A Circular Energy Economy: Cross-Sector Successes in Brazil and India

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Abstract:
A new paradigm for energy production is one that emulates the closed-loop circular systems of natural ecosystems. At once holistic, economical and equitable, energy production based upon reciprocities with other sectors (e.g. telecommunications, water, sanitation, and waste management) can leverage synergies and provide multiple co-benefits. With avoidance of fossil fuels, less pollution and reduced throughput of matter and energy, such a circular energy economy offers a model for critical electricity provision for the next 2 billion people in emerging economies—both those moving to cities and particularly those who remain in rural poverty. Three exemplary cases, one in India and two in Brazil, reveal the efficacy of renewable power created through cooperative, cross-sector initiatives that also yield economic and social benefits. The first, methane recovery in Belo Horizonte, Brazil, illustrates the potential for closed-loop use of a wasted energy source in rapidly urbanizing settlements. Here, the city authorized the construction of methane recapture from its 65-hectare (161-acre-) landfill for utilization in energy generation. This reclamation effort expanded into multiple, colocated recycling initiatives. In the second project, Omnigrid Micropower Company (OMC) was able to leverage affordable electricity for some of India’s poorest rural citizens. Innovatively, it combined the electricity demand from the telecommunications sector to support the economical construction of small-to mid-size solar power plants. Today, these power plants supply renewable electricity to remote telecom tower base stations, and, utilizing micro-grids and adapted appliances, serving the basic energy needs of neighboring communities. In Brazil, the last exemplar is that of Itaipu Binacional (IB), the entity that developed the world’s largest generator of renewable power, the 5-mi.-wide 14 GW Itaipu hydroelectric dam. Concerned with the area’s agricultural waste polluting its reservoir and jeopardizing power production, IB partnered with local farmers to develop an Agroenergy Condominium, whereby agricultural waste is anaerobically biodigested to produce biogas sufficient to energize 2,200 rural households. Belo Horizonte’s integrated waste and energy program, OMC’s cross-sector power plant, and IB’s Agroenergy Condominium, and are examples of cross-cutting, strategic investments in renewable energy. Moving beyond conventional mono-sectoral planning and management of energy systems, these alternative, full life-cycle and circular approaches to power production are solving energy poverty. As blended, multi-functional systems, they also foster job creation, allowing for economic growth while suppressing carbon emissions.
Defining the Circular Economy

The notion of a “circular economy” is modeled on self-sustaining ecosystems and grounded in their complex, self-organizing, and circular flows of energy and matter. By cascading (passing along) waste energy and processing waste nutrients for reuse in the cycle, such a closed-loop, complex system reduces new resource inputs while eliminating waste, pollution and emission outputs.1 Optimized by design this way, a human-engineered system of goods and services may be considered restorative or regenerative. The circular economy stands in contrast to the extractive, once-through, or linear economy upon which our open-ended economic system—and industrialized consumption of resources—has been predicated. Derived in principle from the discipline of industrial ecology—industrial strategies for resource efficiency, dematerialization, and waste prevention—a circular economy lowers energy leakage and the externalized costs and risks associated with waste.2 Increasingly, through governmental initiatives and corporate social responsibility programs, the strategies are being embedded in corporate culture, benefiting business and yielding improved social and environmental benfits.

The concept of a circular economy has been gaining momentum since being introduced in the late 1970s. Most recently attributable in part to theoretical influences such as “cradle-to-cradle,”3 and the proactive work of the Ellen MacArthur Foundation,4 it has gained traction through implementation in China, where it is centrally promoted as a key policy objective.5 In Europe, policymakers have issued a comprehensive European Circular Economy Package.6 As a replacement to the dominant economic modes of the industrialized world, the circular economy, is espoused by environmentalists as a crucial means of steering human society toward operating within the ecological limits of the planet. In contrast to our growth-oriented, business-as-usual means, a circular economy may not only safeguard the integrity of ecosystem services essential for humanity’s survival but also help rebuild natural capital.

Integrated Infrastructural Services as a Mode of the Circular Economy

Assuming that the transition towards a global circular economy has just begun, a track record of its successes built on economic returns on investment will be imperative for motivating such a paradigm shift. As society’s political, economic, and environmental actors foresee the circular economy as a crucial pathway for decoupling finite resource consumption (and concomitant negative externalities) from economic growth, how, we ask, might we apply the circular economy’s high-level operating principles to the key infrasstructural services that underpin

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economic growth—the resource- and energy-intensive provision of energy, sanitation, water, waste management, communications, transport, etc.? Can a circular economy approach to planning and operating these assets deliver more sustainable and resilient services? Might these collectively be reconceived as smart, interconnected systems that reduce dependency on resources and non-renewable energy? The following precedents and the case studies that follow begin to address these questions.

Modelled according to the tenets of industrial ecology, with facilities clustered facilities to capitalize on the efficiencies, the first eco-industrial park in Kalundborg, Denmark exemplifies such beneficial energy and material flows. Developed around a central coal-fired power plant, the waste steam and hot water of which feeds an oil refinery and pharmaceutical company while warming greenhouses, a fish farm and area homes, Kalundborg also recovers fly ash from its stacks to substitute for virgin gypsum in its sheetrock manufacturing plant. These are some of 22 separate exchanges in the park (counted as of 2011). The eco-industrial park’s initial $60 million investment has returned $15 million in annual savings, eliminated 64,000 tons of CO2, while reducing air, water and soil pollution.\(^7\)

In a newly completed neighborhood of Stockholm called Hammarby Sjöstad, officials there used a similarly circular archetype for linking its infrastructural services to reduce metabolic urban flows.\(^8\) In this “Hammarby Model” (fig. 1), connections were fostered across heat and power, sewage and waste handling utilities. Waste heat recovered from the sewage treatment plant, combined with heat issued from a local wood-chip fired Combined Heat and Power (CHP) plant, provides new district heating. Methane gas from wastewater is processed into cooking and vehicular fuel while its residual sludge reverts to fertilize the forest.\(^9\)

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As unique industrialized world examples, these closed-loop, circular arrangements among infrastructural—often including some commercial—assets demonstrate how to leverage multiple synergies from networked energy, water and waste services to bolster both economic and environmental performance. The exceptionality of Hammarby Sjöstad reminds us that uptake of these models for infrastructural development has been slow-moving. Instead, industrial era models mostly hold sway. The convention for developed nations’ “legacy systems” has been to disaggregate water, waste, energy etc. into different sectors, physically and jurisdictionally,
isolating them as single purpose and linear vs. multivalent and closed loop.

The challenge, therefore, for humanity however, will be to foster the embrace of circular planning in the provision of new and extended infrastructural services in both the rural and urban developing world where growth and demand for infrastructural services are rapidly escalating. The following three case studies demonstrate how innovative actors, employing convergent thinking, are already positioned to unlock the value of the circular economy, one that can support economic growth while avoiding resource depletion and ecosystem degradation.

**Resource Loop-Closings and Beyond: Belo Horizonte, Brazil**

With their typically pronounced topography near urban areas, landfill sites are the most visible indicator of our linear economy. Conventionally filled with municipal solid waste (MSW)—a mix of inorganic and organic (46 percent global average)—these sites release harmful methane to the atmosphere. Landfill gas alone leads to the world-wide release of between 19.99 million and 59.99 million metric tons (approximately 22 million to 66 million tons) of methane annually.

Capturing gas from the decomposing organic matter in sanitary landfills for energy generation represents a closed-loop biocycle, and is considered a transitional, carbon-neutral energy solution. Replicating such a biocycle is extremely relevant for low income countries that can only spend a fraction of their solid waste management budgets on waste disposal, with most MSW going simply to waste collection.

**Background to the initiative**

The local government of Belo Horizonte established and operated its first sanitary landfill in a highly-urbanized region of northwest of the city in 1972. The site, which occupied 114 hectares (282 acres), received some 4,200 tons of MSW daily until its closure in 2007. It was just the prior year, that Belo Horizonte had established its Municipal Committee on Climate Change and Eco-Efficiency. Under this umbrella, it was undertaking major projects for GHG mitigation, including solar hot water heating and a rapid-transit bus program.

An early adopter (1993) of Integrated Solid Waste Management (ISWM), a comprehensive waste reduction, collection, composting, recycling, and disposal system, the city’s waste

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scavengers—sweepers, pickers, collectors, packers, and sellers—had formally partnered with the municipal administration. Together they created an effective urban waste management system that professionalized their positions, systematized their processes, and improved working conditions (fig. 2). Creating a closed-loop recovery system of its solid waste by-product was the next step.

Previously the biggest single source of GHG emissions for Belo Horizonte (2014 population 2.5 million), the landfill site was converted in 2007 into a Municipal Waste Treatment Center, the Centro de Tratamento de Resíduos Sólidos (CTRS). When the landfill shut down, it held 17.4 million m³ (22.75 million yd³) of waste that had accumulated since 1972 and covered a land area

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of 65 ha (161 acres) (fig. 3). While an initial goal was to address the odor at the landfill, which continued to be a problem, the city moved to add another option to its renewable energy choices.

Figure 3: Aerial view of the Centro de Tratamento de Resíduos Sólidos in Belo Horizonte, Brazil. Photo credit: Google Imagery copyright 2017.

Closing the biocycle loop

Whereas in most of Brazil, landfill sites had open drainage systems, and the escaping biomethane was wasted through flaring, Belo Horizonte contracted with the bid-winning Asja Ambiente Italia SpA (Asja) company in 2007 to recover and treat the gas for use in electricity generation. By 2010, the site operated a 4.5 MW capacity energy plant.\(^\text{15}\) This was in part thanks to an innovative funding and financing mechanism: the sale of CERs (carbon reduction credits) under the Clean Development Mechanism (CDM), a program established through the 1997 Kyoto Protocol that had been in operation since 2006. Asja is required to comply its operation to the carbon credit certification program.

At the site, Asja operates the Biogas Processing and Utilization Center. Here, the gas production process involves purification to remove sulfuric gasses and decrease water volume. Combusted in General Electric gas engines, the Center generates and supplies to the grid enough energy to support the electricity consumption of approximately 30,000-35,000 people.

\(^{15}\) ICLEI-IRENA, Ibid
Between 2009 and 2010, it reduced the city’s GHG emission by 237,473 tCO$_2$e/y, which by 2016 had fallen to 91,475 tCO$_2$e as the continued extraction depletes the methane accumulation.\textsuperscript{16}

Expanding the Circular System

Today, under the jurisdiction of its Department of Urban Cleaning (Superintendência de Limpeza Urbana (SLU), Belo Horizonte has expanded the complex web of its circular economy at the site, embracing recovery and regenerative processes from complementary sectors. The CTRS operates several colocated facilities (fig.4). These include the following enterprises:

1) a composting plant, which processes selected organic waste collected from markets for the schools’ vegetable gardens, parks and squares of the city.
2) a recycling facility for construction waste, which yields synthetic gravel used for roadway paving.
3) a “seedling station,” which grows plants used to support the environmental restoration of the landfill site.
4) a hazardous medical waste plant.
5) a plant that recovers tire rubber for offsite recycling.
6) an environmental center offering tours to as many as 144,000 students annually to learn about the circular economy.\textsuperscript{17}

\textsuperscript{16} Ibid.
\textsuperscript{17} Ibid.
In recognition of its collocated and integrated solutions to waste management, mitigation of the environmental impacts of the landfill, and reductions of GHG emissions, Belo Horizonte receives 6 percent of the value of the electricity sold. This comes in addition to what the municipality receives as revenue from the sale of approximately 1.3 million CERs sold in the international market during its ten-year CDM crediting period.\(^\text{18}\)

The program falls within the Brazilian government’s initiative to increase the production of electricity from renewable sources and reduce the country’s greenhouse gas emissions by

between 36.1 and 38.9 percent from projected amounts in 2020. By harvesting its myriad waste sources and integrating them in this fashion, this public/private entrepreneurship has not only made major strides towards this goal, it has gained profitable returns. As other emerging economies see their consumption/waste production mount, and begin to shift from open dumps to sanitary landfills, they should seriously consider adopting this comprehensive and integrated solid waste management and energy production model. They too could at once cascade their resources, turning waste to energy, recovering both biological and technical nutrients, while providing educational programs that advance the circular economy in their metropolitan area.

**Omnigrid’s Solar Asset-Sharing Strategy: An Enabling Framework for Value Creation**

Another aspect of the circular economy illustrated in the following case study is the optimization of asset usage through sharing. We are mostly familiar with how peer-to-peer sharing (e.g. Uber, Zipcar, Airbnb) is revolutionizing the transport and hospitality sectors by extending the deployment of a particular asset. Similarly, the combined use of a single infrastructure asset through colocation, means fewer resources consumed and less waste produced. Omnigrid Micropower Company’s achievement in India similarly sets it apart from other power providers. It serves two very different kinds of clients via a single solar power plant, a shared-use arrangement that makes the business model financially viable—selling electricity to the rural poor—without government subsidies.

**Background to the innovation**

The potential of such an eco-innovative and effective approach is enormous. There are approximately 237 million citizens in India who lack access to reliable electricity. Consequently, economic development is stalled for those beyond the reach of the electric grid. Some are already technically “wired” but still receive irregular power supply. While ownership and management of India’s electrical distribution networks is shared between both public and private distribution companies (DISCOMs), the latter, which typically serve large urbanized areas, can neither spare the power nor afford the cost of extending transmission and distribution lines to remote locales. Nonetheless, because sunlight is omnipresent in India— greater than 60 percent of the country receives annual average global insolation of 5kWh/m2/day—the government has embraced the strategy of serving its rural populations with distributed, renewable solar power.

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20 Arup 22


Despite the ubiquity of solar energy, and regulatory support of rural power provision, the remote installation of photovoltaic power plants has been traditionally perceived as financially risk. This is due to the low density of customers as well as the higher cost of distributed vs. grid-served electricity. Additionally, rural communities have experienced faulty or substandard products and overall often unreliable services, despite the higher cost they pay. Therefore the installers themselves are concerned about both the inclination and the ability of indigent rural populations to pay, guaranteeing a reasonable return.

Despite these deterrents, Omnigrid Micropower Co., Pvt., Ltd. (OMC) saw a unique opportunity for solar-powered generation in Uttar Pradesh, one of India’s most populous (200 million) and poorest states. The company envisioned a business model that capitalized on the large energy demand of the dynamic telecommunications industry. With India’s base of in excess of a billion subscribers, a near majority of India’s 400,000 off-grid cell phone tower base stations were running on diesel generators as recently as 2013. These generators are costly from both an operational and maintenance perspective; they also foul the air and contribute significantly to India’s carbon footprint. Starting in 2012, tower operators were mandated by the government to transition 50 percent of their power system to renewables by 2015.

Circular thinking fosters a sharing economy

Founded in 2011, OMC, the Gurgaon, India-based Renewable Energy Service Company (RESCO) finances, builds, maintains and operates solar and wind powered micro power plants. The next year, OMC partnered with Bharti Infratel (India’s leading telecom tower infrastructure service provider) to furnish electricity to these cellular towers with micro- solar power plants, sized typically less than 50kW. Despite the above described drawbacks to powering off-grid populations, OMC recognized the market potential for providing solar-powered electricity in Uttar Pradesh. Their realized that the powering of remote cell phone towers under a long-term supply contract would comprise an “anchor” demand, thereby guaranteeing a revenue stream that could subsidize the service to nearby rural communities. Based on this combined service arrangement, OMC could piggy-back the delivery of electricity to adjacent villages via microgrids, making this otherwise dicey investment more “bankable” from the perspective of their partnering financial institutions.

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By 2013 under this Community Power program, OMC had constructed eleven 9- to 18- kW micro solar power plants, costing about 50 lakh ($75,385) each.28 This stands in contrast to the high capital costs of a coal-fired plant and its long construction timeline—typically 5 to 7 years versus 3 months for an OMC solar plant. Additionally, according to one estimate, powering a single mobile base station with an OMC PV-power plant reduces carbon emission between 40 and 50 metric tons annually while eliminating the energy losses attendant to long distance power transmission.29

Augmenting a low resource-consuming, high efficiency energy economy

Another significant feature of the program capitalizes on a closed-loop biocycle: these power plants may be supplemented by biogas-generated electricity, utilizing biomethane produced by local anaerobic biodigesters fed by agricultural, animal and human waste. The micro power plants can also readily be supplemented by wind energy. The power plants may be equipped with battery banks and/or diesel-fired backup generators to help see them across low solar insolation levels during monsoon seasons (see fig. 5).30

28 Ibid.
29 Tweed, Ibid.
Another aspect of the circular economy is swapping out traditional solutions with advanced technology that saves energy and resources. Supplied through local distributors, villagers are using affordable and technically appropriate microgrid-adapted power equipment. These include portable and rechargeable LED (low-emitting diode) lanterns that eliminate the need for household wiring. Based on a prepayment business model, these lanterns costs about 100 rupees ($1.50) each month, versus 180 ($2.70) for kerosene. The lanterns are collected each morning by “light wallahs,” recharged, and returned to customers later the same day (see fig. 6). To further support elimination of wiring, for 350 rupees ($5.45) a month, customers can lease a bijli box (PowerBox), or battery capable of powering two lanterns, a fan or T.V. and cellphone charger.\(^\text{31}\) Since 2012, mini-refrigerators and high-efficiency irrigation pumps have further diversified OMC electrical services. Critical to OMC’s inventive and circular thinking is understanding the needs and limitations of their remote rural customers.

The game-changing nature of the Bharti/OMC partnership is based on linking the telecom industry’s needs to community power provision. It is significant that more than half of OMC’s revenue stream comes from local residents, disproving the belief that indigent rural citizens may not gain electricity access economically. Where the cost recovery for comparable (non-renewable) power plants might take 7 or more years, OMC breaks even within a half year. A co-benefit of the program to the community is direct job creation: OMC employs between 10 and 15 rural workers per cell tower complex.\(^3\)

Scaling up a circular innovation

Recognizing the first renewable start-up company to realize commercially viable and sustainable grid-less rural power plants, the World Economic Forum named OMC Power a 2014 Technology Pioneer. OMC has gone on the enter further agreements with SunEdison (a global US-based renewable energy company) as well as the Rockefeller Foundation to scale up distributed power for rural India. The Foundation recognizes that energizing these millions of

remote citizens can help unleash India’s entrepreneurial potential.\textsuperscript{33} Workers can enhance their incomes by working after dark, students study, and women prepare meals post-sundown, avoiding the cost and health damaging effects of kerosene. Such transformational accomplishments, effectuated by OMC’s “disruptive innovation” are testimony to the power of relational and circular thinking.

\textbf{Itaipu Binacional’s Full Circle Solution: Rural Agroenergy Affords Hydropower Protection}

Highlighted through the above examples, the prospects for successful circular “infrastructure economies,” are further validated in a third case study, which, through its intelligent caretaking of its assets and integration across economic sectors, yielded results greater than sum of its parts. In solving one of its operational predicaments, this company created a collaborative platform that yielded “circular by design” services, jobs and manufacturing.

Three years after its inaugural operation in 1991, the 8-km (5 mile-) wide Itaipu hydroelectric dam across the Paraná river bordering Paraguay and Brazil was recognized by the American Society of Civil Engineers as one of the seven modern “Wonders of the World.”\textsuperscript{34} Itaipu Binacional (IB) is the bi-national entity that successfully completed and operates this large generator of renewable power. With its 14 GW installed capacity, it supplies 17 percent of Brazil’s energy demand and 75 percent of Paraguay’s. It could be said that its contentious and transgressive construction—displacement of nearly 60,000 occupants,\textsuperscript{35} lost biodiversity, degraded land and water and elimination of a national park—has been partially compensated by IB’s community engagement activities over the last two decades – embracing sustainable development and promoting rural energy access, environmental conservation, and local employment.

While today, its name reflects its locale on the Paraná river watershed separating Brazil and Paraguay, many of the system’s infrastructural assets belong to ANDE, Paraguay’s public utility and Eletrobrás, among the largest of Brazil’s power utilities. It was funded, however, by the Brazilian government. In 2002, despite the fact that approximately 88 percent of Brazil’s electricity is renewably sourced by such hydroelectric generation, the nation established an incentive program to promote other renewable infrastructure, from small hydro, to biomass and wind power.\textsuperscript{36} In December 2009, it set a target of reducing countrywide greenhouse gas emissions by between 36.1 and 38.9 percent below business-as-usual projections by 2020. This was to be achieved through a combination of efficiencies in the building and industrial sectors, additional renewables, and improvements to agricultural and animal husbandry practices.

Precipitating concerns and Itaipu Binacional’s response

The Paraná 3 watershed (8,000 km²) which comprises the power plant reservoir’s main area of influence, is the home of more than 35,000 local farms, which produce mostly soy-beans and maize. It is also home to more than 1.5 million pigs, 30 million poultry, and the agro-industries based on these plant and animal production practices. The combination of intense agriculture and meat production in this basin created problems at the Itaipu dam. The reservoir’s water quality became degraded by deforestation, run-off from soil tilling, and the inflow of phosphorus from agricultural fertilizers and pesticides. The reservoir began to experience both premature filling with sediment and eutrophication, both threats to hydropower production.

Recognizing the linkages between the reservoir’s altered hydrology, the region’s poverty, and the overall ecological impairments due to agriculture, IB enlarged its mission to embrace environmental and social and stewardship in the watershed basin. It instigated the Cultivando Agua Boa (CAB) or Cultivating Good Water program: 63 initiatives including conservation of water, protection of farmland and forests, and reduction of land and water pollution by agriculture. Strategies introduced included no-till farming; new rural sanitation and wastewater treatment; elimination of pesticides; and forest and stream restoration. Through the CAB program, which emphasized civic society’s participation in the farming settlements, IB built an exemplar, multidimensional framework for local stewardship. In 2015, IB received the Best Water Management Practices award from the United Nations Water for Life program.

Agroenergy closes the loop

Established by IB in 2009 in the Paraná river watershed, the Agroenergy Condominium for Family Agriculture Sanga Ajuricaba was a key outcome of a sustainability-oriented partnership between IB’s Office of Renewable Energy, the Institute of Technical Assistance and Rural Extension, the Paraná State Electricity Company, the International Center for Renewable Energies, and other entities. Consisting of 33 small-scale family farms, this cooperative became the focus of IB’s effort to reduce pollution by supporting the production of biogas and biofertilizers from area waste. It also aimed to help eliminate poverty in the region.

IB installed individual anaerobic biodigesters at each farmstead that could process the corn production waste with manure from the farmers’ herds (approximately 1,000 head of cattle and 3,000 swine). The farmers in the condominium collectively have produced 15,800 cubic meters (4.2 million gallons) of agricultural residue and manure annually – organic waste that yields 266,600 m³ (348,699 cubic meters) of biogas. Sent through a 22-km- (13.7 mile-) long pipeline to a central power plant, the biogas collectively generates electricity, heat, and, – after

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39 WWAP ibid.
upgrading – a biogas-based vehicular fuel. Electricity generation of 445,000 kWh/year serves approximately 2,200 area households, with the farmers receiving revenue from the surplus sold to the state’s energy distributor. Notably, the residual slurry is also an excellent organic fertilizer. Finally, the plant’s grain dryer, which runs on the thermal energy produced by the power plant, dries products such as corn, beans, and soy beans, reducing their drying costs by as much as 90 percent (fig. 7).

Figure 7: Diagram of Itaipu Binacionale’s agroenergy condominium for family agriculture, Paraná River basin, Brazil. Credit: Hillary Brown and Logman Arja. (Reprinted courtesy of The MIT Press from Infrastructural Ecologies: Alternative Development Models for Emerging Economies, by Hillary Brown and Byron Stigge).

Given the fact that much of the nation’s agricultural wastes accumulate across the its territories—with 77 percent of Brazil’s population still employed in farming as of 2015—distributed power generation from waste biomass and manure, produced through anaerobic biodigestion, is a commonsense means to rural electrification. Circular logic therefore underscores how agroenergy eco-effectively transmutes the environmental liabilities of Brazil’s farming sector—the methane derived from animal manure and the watershed-polluting organic chemicals from fertilizer—into electricity and bio-fertilizer. Both provide a useful source of additional income for rural settlements while helping to foster decentralized renewable generation and diversification of energy resources.42

The above-described reciprocities between hydro dam water quality protection and rural energy access have also produced a range of co-benefits and employment. These include the water quality improvement of in 206 micro-basins; restoration of riverine buffer zones with 40 million trees; and the creation of two biological sanctuaries. The Condominium biogas initiative, with assist from IB, has also fostered a small local industry, Bio-Kohler, which produces the fiberglass biodigesters, storage tanks, and cooking stoves designed for biogas use.43

At the same time, CAB delivered educational services for: improved nutrition, conversion of industrial farming practices to organic, cultivation of medicinal plants, and the introduction of aquaculture. Simultaneously, CAB established five area waste cooperatives and twenty-five waste associations regionally that improve the livelihood of the solid waste handlers.44

IB has scaled up its circular stewardship well beyond its own customer base. The Agroenergy Condominium model, initiated in Paraná, has been introduced into Uruguay, particularly the State of San Jose, which produces the highest carbon emissions in that nation due to its dairy and agricultural economies. Led by Eletrobrás with funding from a group of the world’s thirteen leading energy companies with IB as project consultant, twenty-two farms will be connected to a central micro-thermoelectric plant, which will produce 764 m3 (1,020 cubic yards) of biogas daily, with an expected energy production of 1.53 MWh/day.45

Conclusions

The three examples outlined above show that a significant pathway to low-carbon energy provision can be found through circular thinking. Belo Horizonte extended its initial investment in landfill gas recovery into a diversified circular economy comprised of waste recovery. As a start-up enterprise, Omnigrid Micropower judiciously perceived critical social and economic advantage in linking telecommunication infrastructure’s demand to its solar power plant’s

42 WAAP, Ibid.
service capacity. In resolving its own critical hydropower problems, Itaipu Binacional’s relational viewpoint astutely captured the potential for rural community agroenergy.

On their road to low-carbon infrastructure, infrastructural service providers in emerging economies—both public and private gas and electrical utilities—can work closely together to find synergistic opportunities to build a closed loop circular systems. They need to be attentive to opportunities inherent in untapped or underused local resources—in particular, waste streams from agriculture, sanitation, domestic cooking, and even municipal solid waste. Infrastructural services economically provided through circular assemblages can create sustainable energy access for remote and impoverished populations with multiple co-benefits.