poverty, deprivation, socioeconomic and infrastructural development, and female empowerment, and 72^{nd} in terms of socio-economic and infrastructural development.[15] It is now widely accepted that 'poverty alleviation and development depend on universal access to energy services that are affordable, reliable and of good quality'.[16] For families and communities living in such remote places as upper Humla, which is a 17-day walk from the nearest paved road, it is also clear that access to improved energy services cannot come overnight. Further, their remoteness, the harsh, high altitude Himalayan climate with very limited agricultural opportunities, are additional reasons for their poverty. Based on these conditions it is evident that sustainable development and life changes, in partnership with the local communities, are not just difficult but need decades of development and education. We therefore argue that in view of long-term sustainable project implementation, local users of SHS must be involved in each of a project's steps. From the initial design phase through the installation of the SHS in their home, the end user needs to participate and thus understand the basic working principle and needs for maintaining the SHS. A basic solar PV course and a hands on training module should be part of every SHS project. These are crucial parts for a project which aims for sustainable development. Of particular importance is that the users know how to handle, manage and maintain the battery bank. In Humla it is not uncommon that batteries from government subsidised SHS programmes have been found to last between 6 months - 2 years. This unexpectedly short life expectancy is mostly due to the flowed installation and maintenance of the batteries. With minimal education and hands on training one not only creates a much stronger ownership feeling and thus high interest and pride in having one's own SHS up and running, but a battery's life expectancy can be doubled if its installation environment and working condition (proper temperature range, correct distilled water level and sulfuric acid gravity, max. and min. voltage protection) is within clearly defined parameters.

[14] Karnali Rural Development & Research Center, Governance in the Karnali, an Exploratory Study, Jumla 2002, page 5.
[15] ICIMOD (2003). The International Centre for Integrated Mountain Development. http://www.icimod.org. Table of composite Index of poverty, deprivation, socioeconomic, infrastructural development and women empowerment index: http://www.hdihumla.org.np/remote-districts-of-nepal.htm
[16] See e.g. in Reddy (2002), or: Saghir (2005).

In the base-case, households freely buy solar systems in the market place. These may be directly purchased in a shop (e.g. in Kathmandu), or be subsidised by a government agency. At present, there is no battery recycling system in Nepal, and government does not make any attempts to collect these batteries and store them. Government monitoring takes place at very discrete time intervals only (in which an inventory of SHSs is made, but batteries are not labelled). Hence, even if the government would set up a battery collection and recycling system, it would not know whether a battery comes from distant rural areas, or from areas nearby the collection facilities. This situation is described by our model in sections 2.3 and 2.4. In case of equal environmental impact (section 2.3), the potential for a (yet not existing) battery recycling programme is low. Batteries from remote areas are unlikely to be collected since the premium for handing in is likely to be lower than the opportunity cost of the trip. Bearing these limitations in mind, we analyse how the environmental impact may still be minimised.

RIDS-Nepal, a non-profit NGO working with rural high altitude mountain communities in long-term holistic community development (HCD) projects in upper Humla, Nepal, has investigated SHSs in Humla, at a two weeks' walking distance from the nearest paved road. SHSs have been installed either by their owners, if they purchased it themselves, or more often by an installer who was contracted under a subsidised SHS program. Often the SHS batteries are found not to perform to the users' satisfaction within a matter of a few months, not providing the promised energy services, which is in most cases limited to basic indoor lighting. One of the most commonly observed shortcomings for batteries were the inappropriate place of installation and lack of needed thermal insulation due to the cold climate. These can easily be avoided with locally available materials if the users have a minimal basic knowledge about SHSs and if they have undergone training in operation and maintenance. Once the batteries have found to be 'dead' they are usually disposed either inside or outside the homes. Some 'dead' batteries are emptied, with the sulfuric battery acid being disposed on the ground, polluting the surrounding area and possibly even the ground water sources nearby. The disposed batteries can easily be accessed by children and other people. That bears potential hazards and dangers to people and the environment. A possible mitigation is to neutralise (pH=7) the battery acid. The neutralisation of sulfuric battery acid (H_2SO_4) on site is possible by using diluted sodium hydroxide (NaOH). The reaction product is aqueous sodium sulfate, which can be discarded into the septic tanks of the existing village pit latrines, without causing environmental harm. This dilution process demands a high level of precision which must be performed by an experienced professional. Furthermore these jobs are dangerous and risky, which can not be left to or done by the local users.

In this base-case scenario, the following conditions for setting up an efficient recycling contract are violated. First of all, the limited monitoring (in terms of data richness) hampers any discrimination between remote batteries and batteries installed nearby (yet to be launched) collection facilities. In addition, the low frequency of the monitoring (once in a couple of years) may overlook batteries that have lived a short life. Second, the support by NGOs (as the sketched RIDS-Nepal case) has not been institutionalised, and hence provides a very fragile solution for damage control. That is, if such NGOs face income drops, or if they become understaffed, they may decide to lower the quality or quantity of monitoring and assistance.

Given the above restrictions, we foresee this base-case scenario is most likely to be adapted by governments that are on a tight budget, and where the impact of dead battery disposal in the environment is roughly equal throughout the country. The voluntary yet uninsitutionalised support by NGOs definitely provides a major improvement, but their effort is unpredictable. In this case, the lack of an institutional infrastructure probably has a larger impact on the environmental problem than the physical infrastructure.

3.4 Scenario 2: Monitoring through NGO*, but no recycling*

Alternatively to letting households go unassisted, some third party might assist the households with a proper installation of the solar PV systems. Apart from the benefit that the systems will most likely last much longer (due to professional installaiton and training and damage is less likely or postponed) compared to the base-case, a main advantage of third-party assistance is that it provides the opportunity to exactly locate all systems, and to set up a registration system with e.g. identified geographical location, battery type and capacity, date of installment, etc.

In order to address and improve the present SHS scenario, in particular in regard to guaranteeing the SHSs' intended energy generation and energy services we again sketch the attempts of the local NGO RIDS-Nepal. In 2002, RIDS-Nepal set up a larger project to design, install and maintain solar PV systems in partnership with the users. [17] The project only runs in upper Humla, and has not been institutionalised by national government. Therewith the below sketch of the programme is only an example of what NGO assistance *might* look like in this 'Scenario 2'.

In the RIDS-Nepal project, three different solar PV system approaches have been developed, each depending on the locality of the user(s) homes, the geography, and on the meteorological conditions. For example, for individual

[17] See `www.rids-nepal.org` for details on the project.

homes stand-alone SHSs are designed, whereas in case 4-10 homes are located in close proximity to each other cluster solar PV systems are designed. Lastly, central solar PV systems are set up for a whole village in which the homes are very close to each other (which is the main traditional building style in Humla). All the village based solar PV systems are designed to provide first time elementary indoor lighting services. Solar PV systems are never installed by themselves, but as part of the NGO's developed holistic community development (HCD) project approach the 'Family of 4'. That means that every household in a village agrees to participate in a project which includes indoor lighting (through an appropriate renewable energy technology such as a solar PV system, a pico hydro power plant, or a small wind generator, utilising the locally available energy sources), a pit latrine, a smokeless metal stove in the house and a village drinking water system. In this way each project can bring forth synergetic benefits through the other, jointly implemented, projects, multiplying the final impact of each project multiple times over. As an initial step before a HCD project is considered in a village, the local people must show their keen interest and willingness to participate in the project. That is mostly done by writing a request letter to the NGO to partner with them in a long-term HCD project in their village. Thus in the case of the 'Family of 4' project, solar PV system, the local people are involved and advised which of the various solar PV system approaches (SHS, cluster or central PV system) is the most appropriate solution in regard to their geographical, meteorological and climatic conditions. Further, previous to the installation, the local established 'solar PV committee' decides who is sent to the 2 weeks solar PV basics and operation and maintenance training the NGO has developed and is an integrated part of each HCD project. Once the needed skills are taught the local trainees can apply their newly learned skills and earn their respect among the village community by participating in the solar PV system installation(s) in the village. Periodical follow-up visits by the NGO staff, who live and work in the area help to support the operation and maintenance and provide an ongoing basis real data and facts about each solar PV systems' performance and condition. Thus any flaw or shortcoming in power generation, battery energy storage or energy service provision is recognize early on and timely appropriate mitigations, maintenance or repair can take place. That helps to keep the PV systems up and running and the users' confidence and pride in their system. Undoubtedly this procedure results in more expensive solar PV systems, but the NGO's last 6 years experience have clearly shown that the installed PV systems in now 7 villages with a total of 422 homes, one school and one health post have performed significantly better with minimal battery problems. The first battery sets had to be exchanged after 4 years in 4 systems after they have been heavily misused by the local users in unauthorised ways. Still there is no battery recycling process in place and the thus far 'dead' batteries from the last 6 years have been collected and stored in the NGO's main office in Simikot Humla, which is a one day trek away from the villages where the 'dead' batteries have been carried from.

In this second scenario, setting up an efficient contract for recycling batteries is greatly enhanced through improved monitoring. Also, assistance in installation, and training in operation and maintenance has extended the lifespan of batteries significantly. Nevertheless, there is still no official database in which key battery data are stored. As a consequence, all improvements relative to the base-case depend upon the NGO. That is, the NGO has all relevant information on the SHSs, but since this information is not shared with other parties, it is the same NGO that has to act as the principal if a battery collection programme were to be set up. Since battery collection need not be the prime task for the NGO (and since the NGO need not be compensated financially, or supported institutionally), there is still an institutional problem to overcome.

3.5 Scenario 3: Monitoring and collection through NGO

In addition to scenario 2, the third party could also collect the batteries. Since the same NGO also keeps track of the batteries from the installment onwards, it is not necessary for the NGO to take care of the transportation from the households to the NGO's office. Given full information symmetry, the only task is to set up an incentive-compatible contract that matches with section 2.1 or 2.2.

Until now there is no battery recycling infrastructure, project or programme through which old batteries are being collected, neutralised and recycled. With the shear numbers of SHSs and batteries installed in Nepal over the last decade under the running last 10 years' solar PV government subsidised programmes, it is more than obvious that this is a serious shortcoming. It may not be a popular topic with the solar PV companies, as that could force them to put an additional price tag on new batteries for the recycling process. It would also demand institutional and physical infrastructure to collect and manage the old batteries. Neither will it be well-liked with the government as this would demand a fairly complex project with huge costs for such new infrastructure, recycling processes and logistics to get the old batteries in and the recycled batteries back onto the market. That demands a country-wide network of collection places with trained staff. The shear costs involved in such an endeavour, considering the majority of the batteries are in very remote places, is mind boggling. Thus this topic has been avoided and has in fact not had a chance to be publicly raised or discussed with the needed seriousness and urgency. To tackle the issue of identifying, collecting and recycling old solar PV system batteries is also not a project one will reap big applause from the public or donor organisations, as for all it is, it just aims to manage 'waste', and that is difficult to 'sell' and raise funds. However, in order to be responsible towards the solar PV system end users and the environment, we can no longer ignore that issue and thus need to start finding appropriate solutions, small and insignificant they may be for the first few years considering the scope of the problem at hand.

3.6 Setting up a recycling programme in practice

NGOs, such as the RIDS-Nepal we sketched above, who are involved in the design and implementation of solar PV system projects, could take a first lead in taking the issue serious and show a way ahead. The problem could be tackled from two sides. On the one hand through a more reliable installation and operation of the SHSs. That is, if SHSs are both designed and installed in accordance with the needs of the local context of the end user(s), batteries will live longer. On the other hand, a battery recycling programme has to be put in place in order to minimise the possible toxic waste damage to the environmental and health risk to the local people.

The following shows a step by step process of such a possible first trial 'battery program' project, paying due respect to both sides. All the steps are done either through a professional staff of the implementing NGO or by subcontracting the task to an external professional solar PV designer.

(1) Define with the end user(s) the needed and affordable energy services.
(2) Collect, monitor and record or simulate (e.g. with METEONORM) the defined location's average daily solar energy resource for an average year.
(3) Design the solar PV system based on the needs, financial affordability and local identified minimal solar resource. That can be done by experienced solar PV designers through hand calculations or with the help of professional software such as PVSyst (`http://www.pvsyst.com/`) or RETScreen (`http://www.retscreen.net/`). Define the battery bank (BB) for 3-5 days independency with a maximum depth of discharge of 35% (i.e., the BB can provide for 3-5 days the same daily energy services without sunshine and with a maximum depth of discharge of the BB of 35% of its full capacity after 3-5 days).
(4) Define the project cost and include an 'old battery collection and recycle' budget according to the project's location and size.
(5) Negotiate the end user(s)' financial and voluntary contribution (in form of labour and local materials) to the project and start raising funds for the remaining cost from external donors and sponsors.
(6) Create a database, identifying and numbering each solar PV system's equipment and each battery. Each battery is listed according to its technology, brand, manufacturer, price, purchase date and company, capacity, installation date, location and designed use (energy in/out per day, depth of discharge, temperature, and sulpheric acid density in the case of liquid acid batteries).

(7) Conduct a basic solar PV training for installation and operation and maintenance for the chosen, village based operators, including hands on training and participation in the system(s) installation(s).
(8) The trainees participate in the installation of the solar PV systems in the village (providing them with practical experience and allowing them to earn their respect from the village community).
(9) Develop a follow-up program to check each installed solar PV system and record the performance and status of the system and battery bank.
(10) Set up a dry and closed 'old battery' collection storage place.
(11) Sign a 'battery recycle' contract with an appropriate company (if available with the needed professional skills and infrastructure) to recycle and refurbish the old batteries.
(12) Organise the transport (porters, air plane/helicopter, road transport) of the old batteries to the recycling company.
(13) Develop a test procedure with benchmarks for the 'refurbished' batteries and test each one before it leaves the company. Identify each 'refurbished' battery once it passed the test successfully and add it to the database.
(14) Develop a 're-allocation' programme for refurbished batteries in the project area.
(15) Include the refurbished battery again in the follow-up programme.

This proposed 'battery programme' project, of which points 1 - 10 are already in action, is a first attempt of a trial project in a limited working area of the NGO RIDS-Nepal, which is engaged in solar PV system projects with the local communities over the last 6 years. It aims to experience what it needs and takes to understand the 'life cycle' of a solar PV system with particular emphasis on the life cycle of the battery bank, through detailed monitoring with sophisticated data loggers of four chosen solar PV systems of different approaches (recording data since 2006 and 2007) and anecdotal monitoring and data recording of all the other installed battery banks. The aim is to understand the most appropriate working conditions for batteries in a defined user context, the recycling and refurbishing (if suitable skills and companies can be contracted) of the old batteries and re-integrating refurbished batteries in solar PV projects. To understand and learn the life cycle of batteries enables designers and project implementers to reduce the potential harm of toxic waste in endangered and fragile ecosystems. That allows for a smaller footprint of a new technology in the strive for sustainable HCD in partnership with impoverished and remotely located people groups.

4 Conclusions

This paper has introduced an incentive incompatibility problem that causes dramatic damage to delicate ecosystems. The aim is to rethink policies that facilitate the introduction of aggressive solid waste in markets with an imperfect infrastructure and in the absence of an aftermarket for the solid waste. We analyse four potential incentive scheme settings, that can help governments to set up a solid waste recycling system. We distinguish between the full information setting, where government knows the location and size of the solid waste, and the asymmetric information setting where government monitoring is absent or poor. In addition, we allow for remote areas having a different environmental impact than areas nearby collection facilities. The four incentive schemes help to identify the necessary conditions for an incentive compatible contract that encourages households to hand in their solid waste rather than dumping it.

We explore the applicability of our model by means of a case study. We sketch a case study in Nepal, where rural electrification through solar systems leads to the dumping of used batteries. We label the puzzle 'the porter problem', referring to the porters who are the most popular transportation medium in the Himalayas. Independent whether the owners of the solar home systems act as porters or hire porters, it is the opportunity cost or the expense for the travel that forms the weak link in the reverse logistics. We outline three scenarios for an institutional response to our ecological problem. First we analyse the laissez-faire scenario, in which solar home system batteries are dumped in the absence of a recycling system. We propose a damage control mechanism through NGOs. The neutralisation of sulfuric battery acid on site is possible by using diluted sodium hydroxide. This dilution process demands a high level of precision which can not be done by a layman. Specialised NGOs could fulfil this task.

In our second scenario, either the government or NGOs monitor the key characteristics of solar home systems installed. Alternatively to letting households go unassisted, some third party might assist the households with a proper installation of the solar systems. Apart from the benefit that the systems will last much longer (and damage is postponed) compared to the base-case, a main advantage of third-party assistance is that it provides the opportunity to exactly locate all systems, and to set up a registration system with e.g. location, battery type and capacity, date of installment, etc. By labelling the batteries, the information asymmetry problem can be eliminated. Such mechanism facilitates the future setup of a recycling system.

In our third scenario, both monitoring and collection of the waste takes place. Since the same NGO also keeps track of the batteries from the installment onwards, it is not necessary for the NGO to take care of the transportation from the households to the NGO's office. Given full information symmetry, the only task is to set up an incentive-compatible contract that matches with our model. We sketch the necessary conditions for an incentive-compatible contract.

Though our case study focuses on a mountaneous setting, where porters are the most popular transportation medium, our model readily applies to other settings. For example in remote islands the porter may readily be replaced by 'ferry' or 'skipper'.

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