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Review

Balantidiasis: A Neglected Tropical Disease Used as a Study Model for a Holistic Approach to Sustainable Development in the Framework of Agenda 2030 Goals

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Abstract: The term "sustainability" could be defined as the process of people maintaining changes in a homeostasis-balanced environment, in which the exploitation of resources, direction of investments, orientation of technological development, and institutional change are all in harmony. The most significant global effort to address sustainable development is the United Nations' Sustainable Development Goals (SDGs). Among the various targets set within the 17 SDGs, the end of neglected tropical zoonoses (NTZs) is an example of how coordinated social, economic, and environmental efforts are needed to achieve this goal. Balantidiasis, caused by *Balantidium coli*, is a zoonotic parasitic disease characterized by high infection and incidence rates; however, it is only scantly investigated and therefore considered a NTZ. In this review article, balantidiasis was used as a model to demonstrate how proper management of NTZs falls in all the SDGs and how a holistic approach to animal and human diseases could improve their health status and other aspects of their being. In this manuscript, the SDGs were divided in three pillars: (i) social, (ii) economic, and (iii) eviromental. This theoretical division helps to demonstrate that the presence and, consequently, the control of an NTZ could be reflected on all the 17 SDGs.

Keywords: *Balantidium coli*; sustainability; development goals; Agenda 2030; neglected disease; neglected zoonoses; sustainable development; sustainable development goals

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1. From the One Health Umbrella to the Sustainable Development Goals and Back

1.1. One Health Umbrella

Even though the term "One Health" could sound as a modern concept, it dates back to the 19th century, when the father of the One Health theory Rudolf Virchow, investigating swine roundworm, *Trichinella spiralis*, highlighted the linkages between human and veterinary medicine and coined the term "zoonosis" to indicate an infectious disease passing between humans and animals. In this circumstances, Virchow stated that "*Between animal and human medicine there are no dividing lines—or should there be. The object is different, but the experience obtained constitutes the basis of all medicine*." This last sentence, which could be called Virchow's paradigm, in 2021 is still valid; in fact, it has been estimated that, globally, about one billion cases of illness and millions of deaths occur every year for zoonoses [1]. In the last three decades, over 30 new human pathogens have been detected, and 73% of the currently emerging and re-emerging pathogenic agents may cause zoonoses [2,3]. The transmission of zoonotic disease occurs at the human–animal interface through direct or indirect exposure of humans to animals, their products (i.e., meat, milk, eggs), the same vectors, and/or sharing the same environment [4,5]. Environment plays the crucial role in zoonosis transmission and spread. In fact, on the one hand, a healthy environment (in which humans, animals, and the environment are in a perfect balance) could mitigate the spread of infectious diseases [6]; on the other hand, environmental changes, including

changes in climate, landscape, and communities of hosts and vectors, have all been implicated in the spread of zoonotic diseases directly (i.e., by modulating immunocompetence) or indirectly (i.e., by modifying the vectors composition and density) [4,7]. Land use modifications, for instance, intensive livestock farming, urbanization, encroachment into wildlife hatbitats, and agricultural changes, account for around 50% of all zoonotic emerging infectious diseases [8]. Pathogens traditionally spilled over from animals to humans; however, as testified by the SARS-CoV-2 pandemic, human encroachment into wildlife habitats, exponential human population growth, and exploitation of the environment make spillover more likely, with potentially devastating consequences [9]. In this regard, the COVID-19 pandemic is not an isolated event; in fact, other epidemics and pandemic zoonoses occurred in the past and as many may likely occur in the future (Middle East respiratory syndrome, swine flu H1N1, avian flu) [10]. A "One Health" approach to zoonoses is a holistic method to reach environmental sustainability, livestock and human health. However, it is not so easy to create healthy ecosystems and environments in which animal and human health is guaranteed, and not all nations have sufficient economic resources to reach this noble aim. In developing countries suffering from economic distress, creation of healthy and resilient ecosystems is especially needed. In this regard, it is mandatory for all the political frameworks and also for the scientific community to look for sustainable solutions.

1.2. Sustainability in the Developing Countries

Today, the term "sustainability" could be defined as the process of people maintaining change in a homeostasis-balanced environment, in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations [11,12].

The most significant global effort to comprehensively address sustainable development is the United Nations' Sustainable Development Goals (SDGs) launched in the framework of Agenda 2030 with the aims of reducing poverty, instilling peace and prosperity all over the world on a healthy planet [13]. The 17 SDGs (Table 1) include 169 targets to achieve the goals set in Agenda 2030. Despite the fact that each goal and the subsequent targets concern different topics, they are closely interconnected and cannot be considered separately, balancing the three dimensions of sustainable development: economic, social, and environmental. Only integrated development of all the three spheres will allow people to live healthily on a healthy planet [14].

Among the various targets set within the 17 SDGs, the end of neglected tropical diseases (NTDs) is an example of how coordinated social, economic, and environmental efforts are needed to achieve this goal [15,16]. NTDs could be defined as a diverse group of diseases whose health and economic burden falls most heavily on the poorest people and communities [17]. Some of these are neglected tropical zoonoses (NTZs) which severely impact the environment, animal and human health and create severe economic losses. NTZs have been at the cornerstone of the One Health/Ecohealth approach, with an estimated amount of $20 billion in direct costs and over $200 in indirect losses [18]. Nowadays, as stated above, the threat of the NTDs emergence due to climate changes, employment of natural resources, the constant increase of the world population and their new lifestyle is increased worldwide. Some NTZs, for instance, soil-transmitted helminths, dirofilariasis, onchocerciasis, dengue, chikungunya, and schistosomiasis, as well as rabies and leishmaniosis, have been extensively studied due to their high pathogenic relevance [19–22]. Furthermore, the linkages and effects that make them relevant to all the SDGs and how the efforts to mitigate their impact will have a direct influence on overall SDGs progress have been investigated [15]. By contrast, other NTZs, such as balantidiasis, despite their wide distribution, have been poorly investigated [23–25].

Table 1. Different Sustainable Development Goals (SDGs), the pillar in which an SDG is included, the linkage between SDG and balantidiasis, the potential efforts against the *B. coli* spread, and the relevant effects on sustainable development progress (SDP).

SDG	Pillar	Linkage between Balantidiasis and SDG	Efforts against the *B. Coli* Spread and Relative Effects on SDP
G1: End poverty in all its forms everywhere	III [3]	Economic deprivation makes some basic services less accessible and limits opportunities for access to medical cures and basic hygienic conditions. Moreover, potential debilitating effects of balantidiasis could cause economic failures due to adverse effects on farm productivity or in terms of workforce when humans are affected.	Easy access to medical cures (preventing concomitant diseases that could enhance the severity of balantidiasis). Basic hygiene standards education would contribute to limiting the spread of *B. coli* infection among animals and humans.
G2: End hunger, achieve food security and improve nutrition and promote sustainable agriculture	III [3]	*B. coli* is potentially one of the most neglected food- and waterborne diseases. The parasite displays a direct lifecycle, and in the developing countries, the main transmission route of the disease is the consumption of cysts-contaminated foodstuffs.	Increasing food security in terms of quality and safety reduces significantly the risk of transmission of the disease.
G3: Ensure healthy lives and promote well-being for all of all ages	I [1]	The main symptom of the *B. coli* infection is dysentery that determines the suffering of the affected human/animal and increases the cysts shedding and therefore the spread of the disease. Furthermore, *B. coli* infection can worsen the life quality of animals and humans affected by other debilitating diseases.	Reducing *B. coli* infection and the relative symptomatology limits its spread and contributes to well-being.
G4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	I [1]	Debilitating effects of balantidiasis can reduce school attendance and, therefore, the level of education. The low level of schooling negatively impacts social and economic growth.	Basic school education is key to social and economic development. Therefore, limiting the incidence of balantidiasis inevitably favors the possibility of school attendance.
G5: Achieve gender equality and empower all women and girls	I [1]	Ending discrimination against girls and women can be impeded and exacerbated by *B. coli* infection. The associated weakening effects limit the ability to carry out all the social activity for their self-determination.	Physical and mental health are essential prerequisites for the emancipation of everyone. Therefore, avoiding any diseases, especially the neglected ones such as balatidiasis, contributes significantly to equal rights between men and women.
G6: Ensure availability and sustainable management of water and sanitation for all	III [3]	In the developing countries, the fecal–oral transmission of *B. coli* occurs mainly through the ingestion of water contaminated with cysts. The lack of adequate sanitation processes favors the spread of the protozoa through contaminated drinking and recreational water.	Water and sanitation play the key role in the spread of the protozoa. Proper management of the sanitation process significantly contributes to reducing the risk of infection.
G7: Ensure access to affordable, reliable, sustainable and modern energy for all	II [2]	Interest in the development of new forms of sustainable energy is growing. Farm waste is among the most studied and used compounds for the development of bioenergy. In this context, *B. coli* could cause losses at farms in terms of production performance such that farmers cannot spend time and economic resources for the development of new sustainable energy forms.	Maintaining healthy farms ensures greater productivity and sufficient resources for the research and development of new and renewable energy that can be useful in economic and social growth, especially of the poorest and most marginalized areas.

Table 1. *Cont.*

SDG	Pillar	Linkage between Balantidiasis and SDG	Efforts against the *B. Coli* Spread and Relative Effects on SDP
G8: Promote inclusive and sustainable economic growth, full and productive employment and decent work for all	III [3]	A neglected zoonotic disease such as balantidiasis can be a significant burden for the economy of small rural areas where livestock farming is the main source of livelihood. Lower livestock productivity and lack of workforce contribute to limitations of economic and social development.	Health education and implementation of control measures for the hygienic management of farms would contribute to reducing the spread of *B. coli*, decreasing the risks of diseases for animals and humans and also increasing job opportunities.
G9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	II [2]	Inadequately constructed and designed houses and farms inevitably contribute to the spread of the protozoan. A high incidence of the parasite was found at overcrowded farms due to insufficient spaces and a higher incidence in humans related to the presence of animals in the domestic environment due to the lack of separate breeding facilities.	The education for basic architectural principles and rules for the correct management of farms would certainly contribute to raising the quality of the infrastructure and at the same time reducing the possible spread of the parasite as a result of poor hygiene of the environments.
G10: Reduce inequality within and among countries	I [1]	Nowadays, global health is considered a multidimensional concept and is the result of biological, economic, social, political, cultural, and environmental processes. Therefore, debilitating diseases (such as balantidiasis) and inequality can both be considered mutual causes and effects: the social and economic burden of diseases contributes to increasing inequalities and social stigmas which, in turn, foster indifference towards the most discriminated.	Promoting active participation of the poorest and marginalized people in the economic and social life of the country certainly reduces the inequalities, pushing for a more inclusive approach towards people who are sick or economically deprived by the disease.
G11: Make cities and human settlements inclusive, safe, resilient and sustainable	II [2]	To cope with increasing urbanization, especially in the developing countries, a more sustainable approach is needed in the management of urban spaces. If this transition is not properly managed (e.g., slum construction), there is a real risk that the incidence of neglected diseases such as balantidiasis could increase as we move from rural to urban areas.	Health education is the most effective way to understand the main risk factors of the spread of balantidiasis and how to manage them.
G12: Ensure sustainable consumption and production patterns	II [2]	*Balantidium coli* is mainly transmitted by ingestion of contaminated water. Chemicals are often used to manage water sanitation. All of this contributes to reducing the availability of drinking water with implications on sustainable growth.	Proper health and hygiene management of farms as well as the disclosure of prophylactic measurements would help to reduce environmental contamination and limit the use of chemicals.
G13: Take urgent action to combat climate change and its impacts	II [2]	Efforts needed to manage *B. coli* infection inevitably require consumption of resources that impact the environment, contributing to an increase in climate change. The increase in temperature, rainfall, and humidity supports the spread of the protozoa.	Awareness campaigns for the causes and effects of climate change would help to understand the relationship between climate and animal health.
G14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development	II [2]	The health of the marine and coastal environments is a prerequisite for the well-being of humans and animals. The freshwater ecosystem can be contaminated with cysts of *B. coli* due to inadequate sewage management from close farms that can reach the marine environment when carried by rivers.	Clean water bodies are important to maintain food security and good sanitation. Proper construction and management of farms should exclude water contamination by *B. coli*.

Table 1. *Cont.*

SDG	Pillar	Linkage between Balantidiasis and SDG	Efforts against the *B. Coli* Spread and Relative Effects on SDP
G15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	II [2]	The breeding of native species represents a reasonable alternative given more sustainable development of the farming system. In addition to a wide range of animal species, *B. coli* was detected in autochthones species, and its potentially debilitating effects raise concerns for the preservation of biodiversity and the development of a more sustainable breeding system.	Increase efforts to enhance local resources and raise awareness of the benefits of proper breeding management.
G16: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	I [1]	Outbreaks of neglected tropical diseases such as balantidiasis can more easily occur during wars, famines, and crises.	Interventions in crisis-hit places can help improve the local situation and instil peace.
G17: Strengthen the means of implementation and revitalize the global partnership for sustainable development	I [1] II [2] III [3]	The economic and social strength of partnerships between private companies and public bodies constitute a surely winning approach to the long-term fight against all neglected tropical diseases, including balantidiasis.	Promote new international partnerships based on previous experiences.

Note: [1] I: social pillar; [2] II: environmental pillar; [3] III: economic pillar.

1.3. Balantidiasis as a Model of Study for NTDs Sustainability Approach

Balantidiasis is a parasitic disease caused by the ciliated protozoa *Balantidium coli* (also known as *Neobalantidium coli* or *Balantioides coli*), which affects a variety of hosts including domestic pigs, ruminants, guinea pigs, and rats [24]. *Balantidium coli* features a direct lifecycle with fecal–oral route transmission that occurs mainly by ingestion of food and water contaminated with cysts [26,27]. This parasite has a worldwide distribution; however, it is more common in the subtropical and tropical regions of the world [28]. The reservoir hosts are the domestic and wild pigs, in which the parasite inhabits mainly the villi or lumen of the large intestine [23]. In its reservoir host, the prevalence of the infection ranges from 0.7% to 100% depending on the animals' reader system, geographic origin of animals, and, mainly, the breeding hygienic conditions [23–25,29,30]. In a reservoir host, *B. coli* is commonly considered nonpathogenic; however, in symptomatic animals, the clinical presentation is characterized by fetid watery diarrhea, appetite loss, dehydration, loss of body condition, and retarded growth, inevitably leading to economic losses [31].

In the developing countries, due to poor hygienic conditions, close contact between humans and farmed animals, malnutrition, concomitant infections, and debilitating diseases, *B. coli* could also represent a serious threat to human health [26,27]. In fact, as is well-known, balantidiasis could be considered a relevant NTZ and particularly in the poorest countries, *B. coli* is regarded as one of the most underestimated food- and water-borne parasitosis [23], while in the developed countries, *B. coli* spread could be occasional and related to contamination or a process failure within water utilities or recreational waters (i.e., in swimming pools, water parks) [32,33]. Moreover, this pathogen could be transmitted by the consumption of raw or undercooked meat following carcass contamination during slaughtering [23,34,35]. In humans, *B. coli* infection could outcome in an asymptomatic way or generate a severe syndrome characterized by mucosal ulceration accompanied by diarrhea and dysentery with possible fatal outcomes [36]. This last scenario is mainly linked to other debilitating conditions, for instance, immunodepression, chronic and infectious diseases [37].

Therefore, in light of the foregoing consideration, with its duality in the developed and the developing countries, balantidiasis could be used as a study model to demonstrate how sustainable management of NTZs falls in all the Agenda 2030 SDGs and how a holistic approach to animal and human diseases could improve not only the health status, but also other aspects of animal and human being.

In Table 1, the different SDGs are reported, the relevant targetx, the linkagex between the SDGs and balantidiasis, the potential efforts against the *B. coli* spread, and the relevant effects on sustainable development progress.

Below, the 17 SGDs were divided between three different sections corresponding to the three pillars of sustainability: social, environmental, economic.

2. Pillar I: The Social Perspective

The study of NTDs from the social perspective contributes to a comprehensive assessment of its causes and effects through an analysis of social factors that might play the key role in the onset, prevention, and treatment of the disease [38].

Nowadays, there is clear awareness that without social cohesion it will be impossible to achieve the Agenda 2030 SDGs. People's welfare is a multidimensional concept that includes all the components of human life such as health, the possibility of healing, living in a safe dwelling, and a healthy environment, quality education, and a stable job [39]. Although all these aspects are strongly affected by the national economy, culture, and rules, as well as by specific territorial and family contexts, everyone should live in a state of equity with the full possibility of self-determination regardless of origin and context. Reducing inequalities in the broadest sense of increasing social inclusion is recognized as an essential requirement for sustainable development. Not by chance many international and national policies promote active participation of the poorest and marginalized people in the economic and social life as an action plan to reduce economic and social distress [40].

Despite the fact that the increase in global productivity has led to an overall reduction in poverty, inequalities have grown, and the several gaps still present must be filled, especially those regarding health (e.g., access to basic medical care), education (e.g., universal primary education), and gender discrimination (e.g., girls and women empowerment).

Inequality and balantidiasis, in some way, can both be considered mutual causes and effects. Cases of balantidiasis reported in the literature are predominantly described in humans from poor rural areas where people live in close contact with their livestock and have no means for animal and human waste disposal [24]. At the same time, the debilitating effects of the disease can have a significant impact in terms of the workforce being able to provide for their livelihood, thus causing poverty and social exclusion. However, *B. coli* is usually considered an opportunistic pathogen that only under certain conditions might determine a clinical disease [41]. The onset of the disease seems to be related, at least in part, to the health status of those affected [42]. In several cases of *B. coli* comorbidity described, although no comprehensive analysis was performed, immunocompromised individuals seemed to be more susceptible to balantidiasis [43,44]. In this sense, balantidiasis might contribute to increasing the social stigma associated with certain pathologies as in the case of two HIV-infected patients and a 54-year-old alcoholic pork butcher in whom coinfection with *B. coli* was observed [45–47]. In other circumstances, combination of the illness and social distress can contribute to the spread of the disease, as described by Young et al. who reported nine cases of balantidiasis in a mental institution in which transmission probably occurred by coprophagy [48].

Cases of human balantidiasis have been described in both adults and children. No direct correlation between age and human infection rates has been described. In the same manner, in pigs, even though there is no common consensus, the differences in infection rates between age groups are mainly related to the management conditions of the farms rather than the age itself. The debilitating effects of balantidiasis in children might reduce school attendance and, therefore, the level of basic education. The low schooling rate triggers a vicious cycle with a significant impact on social life. Participation in school activities, literacy, civic education, and basic training promote social inclusion, increasing knowledge and skills of the future generations that can contribute to the resilient growth of the most vulnerable areas. On the one hand, there is evidence of *B. coli* infection in children mainly associated with dysenteric conditions [49–52]. On the other hand, a comprehensive study carried out on almost 2,000 children from the Altiplano region of Bolivia found a widespread infection with *B. coli* but a low rate of clinical symptoms [49]. The cause lied in the starch-poor diet of the children who appeared malnourished and stunted as *B. coli* needs a source of sugars to survive and replicate [25]. In any case, the authors of the study speculated that although children were asymptomatic carriers of *B. coli*, they would have negative long-term effects. However, there are no scientific evidence-based observations of early-childhood *B. coli* infection associated with functional deficits years later, while it is widely accepted that continued exposure to parasitosis in endemic areas increases resistance to the disease [41].

From the point of view of SDG 8 on gender equality, gender should not be considered a direct risk factor for the onset of the disease. Gender might become a risk factor in farmed animals considering the different breeding practices to which males and females are subjected. Likewise, in some territorial and family contexts, men and women have specific social roles and perform different tasks for the sustenance of their families. In a survey conducted in the central highlands of Papua New Guinea, the prevalence of *B. coli* found in women was twice as much as in men because it was mainly women who cared for the animals [53].

3. Pillar II: The Environmental Perspective

Protection of the environment is among the main priorities of the Agenda 2030 SDGs. Economic and demographic growth entails greater exploitation of natural resources with

an inevitable impact on the environment [54]. Therefore, it is widely accepted that a more sustainable approach is needed to safeguard natural ecosystems and human health [55].

Sustainable development faces several challenges and the demand for new sources of clean energy from renewable resources plays the leading role. Obtaining energy from the Sun, wind, water, or biomass might have an immediate benefit not only in terms of resilient growth, but also against NTDs. For instance, production of biogas by burning the effluent or through anaerobic fermentation processes of manure may sustainably produce energy and might also inactivate *B. coli* cysts or trophozoites contained within [56,57]. Sustainable waste management can also significantly contribute to reducing the use of chemicals intentionally added to wastes for their proper and safe disposal. The main constraints related to the production of renewable energy in rural areas are probably related to the limited economic resources and lack of a properly trained workforce. Financial incentives and targeted public investments for the construction of infrastructure and professional training would contribute both to economic development and long-term control of NTDs [58]. Programs to combat NTDs have contributed to the construction of roads in the poorest and least urbanized countries, facilitating traveling and encouraging the creation of markets, schools, and hospitals, which therefore become accessible and usable, thus resulting in an ever-growing urbanization process [59].

Massive movements of people and animals from rural to urban areas lead to changes in the environment that could affect the epidemiology of NTDs with the risk of spreading to areas not yet infected [60]. On the one hand, urbanization processes encourage social inclusion and economic development; on the other hand, some risk factors of infectious diseases might be exacerbated if not properly managed. This may be due in part to conditions in which the poorest people live in urban centers and to certain habitats that urban spaces offer that facilitate the ability of parasites to survive and spread. Most people confined to rural environments provide for their livelihoods through agriculture and livestock. A higher rate of *B. coli* infection was found at overcrowded farms due to insufficient space and in humans related to the presence of animals in the domestic environment due to the lack of separate breeding facilities [25,61]. Therefore, new urban spaces should certainly consider the need to improve housing. The lack of adequate sewage systems and the supply of drinking water in households are certainly prone to the spread of waterborne diseases such as *B. coli* [24]. As a water- and foodborne disease, *B. coli* transmission is also the result of environmental contamination with feces; therefore, reduction of household environments that represent potential infection hotspots such as open-air latrines and stagnant drinking water containers are relevant for parasite control. Furthermore, ending the practice of open defecation limits the spread of the parasite and contribute to achieving the aims of SDG 15 regarding land and soil degradation.

Protection of the environment also depends on understanding the links between climate changes and the epidemiology of NTDs [62]. These diseases are particularly widespread in subtropical and tropical regions where climatic conditions favor the development and survival of pathogens or their vectors. We could speculate that global warming is likely to expand their geographical distribution in areas with a temperate climate [63]. *Balantidium coli* was reported in various countries of the world, and its prevalence is geographically linked to areas with higher temperature and humidity. The largest numbers of *B. coli* infections have been reported in South Asian countries where warm weather and high rate of rainfall provide a suitable environment for parasite growth [24]. Several authors have assumed that transmission could follow a seasonal pattern, with the highest rate of infection during the rainy season [31,64]. However, the occurrence was also reported in areas with a cold and dry climate such as the Bolivian altiplano, Iceland, and Finland [65–67].

In some epidemiological scenarios, the interface between wild and domestic animals could lead to the exchange and spread of pathogens from the wild side to farmed animals and vice versa. For instance, the prevalence of *B. coli* is usually higher in captive animals than in wild populations [25]. However, these findings could mainly be related to the

breeding system rather than the "wild" condition. In fact, two studies carried out in Italy investigating the *B. coli* prevalence in commercial hybrid pigs reared at intensive farms and autochthonous species of pigs reared en plain air demonstrated that the infection rate was higher in the former [23,34]. The en plein air system determining a "dilution" effect on protozoa excreted with feces might reduce the infection spread, while in intensive systems, the closer contact between animals increases their exposure to the parasite and consequently the infection rate.

Noteworthily, climatic catastrophes, such as typhoons, earthquakes, tsunamis, could result in the appearance of the disease in new areas. The largest *B. coli* outbreaks occurred, in fact, on the island of Truk, Caroline Islands (Western Pacific), following a typhoon that destroyed the rooftop catchment systems for the collection of rainwater, forcing people to drink water contaminated with pig feces, resulting in 110 cases of balantidiasis [68].

4. Pillar III: The Economic Perspective

Despite the fact that since 1990, the extreme poverty rates have fallen by more than half, today, 150 million people still live in abject poverty, predominantly in South Asia and Sub-Saharan Africa [69]. Economic deprivation or precariousness triggers a vicious circle in which several basic services are lacking, favoring the spread and persistence of NTDs. Not by chance, NTDs are prevalent in low- and middle-income countries, especially in rural and remote areas or in conflict zones [15]. The causes of extreme poverty in the world related to NTDs are to be found far beyond the mere lack of income and resources.

Balantidium coli was particularly found among the poorest regions of the world where most of the people live in extreme poverty with less than $1.25 a day [13]. *Balantidium coli* infections in humans and animals were reported in Burkina Faso [70], Central African Republic [71], Ethiopia [72], Guinea [73], Liberia [74,75], Malawi [76], Mozambique [77], Nigeria [78], Sierra Leona [79,80], Somalia [81], and Yemen [82]. However, balantidiasis is not geographically linked to the poorest countries but must be considered a disease of "poverty". In this regard, cases of human balantidiasis have been reported both in countries with lower-middle (e.g., India), upper-middle (e.g., China, Libya, Peru, Turkey, South Africa, Venezuela), and high-income (e.g., France, Greece, Italy) economies according to the latest World Bank classification [83–85]. The adverse effects of balantidiasis on the economy of the most vulnerable countries can occur when either the workforce or livestock is affected. The impact of balantidiasis on the health of the workforce negatively affects the capacity to work, support family, and contribute, by extension, to national development [15]. The decline in livestock productivity due to acute or chronic effects of balantidiasis can cause significant economic losses with potential catastrophic repercussions in the contexts where animals are the only source of income. The disease causes an increase in medical costs for diagnosis and treatment which can have a significant impact on the economic context of the poorest households, assuming that medical services are accessible. Diagnosis of balantidiasis does not require special means and a microscope analysis at low magnification is sufficient to identify cysts or trophozoites in a fresh stool sample [25]. Regarding treatment, tetracyclines have shown high efficacy for *B. coli* infections in both humans and animals [86–88]. In any case, even if health treatments were guaranteed to be free of charge, they could still be considered as economic losses since the prevention of NTDs is based on health and hygiene principles whose realization is certainly less expensive than the treatments required [89]. Although there are no sufficiently detailed studies on efficacy, several authors suggest treatment with drugs belonging to the nitroimidazole family to ensure preventive or curative deworming against *B. coli* [33,90,91].

The direct impact of balantidiasis on nutrition has been only little studied. There is evidence that the onset of the disease could be related to the diet of those affected. As Ponce Gordo et al. have pointed out, a carbohydrate source is a determinant of the development of *B. coli* [25]. This would explain why in a study conducted on malnourished children in whom high *B. coli* prevalence was found, none of them showed symptoms [49]. Shumaker

proved that an existing *B. coli* infection was aggravated by a high carbohydrate diet in rats, especially if rich in starch [92].

Nowadays, it is estimated that the world population will increase in the coming year, and with it the food demand [5]. How we currently exploit natural resources for our livelihoods puts an increasing pressure on the environment on which we depend. A profound change in the world food system is needed if we want to feed the 795 million people who suffer from hunger today and the additional two billion people who will be inhabiting our planet in 2050 [13]. The food chain offers key solutions for sustainable development and is crucial for the elimination of hunger and poverty at the same time. If managed well, agriculture, forestry, and fishing can provide nutritious food for all and generate adequate incomes, supporting rural development and protecting the environment. This will require encouraging sustainable food production, especially improving the capacities of small-scale farmers, allowing equal access to land, technologies, and markets. Sustainable food production must always aim at high quality and safety standards to guarantee public health. In this regard, food safety is endangered by NTDs as many of them are foodborne and waterborne diseases [93]. Although the presence of *B. coli* has been reported worldwide in a wide range of farmed animals, only a few studies have investigated its occurrence in meat and meat products which might represent a relevant route of transmission both for humans and animals [32]. *Balantidium coli* was detected in the feces of slaughtered animals, raising concerns about possible contamination of carcasses [35]. Schuster and Visvesara demonstrated that cysts of *B. coli* can remain viable for weeks in feces if kept away from sunlight in a moist environment [94]. Some authors speculate that under favorable conditions such as cold chain failure, *B. coli* could persist on the carcass surface following fecal contamination during the slaughtering process, exposing humans to potential infection by consumption of raw or undercooked meat [23,34,35]. In this regard, particular attention should be paid to domestic slaughtering widely practised both in the developed and the developing countries for traditional habits and religious rituals where poor hygienic conditions and cross-contamination can be responsible for *B. coli* infection. Moreover, the use of fresh guts to wrap sausages may represent a further hazard; in fact, not well-cleaned and treated guts may be a potential source of *B. coli.* Therefore, despite the absence of evidence regarding the ability of *B. coli* to persist in fresh meat, meat preparations and products, good manufacturing and hygiene practices as well as the cooking of meat should ensure effective management of the risk. Furthermore, even raw vegetables could represent a real risk, especially in those situations where manure is used as a fertilizer.

Water contamination also represents a route of infection, and for *B. coli* it is potentially the main one. Accessible and clean water is an essential goal of Agenda 2030. Our planet has sufficient drinking water to achieve this goal, but due to poor infrastructure or poor economic management, every year, millions of people, most of them children, fall ill from waterborne diseases [13]. The fecal–oral transmission of *B. coli* occurs mainly through ingestion of water contaminated with cysts. The lack of adequate sanitation processes favors the spread of the protozoa through contaminated drinking water with swine feces while fecal contamination of recreational water (e.g., in swimming pools) might represent a relevant source for human-to-human transmission [23]. Proper management of the sanitation processes such as individual household latrines as well as protection of freshwater sources from animals and their waste significantly contributes to reducing the risks of environmental contamination and consequent infection.

5. Conclusions

In this review article, balantidiasis, a widespread neglected tropical zoonosis, was used as a model to demonstrate how debilitating disease could impair sustainable development and how proper management of the disease directly affects the sustainable development process. It is easy to understand how for proper management of NTZs is impossible to overlook from a holistic approach that involves all SDGs of Agenda 2030. Nowadays, even though Virchow's paradigm on "One Health" is still actual, it may be modified accordingly

to the sustainability of development as follows: "*Between animal and human medicine there are no dividing lines - nor should there be. The object is different, but the experience obtained constitutes the basis of all medicine and sustainable development. An unhealthy equilibrium between animals, humans, and the environment does not allow for the sustainable development as well; sustainable development must not be prescinded from a healthy equilibrium between animals, humans, and the environment.*"

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