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Human and animal power – The forgotten renewables

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ABSTRACT

Globally, there is still widespread dependence on traditional forms of energy, and human and animal power still contribute a significant proportion of the energy used in the rural areas of developing countries. After biomass, they are the most important energy sources for their populations. On a global scale, the energy contributed by human and animal power is estimated to be twice that of wind power and 13% of hydro, the largest single contributor of the renewable energy sources. This paper therefore argues that human and animal power should be included in the 'family' of renewable energy sources of solar, wind, hydro and biomass. There are numerous opportunities to improve the efficiency (and output) of hand, foot and animal-powered equipment. Improvements in these technologies will help to reduce the drudgery and hardship of everyday life of those who do not have access to modern forms of energy.

1. Introduction

According to UNDP [1], traditional (and often non-commercial) energy supplies nearly ten percent of the total fuel mix globally. However, in developing countries overall it accounts for approximately 17.9 per cent [1]. In some very low income countries, 80 percent or more of energy consumption comes from traditional sources [1]. In such assessments, traditional sources almost invariably are defined as biomass. Humans and animals, as renewable sources of energy, are not considered. Their omission is also reflected in policy recommendations and in the academic texts describing renewable energy sources and technologies.

There is an unquestionable need to increase the energy supply of those who rely on traditional energy sources in order to improve their quality of life and reduce the drudgery and hardship of everyday life. Renewable sources of energy are advocated to reduce the environmentally damaging effects of fossil fuels and to move towards a sustainable energy supply system. While it seems to be legitimate to advocate improving the energy conversion efficiency of traditional combustion technologies such as cooking stoves, human and animal energy conversion technologies do not receive the same attention except from small dedicated advocacy groups and non-government organisations.

This paper explores the proposition that there are opportunities to reduce the drudgery, improve incomes and health, and raise skill levels by either improving existing tools or by introducing new hand- or foot-powered technology in many remote isolated communities in developing countries. At the same time, the paper makes the case that human and animal power be seen as renewable sources of energy and that the technologies used to harness this energy be equally recognized as part of the 'renewables' family. The authors recognise that it is a dangerous generalisation to characterise all rural areas of developing countries in the same way, and caution that the paper is not a technical evaluation of one particular technology or another. Some examples of what has been achieved are presented merely to illustrate their potential. The paper begins with a summary of the common characteristics of rural areas in many developing countries and uses the data from a published case study to emphasise the main types and ways energy is used. The advantages and limitations of human and animal power are then discussed together with examples in various activities where new or existing technologies might be used.

2. Current status

Several common features characterise isolated rural areas in many developing countries. The main sources of energy are biomass, combined with human and animal power. The areas are heavily dependent on agriculture and any small/medium-sized industries are usually those that process agricultural products. The populations of these areas have a lower income compared to their urban counterparts. Working life is dominated by hard physical labour and human drudgery is common. Finally, there is much unemployment and under-employment. It is estimated that

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in 2025, 40% of the world's 8 billion people will live in the less-developed regions of the world [2].

The energy source-activity profile of a South Indian agricultural village with a population of 932, analysed by Ravindranath et al. [3], exemplifies the rural areas described above (Table 1). The data illustrates the dominance of biomass as the key energy source, which supplies 83% of the total. This energy is used mainly in the domestic sector (73%) and the remainder in industry. Humans and animals collectively supply 12% of the energy used in the village. All fossil fuels (including electricity generation) contribute only 4% of the energy consumed.

Since energy from human and animal power far outweighs fossil fuels in importance in village life, one might legitimately ask why these sources of energy are not included in contemporary assessments of renewable energies and their respective conversion technologies. In renewable energy policy and academic literature there is massive emphasis on the more well-known renewable energy sources such as solar and wind power. So why are human and animal power not included? There are several possible explanations for this omission. Human and animal-powered technologies are not very fashionable; they lack big company support; there has been a decline in their use in industrialized countries; and finally perhaps their reputation has been blemished with misconceptions about appropriate technology.

Despite the above omissions, some non-government organisations recognize and promote their potential. Organisations such as the UK's Intermediate Development Technology Group (IDTG), the International Forum for Rural Transport and Development (IFRTD) and the World Association for Transport Animal Welfare and Studies (TAWS) all publish information on human and animal-powered technologies. Some of their work is referred to in later sections of this paper, which in turn looks at the potential to use human and animal power more effectively.

3. Human power

As a 'machine', the human body has limited output. Peak power output for a fit and healthy adult is about 900 W [4] but this can only be sustained for a few seconds. Putting this power output in some context, activities such as hoeing and tree felling require 300–500 W and 600 W of gross power respectively [5]. Assuming an energy conversion efficiency of 25%, the net power output for tree felling is 150 W, which is confirmed by [6]. These figures explain why the amount of time we can spend working hard is limited and regular resting is required. Tiwari [7] believes that a continuous output of 60 W pedalling at 50 revolutions per minute for a long duration is reasonable. Such an output is ideal for many activities such as water pumping, threshing, maize shelling and grain grinding. The productive impact of hand- or foot-operated machines in the areas of transport, crop processing, manufacturing and water pumping are discussed below.

Table 1
Energy source-activity matrix for South Indian agricultural village (GJ a^{-1}) (adapted from Ref. [3]).

Source	Agriculture	Domestic	Lighting	Industry	Total
Human	214	502	–	133	849
Animal	353	–	–	33	386
Firewood	–	6549	–	1083	7632
Agro-waste	–	681	–	–	681
Electricity	93	–	34	11	138
Kerosene	–	5	202	28	235
Diesel	1	–	–	–	1
Coal	–	–	–	41	41
Total	*661*	*7737*	*236*	*1329*	*9963*

3.1. Transportation

Basic access to markets and services such as health and education is a fundamental necessity for sustainable development. Although isolation is known to be a major cause of poverty, there is usually little or no government support for improved transport in remote rural areas where unsealed roads and tracks dominate. Transport policies are usually formulated in capital cities and the focus is on roads and motorised transport. This shortcoming is unfortunate because there are opportunities to improve the movement of goods and people in remote rural areas.

In remote rural areas, walking, bicycles and animals are the most common means of transport. It has been suggested that "the most important development, technically and socially, in the nineteenth century was the bicycle" [8]. In 2007, global production of bicycles was 130 million, more than twice the level of car production [9]. In many developing countries, the influence of the bicycle is massive. In terms of efficiency, a 75 kg person on a bicycle is superior to other animals or machines, using a mere 47 kJ per km of travel (Fig. 1) and in terms of energy intensity per passenger km, it is an order of magnitude less than even a mass transit system ([10], cited in Ref. [11]).

In terms of load carrying, a comparison of human-powered transport modes demonstrates the significant benefits that are achievable. A wheelbarrow allows the user to carry three times the load (or alternatively make one trip instead of three) compared to portage on the head or back (Table 2), which has been shown to have long-term adverse physiological effects [14]. A handcart can carry double the load of a wheelbarrow and is already an important part in the transport system of some countries. In 1995 in Kenya, for example, it was estimated that there were 100,000 handcarts in use, playing an important part of the economy [15]. Handcarts are even superior to animal carts for small loads and short distances because it is simpler than hitching up an animal [16]. In terms of speed, the bicycle is by far the quickest form of transport, travelling about three times faster than all the other modes.

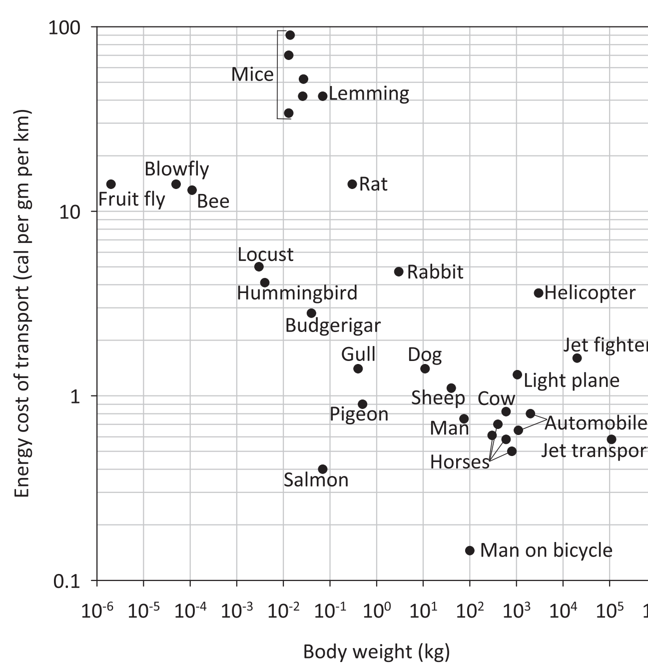

Fig. 1. Energy cost of transport for various animals and machines (source: adapted from Ref. [12], cited in Ref. [13]).

Table 2
Comparison of load carrying capacity and distances for various hand- and foot-operated devices (source Ref. [17]).

Transport mode	Typical load (kg)	Average speed (km/h)	Daily range (km)	Transport capacity (t km/h)
Human carrying	30	4–5	15–20	0.12
Wheelbarrow	90	3–4	5–6	0.35
Handcart (1 person)	200	3–4	10–12	0.80
Cycle with carrier	40	12	40–50	0.48
Cycle trailer	125	10	30–40	1.25
Donkey cart (1 animal)	300	3–4	20	1.10
Ox cart (2 animals)	900	3–4	20	3.20

3.2. Crop processing

Since rural areas are dominated by agricultural production for personal consumption and income generation, crop processing is often a dominant activity. Traditional methods of crop processing are slow, inefficient and hard work. These characteristics have long been recognized and have provided the impetus for the research and production of small machines to improve output, and reduce the time and effort required using traditional devices. For example, grain milling is traditionally carried out with a mortar and pestle or between grinding stones. Table 3 compares the output of some traditional methods and hand-operated (H–O) devices for processing some common agricultural crops. Improvements in output are increased considerably e.g. 3–4 times for threshing and 2–7 times (per person) for the various shelling operations.

3.3. Manufacturing

Good shelter is a basic need, and bricks and blocks of various sizes are used in most cultures where suitable raw materials are available. Hand-made bricks may be desired in rich countries to achieve a particular architectural style but in poor countries the technique is often used out of necessity rather than choice (Fig. 2). Traditional brick makers, often children, work long hours in arduous conditions. Trevalyn and Haslam [22] provide data that can be used to calculate the output of makers of hand-made bricks in the U.K. Their research also provides evidence of the deleterious physiological effect of such repetitive work. To meet a weekly quota, workers in the moulding department were required to produce 132 bricks per hour. This output level is similar to that cited for children in one developing country who produce up to 2000 bricks in a 14-h day (www.youtube.com/watch?v=n06xec-8oWQ). Hand-operated machines are available which can improve output with less hardship. One commercially-available hand-operated machine is claimed to be capable of producing 5000 similar-sized bricks in a 9-h day. However, the number of operators required is unspecified.

3.4. Water pumping

Water is essential for life, good health and reliable agricultural production. Water is also heavy and moving it by hand using containers or other traditional devices is arduous. There are many types of traditional water-lifting device including the counterpoise lift ('shadouf'), the pivoting gutter ('dhone'), swing basket or simple rope-and-bucket systems [23]. The modern suction handpump is now widely used as an alternative. A comparison of the characteristics of two traditional devices with the suction handpump shows that the latter combines good water delivery and lift characteristics (Table 4). In terms of combined volume and lift factor (m^3m) of water per unit time at the handpump, it is, on average, 40–75% better than the two traditional devices.

Mirti et al. [25] have calculated the power output of 13 different types of human-powered water-lifting device using different literature sources. In general, power output levels do not exceed 40 W. Foot-operated pumps are usually superior since leg muscles are more powerful than those in the arms. Because of their low output, suction handpumps are more suitable for drinking and stock water supply than irrigation.

Fig. 2. Brick making by hand in Nepal.

4. Animal power

According to FAO [26], animal power is still "persistent and widespread in Asia and Latin America" and its use in even "expanding in Africa". In terms of numbers of working animals, estimates vary. Wilson [27] estimates there to be at least 300 million draught animals, although acknowledges that other estimates are much higher. FAOSTAT [28] indicates that there are 110 million equines alone. In terms of net efficiency, animals are comparable with the tractor with efficiencies above 30%, but walking and maintenance reduces their efficiency significantly to approximately 10% [29]. The input–output model of [30] illustrates the multiple function of a working animal (Fig. 3). While this representation indicates the generic inputs, outputs and waste products of an animal viewed as an energy conversion device, the reality is much more complex. To 'operate' an animal may require human inputs for tasks such as herding, cleaning stalls or pens,

Table 3
Comparison of traditional and various hand-operated crop processing devices.

Task	Traditional method	H–O device	Reference
Threshing	20–40 kg/h	100–150 kg/h	[18]
Grain milling	2.9 kg/h	11.1 kg/h (2 persons)	[19]
Maize shelling	Few kg/h	6.82 kg/h	[20]
Ground nut shelling	1–3 kg/h	21–42 kg/h (2 persons)	[21]

Table 4
Performance comparison of two traditional water-lifting devices used for open and shallow wells with the modern suction handpump (source Ref. [24]).

Pump type	Maximum lift (m)	Typical flow (l/min)	Typical lift (m)
Shadouf	4	60	2
Rope and basket	100	15	10
Suction handpump	7	24–36	7

Table 5
Improvements achievable through better harness design (source: adapted from Ref. [34]).

Indicator	Yoke	Breastband	Collar
Draft (kgf)	57	65	64
Speed (m/s)	1.0	1.0	1.1
Power (W)	520	600	670

(Note:1 kgf = 9.81 N).

milking, harnessing and guiding. Cash 'inputs' may also be required to purchase occasional feed or veterinary care. Cash income for live or dead animals is also an important 'output' from a farmer's perspective (see later Table 9). The monetary value of the multiple goods and services provided by some animals is significant e.g. cattle in South Africa, analysed in detail by Shackleton et al. [31]. Animals are consumers and producers of biomass. In both its raw and digested forms, biomass production is always included in assessments of renewable energy potential. However, with a few notable exceptions [26,32] the output of the energy conversion process i.e. the animal itself is not regarded as a source of renewable energy. It is not ignored, of course, by those who live and work in the rural areas of developing countries.

The force exerted by a working animal is approximately equal to 10–12% of its live weight, and this means, for example, that a buffalo has a power output of about 300 W, or 5.4 MJ/d, if it is assumed that the animal works for 5 h per day. However, many factors can reduce this output significantly. These include stress, malnutrition, a poor fitting harness, difficult ground etc. The impact of poor nutrition is significant because thin, underfed or sick animals will not be able to work efficiently. Output can decline as much as 50% in oxen and buffalo, according to Pearson [29]. Both food quantity and quality is important and a 400 kg animal will need approximately 44 MJ/d in food [33]. Assuming their availability, the ability to provide adequate feed and health care to animals is principally about knowledge and education, rather than technology, like harnesses, cultivation implements and carts. The impact of improvements that are possible in these technologies is discussed below.

4.1. Harness design

The traditional method of harnessing animals is often a yoke, which rests on the back or neck of the animal. In this arrangement, both the animal and the activity are disadvantaged. For the animal, the load is transferred through a single point of contact which can result in sores at the pressure point. The position of the yolk and control of the animal is via a rope under its neck, which in turn leads to pressure on the throat and discomfort. The development of draught power is disadvantaged because the angle of pull is high and there is a high vertical component in load.

By improving the harness, both these disadvantages can be reduced. The three-point harness is an example of technology that overcomes the problems described above (Fig. 4). A comparative study between the traditional and two improved harnesses by Geza [34] illustrates the positive effects (Table 5). Draft, power and speed have all been improved. Adoption rates for better harnessing are reported to be low [16], however, possibly due to cost, and the complexity for harnessing more than one animal. Other factors such as tradition may also influence acceptability.

Table 6
Comparison of traditional and improved ploughs (source Ref. [40]).

Performance parameter	Traditional	Improved
Number of ploughings	5	5
Average depth of cut at final ploughing (mm)	98	128
Average width of cut (mm)	154	160
Average pulling force (kg)	26.7	22.0
Deepest cut (mm)	108	143
Widest cut (mm)	211	215

Table 7
Soil preparation times using hoe, plough and cultivator (source Ref. [42]).

Power source	Hoe (hr)	Plow (hr)	Cultivator (hr)
Hand	60	–	–
Donkeys	–	20	13
Oxen	–	7–10	4–5

4.2. Transportation

While handcarts may be superior to animals for transporting small loads over short distances, the importance of animals in rural transportation is unquestionable and their widespread use is testament to this fact. In India alone, there are an estimated 14 million animal-drawn carts [16] and 700,000 in Africa [17]. In most cases, animals pulling carts have a superior transport capacity to humans and can certainly carry significantly heavier loads (Table 2). Animal carts can carry almost a tonne of produce. An example of how modern design and materials can improve traditional animal cartage is the Golovan cart (Fig. 5). Designed to be drawn by a single ox (rather than a pair), it weighs 320 kg and has a payload of about 500 kg, which is directly over the back axle, minimizing the forces on the neck of the animal [36].

4.3. Agriculture

According to IFAD [37], two billion people live and work on small farms in developing countries and most of these smallholder farmers live on less than $2 per day. Many of them rely on traditional technologies to perform the arduous tasks of agricultural production such as ploughing, planting, harvesting and processing. Some examples of technologies to improve the efficiency of the last of these activities have been cited in Table 3. The FAO [38] cites data from more than 27 developing countries across Central America, South and South East Asia, and Africa used to analyse the various activities undertaken by rural households to generate income. In many countries, the percentage of small farms using mechanized equipment is less than fifty percent indicating that there is substantial room to introduce more efficient hand, foot or animal operated equipment. Two examples of the improvement possible are described in the following paragraphs.

The traditional plough or 'ard' is used in many countries. There are numerous designs but they often have disadvantages such as: being jerky to use; leave large areas unploughed; are slow and hard work; have a limited cutting depth; and need multiple passes. Various new plough designs have been developed with improved results. For example, Sarker and Barton [40] tested their improved design which had a variable pull angle, redesigned and replaceable share at a lower cost. The new design produced a cut that was 30% deeper and 4% wider using 18% less force (Table 6).

Table 8
Comparative costs of solar panel and some human and animal-powered devices (adapted from Ref. [43]).

Technology	Cost (US$)
40 W PV panel	210
Manual grinder	56
Manual water pump	63
Animal-drawn cart	70
Animal-drawn plough	100
Sewing machine	115

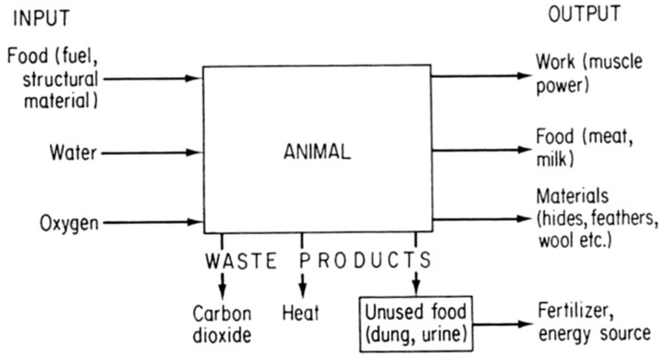

Fig. 3. Input-output block diagram for working animals (source Ref. [30]).

Animal-drawn wheeled tool carriers have been identified as a step between traditional implements and the tractor. Developed in the 1950s, these implements can carry a range of tools for field preparation, as well as being adaptable for carting and spraying. Starkey [41] has traced their history and warned that success on research stations does not necessarily translate into successful technology transfer. Farmers have found them to be costly, too heavy and complex, and risky because breakdown could result in a loss of all processes, rather than one in the case of the traditional implement. The effectiveness of an animal-drawn cultivator compared to other traditional implements for soil preparation, measured in operational hours, has been demonstrated by Veikko and Pitois [42] (Table 7). In this example, improvements, measured in orders of magnitude, are possible using a cultivator harnessed to the oxen.

5. Investment benefits

This paper has so far argued that there are opportunities to improve the life of those in the most rural areas of developing countries with hand-, foot- and animal-powered devices. However, there could also be investment advantages compared to conventional renewable energy technologies. Karekezi and Kithyoma [43] contrast the cost of solar PV with various other rural energy devices (Table 8). It can be seen that even a small PV panel is 2–3 times more expensive than the human- and animal-powered devices. Such data strongly supports the argument that investment in these technologies is just as (or even more) important as that directed to the more conventional renewable technologies.

The superior value of animal- compared to machine-power in some situations is certainly recognized by users. Table 9 summarizes the reported preferences of some Thai farmers for buffalo compared to the 2-wheel 'walking tractor' for preparing fields for rice planting [44]. Clearly for those with a small land area, the buffalo is superior in terms of capital and running costs, and there is even some value as meat at the end of the animal's useful life.

Table 9
Comparison of buffalo and 2-wheel walking tractor (source: adapted from Ref. [44]).

Criteria	Buffalo	2-Wheel walking tractor
Capital cost	US(1986)$ 192–260	US(1986)$ 720–1000
Durability	25–30 years	5–10 years
Running costs	None	Petrol and repairs
Length of working day	4–6 h/day	8–10 h/day
Ploughing rate	0.1–0.2 ha/d	0.5–0.8 ha/d
Suitable farm size	0.5–1.6 ha	3.2 ha or more
Value at end of life	US(1986)$ 40–80 (meat value)	Scrap only

Fig. 4. Three-point harness (source Ref. [35]).

6. A global perspective

There are very few estimates of how much energy human and animal power contributes on a macro scale. The analysis of the energy use of an Indian village by Ravindranath et al. [3], cited earlier, is one example. Alam et al. [45] have carried out a similar study for a village in Bangladesh. Ramaswamy [46], cited in Ref. [27], estimated that draught animal power was equivalent to the use of 20 million tonnes (840 PJ) of petroleum products by motorized equipment.

Like the non-commercial use of biomass, human and animal power would be impossible to monitor and record accurately. However, it is possible to calculate an 'order-of-magnitude' figure using the available data. If it assumed that the 1.3 billion people currently without electricity [47] live as the villagers analysed by Ravindranath et al. [3], then those humans contribute nearly 1200 PJ per annum. Likewise, if it is assumed that the estimated 300 million working animals are contributing about 1 GJ per annum each (as Ref. [3]), then their annual contribution will be 300 PJ. Together, humans and animal energy represents approximately 1500 PJ per annum. In 2008, wind power was estimated to produce 227 TWh [48] and hydro power contributed 2.2% (270 Mtoe or 11,340 PJ) of the world's primary energy [49]. This means that

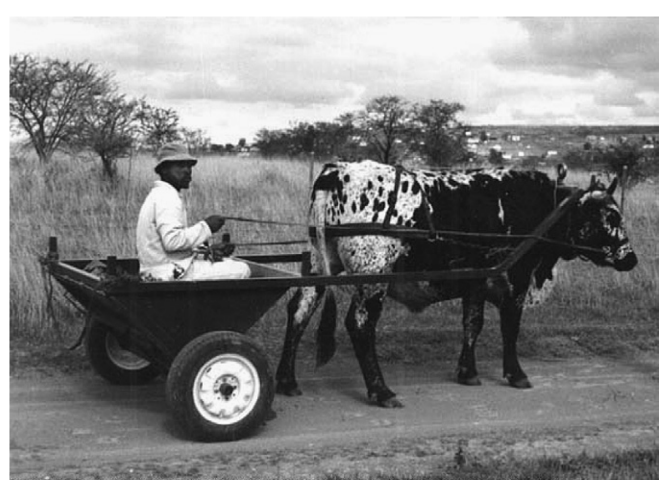

Fig. 5. The Golovan cart (source Ref. [39]).

human and animal contributed almost twice the energy of wind power and approximate one seventh of the energy of hydro power. These figures alone justify that more attention should be given to human and animal power.

The examples and opportunities for using human and animal power have been drawn from research that has focused on the needs of developing countries. The relevance of such technologies to developed countries, however, should not be overlooked. Cheap and plentiful energy in these countries has led to a decline in the use of manually-operated technologies. Every household implement that could be motorized is now available, adding to fossil fuel demand, particularly electricity. The decline in physical activity has also undoubtedly contributed to a decline in bodily health and well-being. For many who live in developed countries, their muscle tone is now maintained in gymnasiums rather than in the home and garden. By re-embracing human power for some tasks, environmental and health benefits are likely to result.

7. Barriers to dissemination and adoption

The preceding sections have argued that human and animal power play a crucial role in the day-to-day activities of many who live in the rural areas of some developing countries. Improvements in the technologies could increase outputs and save time. If this is the case, what are the main barriers to dissemination and adoption to the introduction of these improved technologies? The literature suggests a number of contributing factors.

Firstly, Karekezi and Kithyoma ([42]:1082) suggest there is a pre-occupation with electricity – or more precisely, the lack of it. In sub-Saharan Africa, for example, they say that "external observers and experts react with a great deal of concern when shown data indicating that in a typical sub-Saharan African country, <5% of the rural population have access to electricity. Since most of the experts come from countries with almost universal electricity access, the thought of any form of development without electricity is perceived as unthinkable". As a result, numerous electrification programmes have been launched in that region, effectively shifting the focus away from more beneficial technologies such as hand-operated and animal-drawn implements, "which would increase the agricultural productivity of rural Africa."

The cost of the improved technologies is a significant barrier to their adoption. Dennis [17], discussing alternatives to carrying loads on the head or back, states that many rural people are unable to afford simple technologies such as wheelbarrows, handcarts, bicycles and animal-drawn carts. According to Ref. [17], the cost of an animal cart may represent up to 3–4 times the average annual household income. In some cases, locally-run credit schemes can overcome this barrier.

The isolation of those who would benefit most from the introduction of more efficient hand and animal-powered technologies is also a major factor influencing the steps in a successful technology transfer process. The voices of those far from the decision-making centres are least heard and therefore their needs in terms of what is appropriate are less well articulated. Lack of information and/or misconceptions about what technologies are available, how to access them, lack of political power and poor infrastructure all stem from the isolation of communities. Paying particular attention to the choice of technology and the infrastructure for its repair and maintenance is largely credited as the reason for the success of a World Bank-funded handpump project in Mali [50].

The FAO ([26]:9), however, believes that the constraints to further use of animal power are not technical or economic, rather psychological or social. The organisation contends that decision makers and educators do not regard animal power as "a modern development option". It is believed that portraying animal power as a "renewable technology that is relevant to the modern world" through various media and education outlets would do much to change its image.

8. Conclusions

This paper has argued for the place of human and animal power in the family of renewable sources of energy. Human and animal power clearly makes a massive contribution to the energy used in the rural areas of developing countries. In global terms, this contribution is also significant compared to more conventional renewable energy sources such as wind and hydro. Opportunities exist to improve existing tools and techniques, as well as to introduce new low cost technologies in order to reduce drudgery, improve health and well-being, and improve income generation opportunities. There is evidence to suggest that investment in these technologies is likely to be more cost-effective than in more popular renewable technologies such as solar home systems.

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