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Sustainable housing applications and policies for low-income self-build and housing rehab☆

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A B S T R A C T

Recent years have seen an increased focus on the role of house construction and retrofitting within the broader agenda of sustainable development and climate change. To date this focus has largely targeted middle- and upper-income residential neighborhoods in urban areas. However, in the United States, and in middle developing countries such as Brazil and Mexico, there is growing recognition that urban sustainability will only gain traction if widespread applications are also incorporated into self-help and do-it-yourself housing construction and home improvements, especially those that address lower-income housing markets. Here we explore some of the potential ways in which contemporary sustainable housing applications may be integrated into the existing housing stock in low-income and informal settlements in the United States and in Latin America. We document the range of sustainable housing applications that are increasingly available in the U.S. as a baseline for discussion and evaluation of the potential application to lower-income segments of the housing market in both developed and developing countries. A heuristic model is presented to assess the extent to which policy makers, NGOs and low-income owner households may realistically participate in sustainable home building. Beyond physical development applications we close by emphasizing that sustainable housing agendas must adopt a holistic approach: one that embraces community and social organizational development, as well as fiscal and juridical policy dimensions.

Introduction: making sustainability sustainable

In a noteworthy weatherization rollout speech given on December 15th 2009 from a Home Depot store, U.S. President Barack Obama described the notion of retrofitting homes with energy efficient insulation as “sexy”.[2] Though the moniker “sexy” may surprise many, improving existing housing stock has been an integral component of sustainability since the very inception of the term, which is most commonly dated to the publication of the UN’s Brundtland Report in 1987 and which identified “the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Sustainable Development, 1987). While it remains a contested concept (Connelly, 2007) within urban planning and housing policy, sustainable development is considered to be the product of three fundamental goals: environmental protection, economic development and social equity (Campbell, 1996). In meeting these three goals, especially that of social equity, the role of environmental protections and improvements for the poor is key (Higgins & Lutzenhiser, 1995), and must necessarily include attention to low-income and self-help housing – as the Brundtland Report clearly states in Chapter 2.

In the decades since its publication there has been mounting concern over the need to “green” the new as well as the existing housing stock, and it is increasingly evident that sustainable rehabilitation must also address informal and self-help housing, and not just formal and better off residential development. Yet this remains largely a blind spot in housing policy and research, notwithstanding a resurgence of interest in informality among

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[2] http://firstread.msnbc.msn.com/_news/2009/12/15/4427454-obama-insulation-is-sexy.

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architects, planners and policy makers (Brillembourg, Feireiss, & Klumpner, 2005; Roy, 2005). This includes the call for sustainable housing policy to prioritize the needs of the poor, especially those in informal and self-built settlements (Choguill, 2007), together with a shift in focus that not only includes production of housing but also the rehabilitation of the existing stock (Priemus & ten Heuvelhof, 2005).

The importance of addressing the environmental impact of housing within larger debates about climate change and energy usage is both well established and widely accepted. However, the investment necessary to increase the environmental efficiency of existing homes is often seen as incompatible with affordability goals for low-income residents, so that much of the attention paid to home rehabilitation and sustainable home improvements concentrates on formally produced middle- and upper-class housing. Moreover, the focus is mainly in urban areas and developed countries (Varol, Yalciner Ercoskun, & Gurer, 2011), even though the largest areas of residential development in developing countries are to be found in low-income settlements, much of which is developed informally through self-build at the urban periphery (Balchin & Stewart, 2001; Gilbert & Ward, 1985). Thus if significant and meaningful inroads into achieving more sustainable housing are to be achieved it will necessary to figure out ways of making "green" and other applications more accessible to low- and very low-income communities, including those that are self-help or informal – "the acid test of housing policy for the lower income groups" (Choguill, 2007, p. 147). The aim of this paper is to offer insights about how this might be achieved in self-managed and self-built housing undertaken by low-income households in developed and less developed countries. Research from Texas and from a major multi-city housing project in Latin America provide the context for this analysis, and we provide a series of models that highlight a range of sustainable and often low-cost housing policy applications for energy conservation and weatherization; garden and microclimate design; water and wastewater; and solid waste disposal.

Sustainable applications for self-help and housing rehab in comparative perspective

Thus our paper responds to the desire for creative thinking about how sustainable technologies might be applied both to low-income (self-help) settlements in less developed countries, as well as poorer neighborhoods in the USA in order to make them more resource efficient and more sustainable, both to improve the quality of life of the residents as well as to benefit the environment (Winkler, Spalding-Fecher, Tyani, & Matibe, 2002). We will outline new approaches of sustainable housing applications in two contexts: first, that of informal self-help and self-managed low-income housing environments in Latin America and in the southern USA; and second, in the context of lower and middle income do-it-yourself home improvements associated with housing rehab in the older and often deteriorated "first suburbs" housing belts in Latin America and U.S. metropolitan areas. In focusing upon sustainable technologies in the developed countries, we wish to explore the relevance that our findings in the U.S. can have for the self-built housing stock of Latin America. We are interested in exploring how such a "baseline" of possible housing applications might be applied more widely in housing practices and policies, especially in Latin America where poverty levels are more acute, and where self-build is widespread.

Self-help and informal settlements

In Latin America and in less developed countries the majority of the urban population lives in informal settlements in which self-build is the norm (Gilbert & Ward, 1985; Ward, 2012). New settlements continue to be created informally at the urban periphery, albeit at pace that appears to have slowed in the past decade or two, and government policies, quite reasonably, continue to prioritize the provision of basic infrastructure and title regularization However, apart from some "low tech" policy solutions and approaches to sustainability, interest and commitment to urban and housing sustainability in Latin America have not been as well developed as in the U.S.

Less widely known, and with evident differences that cannot be overlooked, low-income and self-help communities in the U.S. share some important characteristics with their Latin American counterparts. One area in which these commonalities are most clearly observed are the peri-urban and *colonia*-type settlements that house some of the nation's lowest income residents. *Colonias* are widespread especially in the southern states bordering Mexico (Mukhija & Monkonnen, 2006; Ward, 1999) and comprise low- and very low-income populations with households earning on average $15,000 or less per year. Informal homestead subdivisions (IFHSs) are similar except that they are to be found beyond the border region in the interior of the Southern states, located 10-20 miles outside of metropolitan areas (Ward & Peters, 2007), and are not quite so poor (average household incomes are likely to be around $25,000), and affordability is achieved through informal or self-financing, as well as through self-help building and management. Different types of self-managed housing exist: self-built homes and extensions; manufactured homes (single or doublewide trailers) that vary greatly in age; and modular housing structures that are erected on site (Ward, 2003). But here, too, the policy agenda has largely eschewed housing sustainability options for self-help and improvement, although the production of new manufactured homes increasingly makes use of more sustainable and energy efficient housing elements (Krigger, 2006). However, for *colonia*-type environments the major constraint when thinking about housing sustainability tends to be that of affordability, and – at least in the past – the lack of low-cost sustainable housing applications provided through the larger do-it-yourself stores such as Home Depot, Lowes, etc. That is rapidly changing as technologies become available at much lower cost, as public awareness and commitment to green practices expands, and as government incentives such as the U.S. Department of Energy Weatherization Assistance Program (McCold, Goeltz, Ternes, & Berry, 2008) and the American Recovery and Reinvestment Act of 2009 come on line to support weatherization and energy efficient home improvements and upgrades.

Rehab of lower-income "first suburbs" and "innerburbs"

Increasingly, too, throughout Latin America older (now) consolidated informal settlements that were created thirty years ago today form part of the intermediate urban area, usually forming rings around the older urban core (see www.lahn.utexas.org). These older settlements developed in the 1970s and 1980s are now fully integrated into cities such that most observers would not imagine that they had begun as shacks and squatter settlements. Families have often subdivided their lots and housing units among (now) grown children and grandchildren. While these settlements are usually fully serviced there are urgent needs for the rehabilitation of the residential environment in order to retrofit and recast the neighborhood and dwelling space to meet contemporary community and household needs (Ward, Jimenez, Grajeda, & Velázquez, 2011).

Similarly in the U.S. the older "first suburbs" of working and middle class neighborhoods that formed from the late 1940s through the 1970s today comprise an inner ring of suburbs that invariably urgently require renovation and rehab (Katz, Lang, & Berube, 2006; Puentes & Warren, 2006). As others have pointed out, rehabbing this large stock of older and less energy efficient housing is a crucial (Galster, 1996), though often overlooked component of urban sustainability: "…Even as new green building technology improves household energy efficiency, the challenge to broad energy use reduction will be creating the economic opportunity for technology investment and retrofitting of old infrastructure" (Agyeman & Evans, 2003, p. 46). Many of the U.S. "first suburbs" are undergoing major physical changes as former working class neighborhoods are subject to urban renewal and "gentrification"(Katz et al., 2006). Whether through the construction of new housing, or the rehab of existing structures, in U.S. cities the inner urban areas are often in the vanguard of policies to reverse urban decline, laying the basis for greater sustainability with less commuting, more efficient use of public transport systems, higher densities, and the creation of more integrated communities (Fainstein, 2010).

However, because they are often costly, sustainable applications are most easily adopted among the more economically advantaged sectors (Wilson and Dowlatabadi, 2007) namely in middle and upper-income residential neighborhoods, or among "back to the city" gentrifiers who can afford the costs of "smart housing" with higher levels of energy efficiency and investments in renewable energy applications. As the negative impact of buildings on carbon emissions and total energy consumption continues to be documented (Hammond, 1972), there is growing awareness of the social equity argument in favor of making sustainable housing solutions much more widely available (Holden, Roseland, Ferguson, & Perl, 2008). Doing so extends access to the health benefits of sustainable upgrades (such as indoor-air quality), as well as the economic benefits of energy and water saving technologies. Indeed, the lack of energy efficient housing in low-income communities means that poorer households often find themselves incurring higher utilities costs relative to their incomes and capacity to pay (Wolfe, 2007). The U.S. Department of Housing and Urban Development recognizes that utility bills disproportionately burden the poor and can even cause homelessness. High utility bills and the threat of being shutoff leads households on tight budgets to make difficult tradeoffs, purchasing heat or electricity for air-conditioning instead of food or medications (HUD, June, 2009). Meanwhile investments in residential energy efficient interventions have increasingly significant positive rates of return for homeowners when compared to upfront costs (Laitner, Karen, & Prindle, 2007).

Recent initiatives in the U.S. and in Latin America are taking up the call to make sustainable housing solutions more widely available. Although they have been in existence in the U.S. since 1976, weatherization programs have received a major fillip as part of President Obama's stimulus package that targets residential improvements and weatherization programs in order to achieve two major outcomes: first, to put people into the workforce in the production of energy efficient housing elements (e.g. doors, windows, electrical appliances etc.); and second, to promote the demand for these home improvement items through grants, loans, rebates and other incentives. Today issues of sustainability and housing improvement are firmly on the urban and housing agenda, with the important difference that they are now being promoted as part of the mainstream for all income groups including those living in informal and self-built housing (Berner, 2001), in manufactured housing, and in so called *colonias* and informal homestead subdivisions in the peri-urban areas many metropolitan areas especially in the global South (García Pleyán, 2001; UN-Habitat, 2009).

In Latin America, Brazil and Mexico stand out as leaders in this respect. Recent initiatives in Mexico, Brazil, and elsewhere have indicated that middle developing countries are becoming invested in issues of sustainability, global warming, and renewable energy usage as part of the global debate. In November 2009 Mexico's principal workers' housing agency (INFONAVIT) organized the "First International Conference on Sustainable Housing" in which Mexico's President Calderón made a major speech advocating the need for a broadening and deepening of sustainable housing applications both within low-income formal housing projects as well as for self-build settlements.[3] In Brazil in 2010 the American Planning Association (APA) launched its newest initiative, the Energy and Climate Partnership of the Americas (ECPA) which is designed to encourage city leaders, academics, state and national policy makers, and practitioners across the Western Hemisphere to engage in dialog on housing and urban planning solutions specific to Latin America and the Caribbean. If the concept of urban sustainability is to become meaningful in developing nations, then "green" solutions and approaches need to be configured for low-income housing production – whether this is formal or informal in nature.

Research objectives and methodology

As noted above, middle- and upper-income housing has overwhelmingly provided the context in which green home solutions are tried and tested. Broadening the application of sustainable home technologies and rehabilitation to low-income and self-help housing requires careful consideration of the feasibility, cost and potential benefits of specific technologies in the particular context of low-income, often informal, homes and communities and this formed an integral element in the research that was reviewed for this paper.

In the remainder of this paper we offer a comparative assessment of a broad range of items and applications that we considered in order assess their potential for rehabilitating low-income housing. Energy efficiency and renewable energy issues are the most frequent foci for studies about sustainability at the household scale, but we are also interested in other arenas of sustainability: namely water and wastewater management, solid waste disposal systems, and microclimate or garden design applications including home alignment, shading, rainwater harvesting, home composting, etc. In addition to exploring the range of applications in each case, our goal here is to focus attention upon the more modest and low-cost approaches that could find immediate and widespread adoption among lower-income residents in the U.S.A. as well as in less developed countries (Verbruggen et al., 2010). In so doing, we wish to identify the primary constraints that act to limit sustainable housing applications whether these are legal and regulatory, organizational and human resource-based, knowledge and culture based, or based upon resources and affordability. In short, thinking about sustainability goes beyond the realm of practical physical applications – "green" or not. It includes an understanding of social, juridical and fiscal approaches that support the implementation of technologies.

This research was undertaken in several phases. First we gathered data that would synthesize the range of applications available for sustainable home improvements, highlighting those that appeared to be most immediately applicable for use in low-income and self-help communities. Second, we created a rubric for rating the effectiveness of selected applications and assessed them according to defined categories (discussed at length below). Third, we developed a comprehensive matrix of the ratings of these

[3] 1er Foro Internacional de Vivienda Sustentable, INFONAVIT, Mexico City, Sept. 10–11 2009.

technologies that compares their performance across the pre-defined categories of sustainability mentioned above.

The sources for this comprehensive literature review included academic, technical and legal literature on various technologies: specifically books, academic and trade journals, government reports, and industry manuals. We also consulted directly with experts including utilities providers, manufactured housing suppliers, community organizers, and homeowners themselves. This led to a major report, which can be found on the website: http://www.lahn.utexas.org. (Click on Texas Colonias Studies – Sustainability) The report includes access to an annotated bibliography and over one hundred pages of appendices. This compendium of materials was used to create a rubric by which we rated the various technologies in terms of: ease of maintenance, cost savings, initial cost outlay or investment, and amount of sweat equity or professional expertise required for implementation. We present these valuations and the details of how they were constructed in the findings section below.[4]

Ultimately our goal was to produce a single chart that will allow NGOs, community groups, local authorities and individual users themselves to more readily assess the feasibility and desirability of a broad range of sustainable applications available to new self-build home construction as well as in housing rehab and home improvements. The aim is to create a set of tools that will facilitate discussion about how these applications might be applied to lower-income segments of the housing market, with a special interest in informal communities, in both developed and developing countries.

Dimensions of sustainable housing applications

Implementation of sustainable upgrading in the types of low-income communities outlined above requires providing residents with affordable homes that are resource efficient, healthy, and comfortable. In the U.S., energy efficiency of homes is the area of retrofitting most commonly addressed by federal and local incentive programs although we note that this is only one area of sustainable retrofitting. High-tech renewable energy technologies, such as photovoltaic (solar) panels are not likely to be appropriate or feasible in low-income, self-built, or manufactured housing. However solar panel water heaters are widely available costing between U.S. $1100–1300 (Eaton, 2009). These heaters comprise single solar panels that heat water to a tank that passes (or bypasses) the regular water heater tank and can reduce a household's energy costs by 80 percent. In developing countries this remains a relatively high cost investment although many of the large-scale new social interest home construction projects in Mexico are including these panels on rooftops as standard. Elsewhere – in the Caribbean for example – they are common, but are mostly tied to the homes of the wealthy. But much lower cost alternatives exits, such as "passive" water heaters that simply use solar radiation to heat a water tank or hosepipes to provide partially heated water at no cost.[5] This is but one example of the range of technologies that are not only appropriate for the construction of self-built and manufactured housing, but which are also low-cost, affordable, and easy to operate and maintain.

Optimal sustainable interventions for low-income households

Our research identifies four different arenas of technological interventions that we believe are highly applicable to low-income, self-managed, and manufactured housing:

1. Microclimate design and technologies to support greater energy efficiency;
2. Renewable energy technologies to support access to alternative energy;
3. Water and wastewater technologies to promote water conservation and quality; and
4. Waste systems to promote resource reuse and recycling.

One of the earliest and most important insights in our research was when we became aware of the large number of effective actions that can be undertaken at very little, or only modest, cost. This finding reinforced our initial premise that, once properly understood, sustainable housing has considerable relevance for many low-income populations and different dwelling environments. While solar panel arrays costing hundreds (and sometimes several thousand) of dollars are likely to be the preserve of middle and upper-income homes, other low-cost initiatives such as "passive" water heaters, basic insulation improvements, window louvers and awnings, properly sealed doors and windows, improved air circulation, rainwater capture and retention, and micro-climatic adjustments can often be achieved at two figure sums or less. Other initiatives such as reduced water usage, low-energy incandescent lighting fixtures, reflecting foil on exposed windows, and better planning of house construction and window apertures to capture or reduce solar gain, can all be achieved at minimal or virtually no cost and lend themselves to self-help improvements.

Modeling the assessment of sustainable housing applications

Our main goal in this paper is to explore and assess how far the benefits of "green" housing home building and rehab could be extended to low-income households. In order to do this we sought to: 1) outline the range of possible sustainable housing interventions across a number of different arenas; 2) document their relative costs; and 3) quantify the feasibility and relative ease of implementation.

Because we wanted to examine only those interventions that are most appropriate for low-income households we paid special attention to the economic and social feasibility of implementing various sustainable technologies. We recognized that the primary constraining factor that determines the feasibility of an intervention among low-income communities is cost: specifically the front end economic investment required, the technological complexity of the proposed intervention, and the labor and human capital involved in its installation. Thus in constructing our charts we identified the principal evaluation axes as: 1) the suitability of different technologies in terms of their cost; 2) their ease of operation; and 3) their ability to be installed using the sweat equity of the homeowner his or herself.

This framework allows us to assess each technology or intervention in terms of cost, savings, opportunities for self-help, and the relative ease of implementation. These results are described and presented in diagrammatic form utilizing a standardized rating scale that ranks each intervention in terms of: i) ease of maintenance, ii) cost savings to homeowner once

[4] A second (sidebar) report (Rancho Vista and Redwood Study) is also available at the same website and was prepared by several members of the same graduate research team. This is a major survey of housing conditions and weatherization opportunities related to home improvement. In surveying these populations we also gathered information about attitudes and knowledge of sustainability, and the study provided valuable hands-on and local insights about potential applications that might gain traction in making home improvements in low-income self-help housing communities.

[5] Many low-income residents in spontaneous settlements already bathe in lukewarm water from passive water heaters, and minimize water heaters.

installed, iii) initial cost outlay or investment, and iv) the amount of sweat equity or professional expertise required for implementation.

The following four diagrams represent each of the four areas outlined earlier, namely: microclimate, renewable energy, water and wastewater, and solid waste management. In each of the following charts we assess the economic and practical feasibility of select technologies and applications within each of these four arenas. The final (fifth) chart of circles combines all four sets of interventions into a single graphic overview.

Rubric to the figures

A key to our assessment is included in each of the following four charts: Weatherization and Microclimate, Recycling and Solid Waste, Water and Wastewater, and Renewable Energy.

For "*Ease of Maintenance*" we ranked each intervention on a scale of 1–10, with 1 indicating that the technology needs minimal to no maintenance once installed and 10 indicating that the technology must be consistently or precisely maintained.

For "*Savings*" we indicated the amount of savings made possible by the intervention. For ease of comparison across the four areas we interpret savings to mean total savings on utility bills made possible by the intervention. Again we used a scale of 1–10 with 1 indicating minimal savings and 10 indicating savings of about 50% of energy or water used, or money spent. Often this was a qualitative assessment based the percent of total water, energy or expenditure that could be offset if the intervention were made.

For "*Initial Cost Outlay*" we created six categories to represent different levels of initial capital investment. The majority of the technologies are captured in categories that range from one to four dollar signs. A key to these symbols is included in each chart. Those interventions that require less than $20 in initial investment are denoted by a 1-cent symbol, while at the other end of the cost spectrum interventions that require more than $5000 (new energy efficient AC systems or solar arrays, for example) are denoted by a diamond symbol.

For "*Human Capital*" (denoted by hammers in the diagram), we use a visual representation of a composite variable that attempts to capture three things: first, the amount of time and labor necessary to implement or install the technology; second, the opportunity for the homeowner to use his or her own sweat equity (an important element in self-help); and third, the necessity to employ professional assistance or expertise. Here the number of hammers is the amount of labor necessary: one hammer indicates minimal labor, two hammers indicate moderate labor, three hammers indicate intensive labor and four hammers indicate that the amount of labor needed may be prohibitive to some households. The hammers are also shaded on a gray scale to represent the level of expertise required to implement the upgrade: light gray means a novice can do the work; medium gray means some skill is required; and dark gray means expertise or professional assistance is necessary. A circle (in place of hammers) means that negligible labor is required (as in the case of installing compact florescent bulbs, for instance).

We created a valuation of each intervention across the four categories of: ease of maintenance, cost savings, initial cost outlay or investment, and amount of sweat equity or professional expertise required for implementation and present these valuations in the following four charts.

Weatherization and microclimate

Fig. 1 demonstrates that there are a greater number of potential interventions in the area of weatherization and microclimate than in any of the other areas that we studied. It is also apparent that many of these interventions are quite affordable and can produce significant savings (savings rated over 5 on a scale of 1–10). However, it is also apparent that the majority of these interventions require significant labor on the part of the householder, as well as some degree of technical proficiency or the help of a professional.

Recycling and solid waste

The area of recycling and solid waste, Fig. 2, offers most opportunities for self-help (i.e. it shows the most interventions rated with one light gray hammer). The key exception here is recycling cooperatives; these community-wide initiatives require a large human capital investment and a moderate degree of expertise. The use of bio-digesters as a solid waste disposal method also stands out as an intervention that requires more economic and human capital investment but produces significant savings.

Water and wastewater

The water and wastewater technologies chart, Fig. 3 shows that there is a range of very high and very low-cost interventions that produce significant water savings relative to their use. There are also a number of effective gray water technologies that recycle used water from faucets and baths for other home and yard uses.

Renewable energy

Interventions in the area of renewable energy, Fig. 4, are some of the most expensive and require the most labor and expertise for installation and the most maintenance. But as already mentioned there are several relatively low-cost applications that merit consideration and wider application. However, the savings that these technologies provide to households varies greatly and more often than not other investments such as weatherization will generate greater immediate savings, and may also be a prerequisite before more complex and expensive interventions can be made.

Overview: the comprehensive diagram

The comprehensive diagram, Fig. 5, depicts all of the above findings on a single graph. A single circle represents each technology or intervention. Different hatchings are used to show the area of sustainable applications to which each circle, or technology, belongs:

- Circles with vertical narrow hatching: Water and Wastewater interventions
- Circles with horizontal narrow hatching: Recycling and Solid Waste interventions
- Circles with vertical wide and narrow hatching: Renewable Energy interventions
- Solid black circles: Weatherization and Microclimate interventions.

The *X*-axis of the graph depicts ease of maintenance for each intervention on a scale of 1–10 where 1 means "little or no maintenance" and 10 means "consistent and careful maintenance." The *Y*-axis represents the amount of human capital/labor investment required, where the number of hammers indicates the amount of time and labor needed to install the technology. Included in our valuation of sweat equity is the need for technical expertise. The need for professional assistance, which was indicated by a gray scale in the human capital hammer symbol in the four separate charts, is

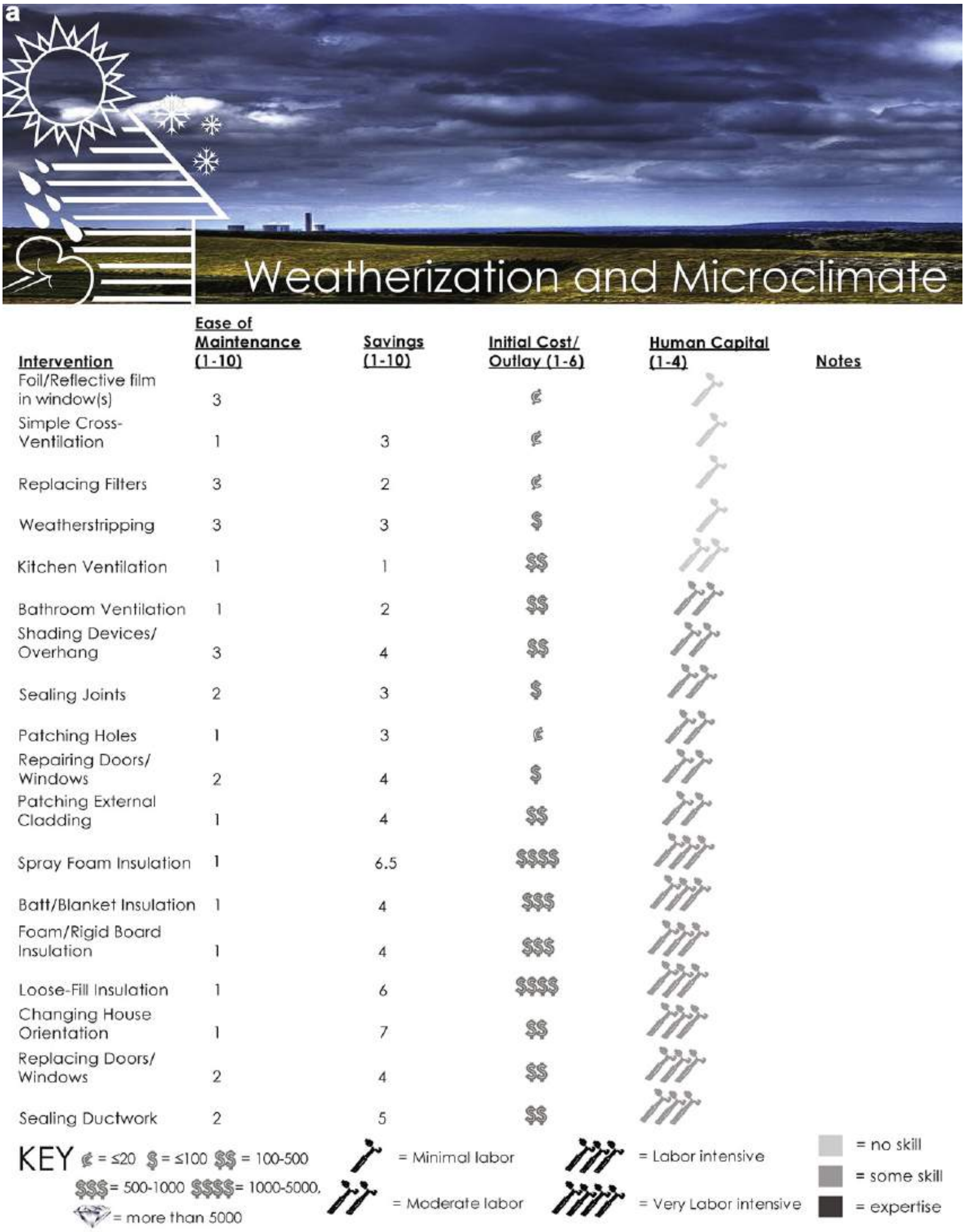

Fig. 1. a. Weatherization and microclimate. b. Weatherization and microclimate chart continued.

indicated here by a dot on the circumference of each circle. A black dot represents that some skill is required and a white dot indicates that professional expertise is a prerequisite. Circles that do not have a dot on their circumference represent technologies that do not require professional skill or expertise and thus are most suited to self-installation and sweat-equity programs.

Each intervention is represented by a different-sized circle. The circle's total size represents the initial cost of the intervention. Thus, the circles comprise ten different sizes that correspond to the 1–10 value designated in the 'Initial Cost' column in the above charts. The thickness of the ring around the circumference of each circle represents the 'Cost Savings' valuation, again based upon a 1–10 value (low to high). Thus, when each circle is viewed in terms of its total size, relative to the width of the ring around its circumference, this is an indication of the total cost of a technology in relation to the total savings it can produce for a household.

As we anticipated a priori, there are many low-cost, low-tech options that have the potential to produce significant savings for low-

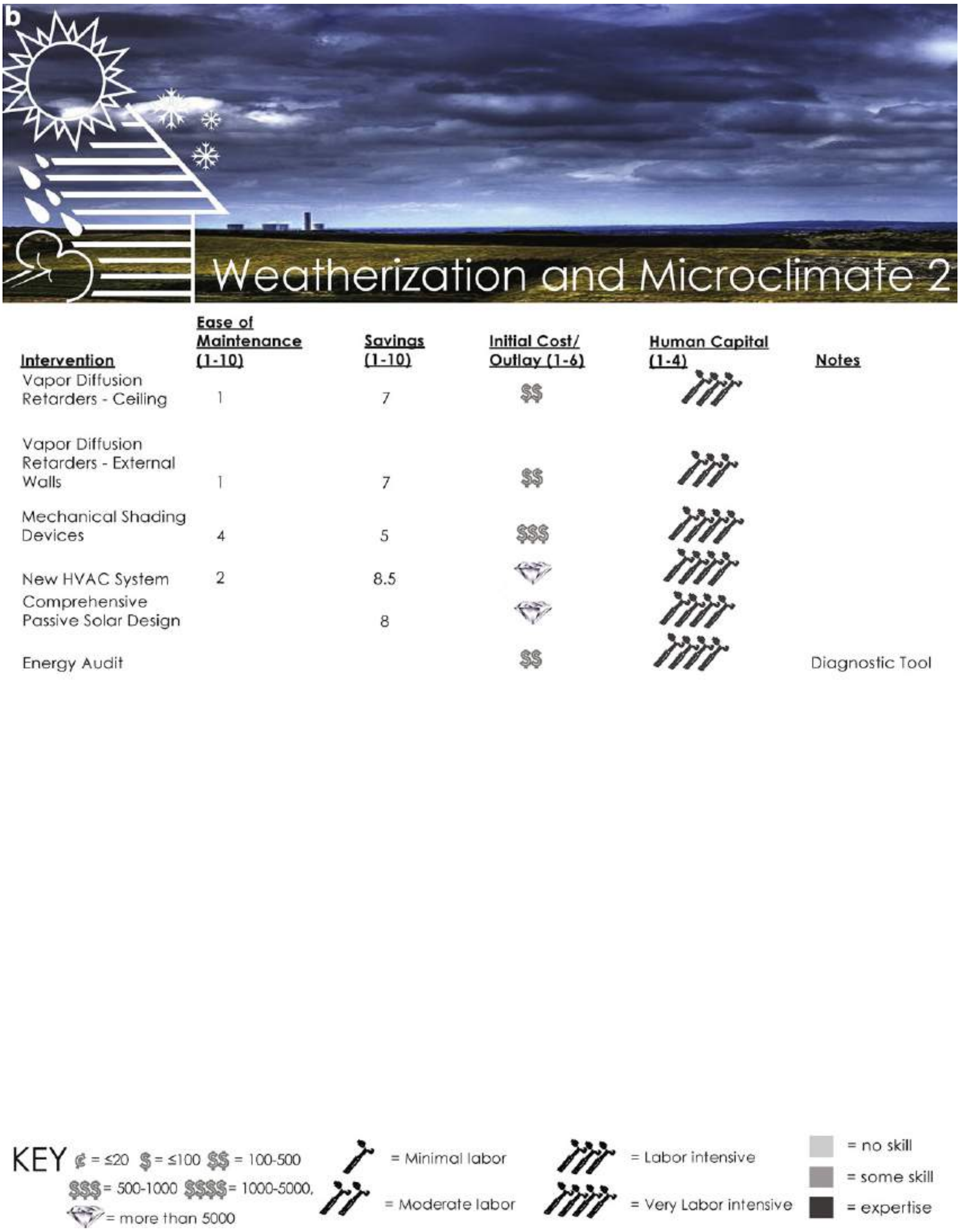

Fig. 1. (*continued*).

income households and which stand out in the diagrams. Several of our depicted arrays of interventions show high cost savings relative to initial cost ratios (i.e. a thick circumference ring relative to small total circle size). We also found that many of these interventions were located in a section of the chart that requires low levels of maintenance, and minimal labor and human capital investment – technologies that should be relatively easy to implement in low-income communities in Latin American and the U.S. Because the circles that represent the various interventions are patterned according to the area of sustainability to which they belong, it is clear that that some sustainable retrofits – especially those dealing with weatherization and microclimate (i.e. the solid black circles) – are clustered in the highest potential zone which requires low maintenance and relatively low human capital requirements.

This comprehensive graphic might be most usefully applied by households, community leaders and policy makers that wish to rehabilitate current homes, develop new and more sustainable low-income housing, and/or create programs that utilize sweat-equity. Together, the diagrams provide a heuristic to demonstrate the range of possible technologies for rehab and new development,

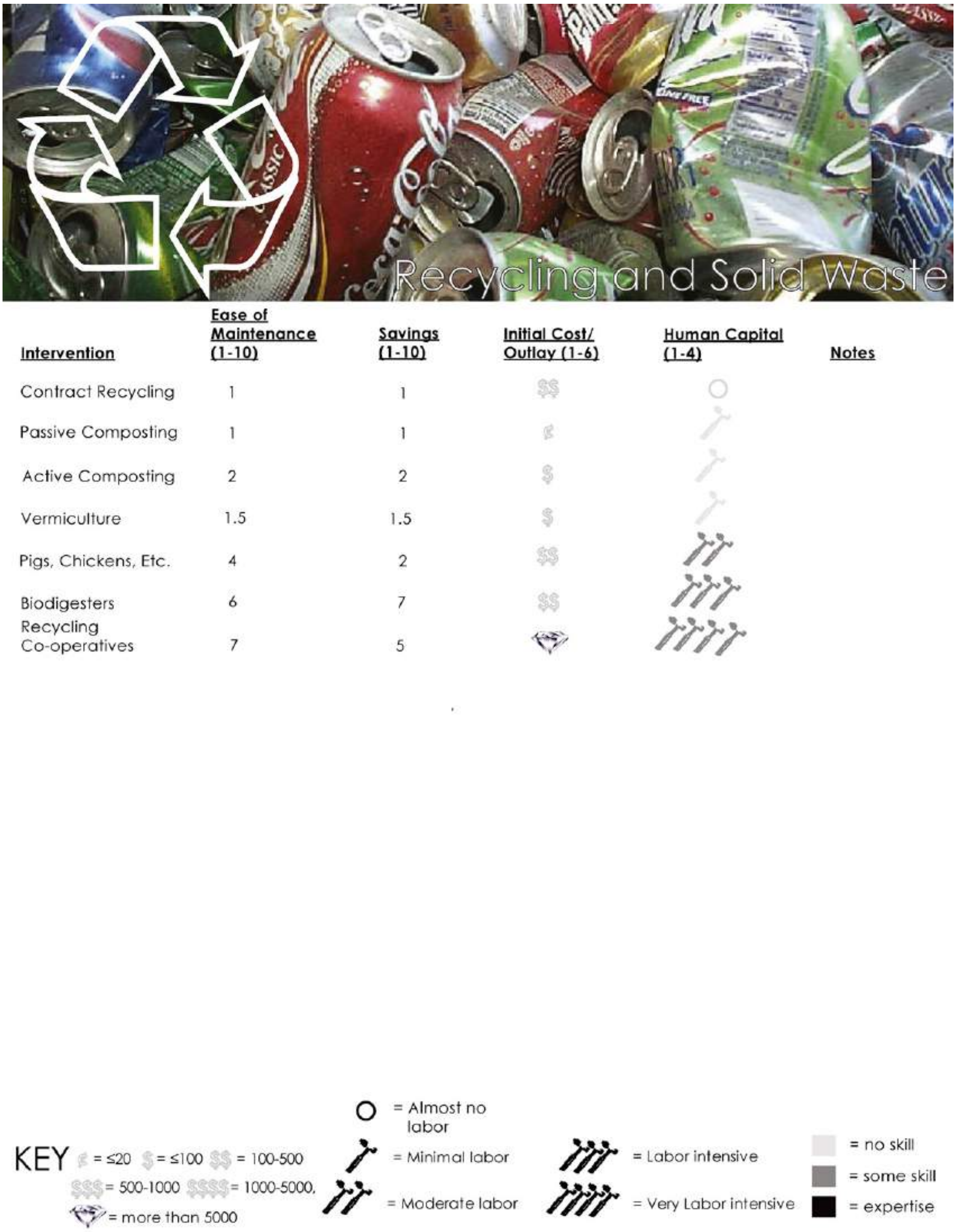

Fig. 2. Recycling and solid waste chart.

the contexts in which they are most suited, the potential outcomes, and the anticipated benefits to individual households.

Final thoughts: dimensions of sustainability and policy making

It is widely argued that any analysis of environmental issues in housing studies needs to be linked to broader themes such as social and economic sustainability, social integration and globalization (Brown & Bhatti, 2003). This is a truism and there is always a danger that by focusing upon available technologies and their implementation, as we have done in this paper, may create a misleading impression that technological policy “fixes” and applications alone can improve the lives of residents. Not so, of course, and the creation of more sustainable urban environments – whether in developed or less developed countries – will require a more

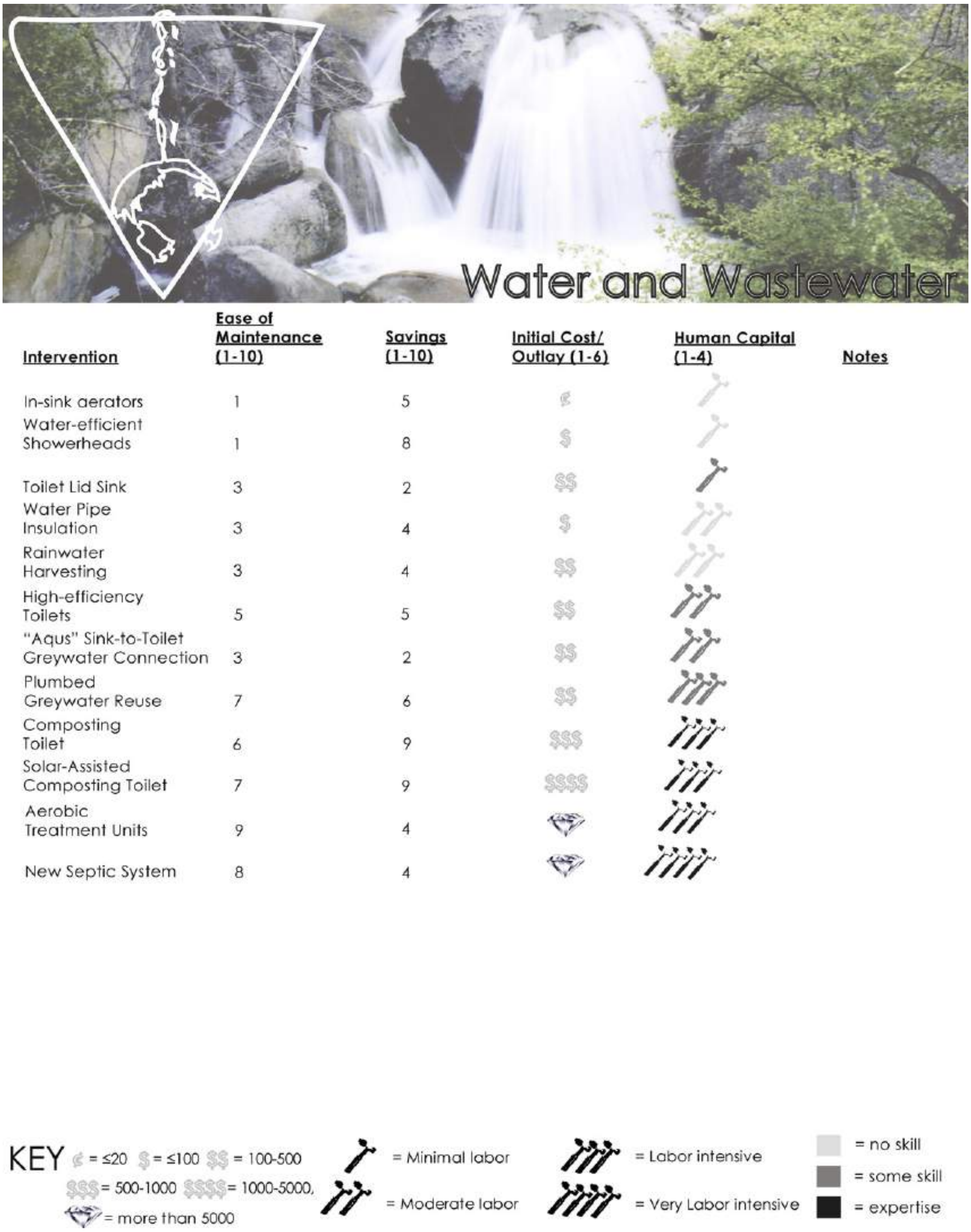

Fig. 3. Water and wastewater chart.

holistic understanding and convergent policy approaches along three principal dimensions: social, juridical (regulatory) and fiscal. In order to ensure that our physical applications models outlined above are more holistically framed, we wish to briefly underscore these other key dimensions.

Social sustainability requires the broadening and deepening of participation and buy-in in sustainable living practices, yet because of its subjective characteristics it has been difficult to define (Shen, Ochoa, Shah, & Zhang, 2011). It is sometimes defined as development that is "compatible with the harmonious evolution of civil society, fostering an environment that encourag(es) social integration, with improvements in the quality of life for *all* segments of populations" (Polése & Stren, 1999, p. 15–16). Pursuing social sustainability according to this definition will require better information and public awareness, support for social capital formation and community mobilization, capacity building, and education. In less developed countries high level of social mobilization often accompany self-help housing processes especially in the earlier phases of land capture and development. However, once neighborhoods are established and consolidated, public participation

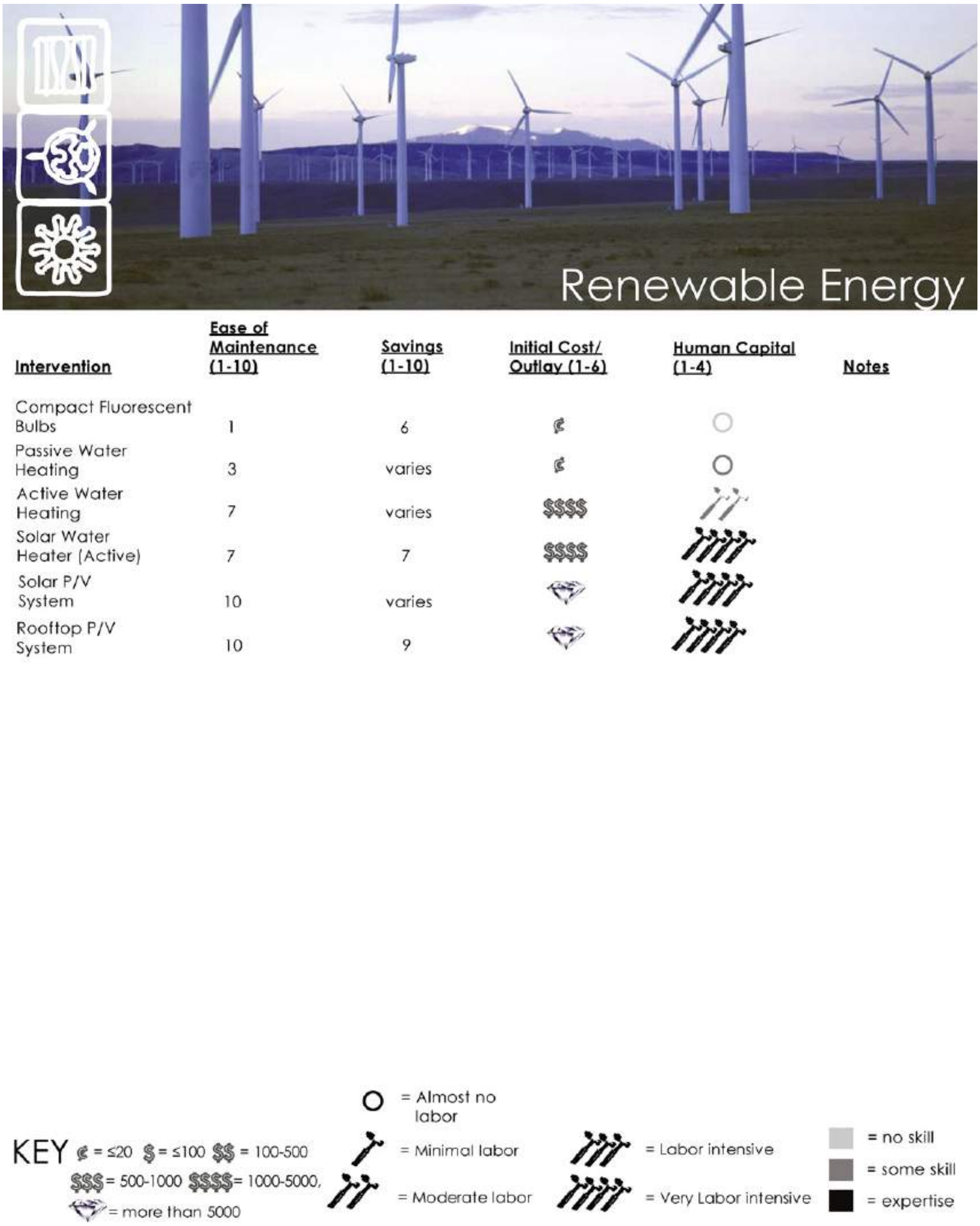

Fig. 4. Renewable energy chart.

atrophies, and it is necessary to revitalize mutual aid and community development programs around regeneration and housing rehab. The same is often true in inner city and first suburb neighborhoods in the U.S. where multiple stakeholders need to be engaged.

Juridical sustainability entails policy actions that ensure sensitive planning controls and zoning to discourage the proliferation of unsustainable housing development, but do so in a way that will also enhance greater commitment to and participation in sustainable housing practices. This might include the creation of mini social development zones in which approved upgrading and improvement initiatives encourage "progressive" (gradual) compliance with planning norms over an extended period of time, since these can rarely be achieved overnight. Regularization of property title, and the adoption of simple inheritance procedures will do much to encourage investment in home improvements, especially in long established inner urban neighborhoods where heirship and inheritance is often confused. Creative systems of shared titling, ownership, and cooperative management will foster stakeholder engagement in home improvement.

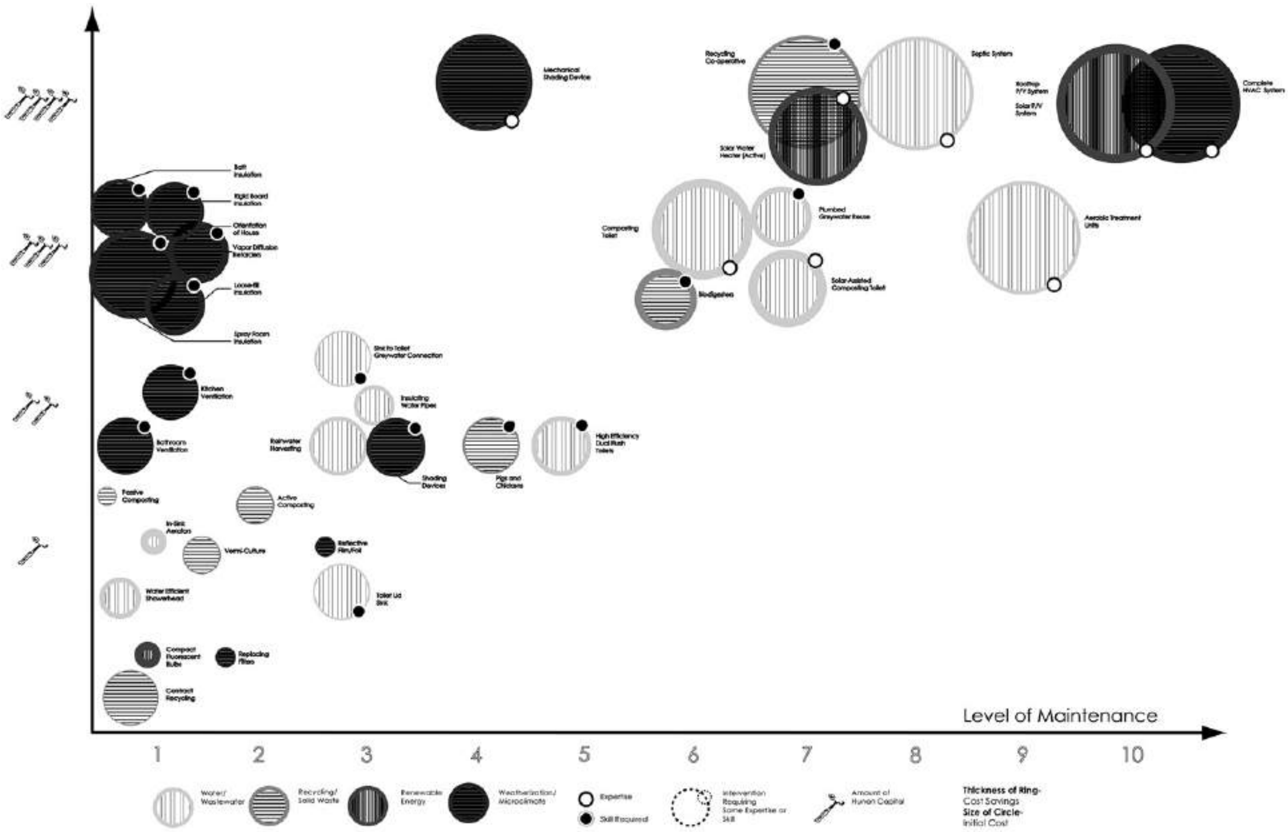

Fig. 5. Comprehensive diagram.

Fiscal sustainability is the third dimension. Cities need to be able to sustain themselves financially through taxation and effective pricing policies for public goods and services. This is the platform on which creative policies to leverage federal and other investment stands, providing appropriate incentives for much of the sustainable dwelling applications described in this paper. Many tax and other rebate incentives to encourage more energy efficient practices and appliances already exist, but mostly fall to the middle and upper-income groups. Just as we have emphasized the importance of engaging lower-income groups' knowledge and participation, it is also necessary to offer them tangible fiscal incentives so that they are not locked out of enjoying at least some financial advantages. Also, fiscal incentives should not just obsessively pursue sustainable energy practices (although these are important and the hard end of current thinking), but should also offer other arenas of sustainable housing activities such as lower-tech water, wastewater, and solid waste disposal systems.

Arguably, with the exception of the first suburban ring, the settlements that we have identified in this paper are in some respects *fundamentally unsustainable*. In the United States, for example, peri-urban suburbs dependent upon long commutes and largely private (rather than public) transportation are not sustainable, and are one of the principal reasons for the "back to the city movement" and "smart" downtown and inner-city growth and densification policies. But these are relatively recent, and since the 1950s suburbanization and sprawl have been the norm, invariably predicated upon private car use. Expansion into peri-urban areas and exurbia by low-income *colonias*, and informal homestead subdivisions in the 1980s and the proliferation of large lower cost formal housing developments since the late 1990s present major challenges to smart and "green" growth initiatives. However, no matter how far the growth of these residential suburbs and exurbs are controlled in the future, those already in existence can only benefit from sensitive policy measures that encourage awareness and adoption of sustainable housing options as we have outlined in this paper: they already exist and will not go away, such that maximum effort is desirable to minimize their negative environmental impacts and carbon footprints.

In Latin America and other less developed countries, irregular self-help settlements and modes of housing production and home improvement are and will continue to be the norm, and a fundamental barrier to sustainability in these communities is poverty. And while cities and local authorities are often administratively weak and fiscally challenged, the nature of informality and the weaker juridical and regulatory environment offers these populations considerable flexibility in allowing them to go it alone. Socially, too, these irregular settlements display greater mutual aid and community mobilization capacity than their U.S. counterparts, especially in their formative years. Here we expect that galvanizing support for home and community level improvements that also embrace an agenda of sustainability should be quite possible. In the older established consolidated areas this propensity for mutual aid has often waned, and there is a need to re-galvanize some of that erstwhile social and community mobilization. However, the stability of many owner households in these neighborhoods where neighbors know each other well and interact closely provides a basis for community mobilization, defense of interests and engagement around sustainable community renovation, service retrofitting and dwelling rehab. The paradox is that many of these settlements – whether peripheral or located in the innerburbs – are potentially much more sustainable than their peri-urban U.S. counterparts, being, as they are, more compact, with higher densities, and with a greater dependence upon collective transportation systems.

Ultimately, however, whether in developed or developing countries, issues of urban and housing sustainability will only become truly meaningful if they can embrace lower-income populations and poorer residential environments. We have shown in this paper that much can be achieved by taking small steps, which even if very modest in their impact, will do much to raise awareness, commitment, and buy-in among what are often the majority population of the world's cities.

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