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Making local futures tangible—Synthesizing, downscaling, and visualizing climate change scenarios for participatory capacity building

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ABSTRACT

Local in its causes and global in its impacts, climate change still poses an unresolved challenge for scientists, politicians, entrepreneurs, and citizens. Climate change research is largely global in focus, aims at enhanced understanding, and is driven by experts, all of which seem to be insufficient to anchor climate change action in regional and local contexts. We present results from a participatory scenario study conducted in collaboration with the municipality of Delta in SW British Columbia, Canada. This study applies a participatory capacity building approach for climate change action at the local level where the sources of emissions and the mechanisms of adaptation reside and where climate change is meaningful to decision-makers and stakeholders alike. The multi-scale scenario approach consists of synthesizing global climate change scenarios, downscaling them to the regional and local level, and finally visualizing alternative climate scenarios out to 2100 in 3D views of familiar, local places. We critically discuss the scenarios produced and the strengths and weaknesses of the approach applied.

1. Introduction

Extensive attempts have been made to engage the international policy community in responding to the projected impacts of climate change, through, for instance, the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Increasingly attention is also being paid to the need for awareness and action at the local scale, where the impacts of climate change manifest and the responses are undertaken (IPCC, 2007a). However, it seems to be very difficult to overcome the politics and behavior 'as usual' at the *local* level (Bizikova et al., 2007).

The Intergovernmental Panel on Climate Change (IPCC) has been instrumental in framing the problem of climate change. Using global emissions scenarios, the IPCC has projected future impacts of climate change while also communicating various response strategies available to policymakers, primarily at the national scale (IPCC, 2007b). The latter scenarios include ways to adapt to projected impacts and to reduce overall vulnerability to climate change via mitigation. With these goals driving the IPCC assessment process and becoming the foundation for its credibility in the policy sphere (Shaw, 2005), the IPCC has taken an approach that is targeted at an improved *understanding* of climate change.

Following the IPCC's lead, climate change is still largely addressed by an expert-driven process including the 'communication-as-transmission' concept—knowledge is best generated by scientists, and simply needs to be transmitted to decision-makers and the public for subsequent action (cf. Lubchenco, 1998, p. 491). Despite substantive critique (e.g., Gibbons, 1999), the concept seems to persist in the climate change discourse.

All three features of this approach to climate change, namely being global in focus, aiming at enhanced understanding, and being expert-driven, seem to be insufficient to anchor climate change *action* in regional and local contexts. Yet, a number of recent studies demonstrate new ways to holistically communicate climate science (cf. Moser and Dilling, 2007). First, *contextualizing* climate change impacts on the regional and local level by means of iconic locations allows people to 'encounter' the possible impacts of climate change and make them more meaningful (Leiserowitz, 2004; Balmford et al., 2004). Second, *visualization* seems to be a viable aid to link the understanding of climate change impacts to behavioral change and action (Nicholson-Cole, 2005; Sheppard, 2005a). Finally, studies on the science–policy interface have provided evidence that ownership and social robustness of problems and solutions requires co-production of knowledge

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(Gibbons, 1999; Shackley and Deanwood, 2002; Shaw, 2005; Robinson and Tansey, 2006). Engagement of non-academic stakeholders does not simply mean transferring information, but needs to occur throughout the research process to create ownership, accountability, and a willingness to act (UKCP, 2009). In sum, progress towards climate change mitigation and adaptation seems to be more likely if credible information is localized, visualized, and co-constructed (cf. Lorenzoni et al., 2007).

The scenario study we present in this article follows the insights summarized above. The study developed and visualized local climate change scenarios for the municipality of Delta (Metro Vancouver, Canada), in close collaboration with decision-makers and stakeholders from the community—scenarios that would be scientifically credible and salient to local stakeholders. The study aimed at building capacity for climate change adaptation and mitigation as part of a larger research project entitled the "Local Climate Change Visioning Project" (LCCVP) which was conducted in collaboration between the University of British Columbia and two municipalities in Metro Vancouver, namely the municipalities of Delta and North Vancouver (Sheppard et al., 2009; Shaw et al., in preparation).

The study pursued three main research questions: first, how can credible global scenarios be synthesized from a number of major studies in order develop a more comprehensive understanding of key drivers and impacts of climate change? Second, how can the synthesized scenarios be downscaled to the regional and local levels in a defensible way? Third, how can we 'localize' information and communicate it using visualizations in a way that is both defensible and compelling?[1]

The remainder of this article is structured as follows: Section 2 outlines the methods and steps followed to synthesize, downscale and visualize climate change scenarios from the global to the local level. Section 3 describes the resulting scenarios and supporting information. We critically discuss the strengths and weaknesses of the approach applied in Section 4 and conclude with implications for further research in Section 5.

2. Participatory scenario approach

The participatory multi-scale scenario approach employed in this study is structured into three main steps (Fig. 1): synthesizing global scenarios of climate change (Step 1); downscaling global climate change scenarios (Step 2); and visualizing local climate change scenarios (Step 3). The steps and results are illustrated in Fig. 1.

A conceptual framework was generated to guide the scenario study with respect to key variables, time frames, etc. that would be relevant to local response planning (Sheppard and Shaw, 2007; Sheppard et al., in preparation). The conceptual framework addresses causes, impacts, mitigation and adaptive responses at various scales, and was used to structure four 'climate world' scenarios with varying greenhouse gas (GHG) emissions and response strategies ('Do Nothing', 'Adapt to Risk', 'Efficient Development', 'Deep Sustainability': see Section 3).

A municipal case study (the community of Delta) was chosen to pilot the approach, based on three criteria: first, its vulnerability to climate change as a coastal community subject to sea level rise and other threats; second, the availability of (downscaled) data; third, the potential to visualize climate change impacts and responses which would be visible and compelling. Given the general shortage of locally specific climate change data and uncertainties in assessing vulnerability and adaptability to climate change, a qualitative approach was taken to consider the biophysical and social impacts, except where quantitative data was available. While vulnerability to climate change and adaptive capacity were adopted as guiding concepts (Fussel and Klein, 2006; IPCC, 2007b; Adger, 2006), we did not perform comprehensive assessments (cf. Turner et al., 2003; Vogel et al., 2007). Instead, possible response options were based on international best practices and local input. Available local sea level rise data and projections quantitatively anchored the project's appraisal of coastal vulnerability and impacts (Hill, 2006). This approach was considered sufficient for a participatory exploration of biophysical and social vulnerabilities as well as response options under the four scenarios.

A key characteristic of the scenario approach is the use of non-probabilistic scenarios as the basis for the analysis. In keeping with the approach taken in global assessment literature (Nakicenovic and Swart, 2000; Carpenter et al., 2005) and more generally in future studies literature (Swart et al., 2004), scenarios are used to explicate alternative non-commensurable portfolios of changes to key drivers and outcomes associated with different sets of choices. This approach allows the user to explore the consequences of different choices, rather than try to predict the most likely future (Robinson, 2003).

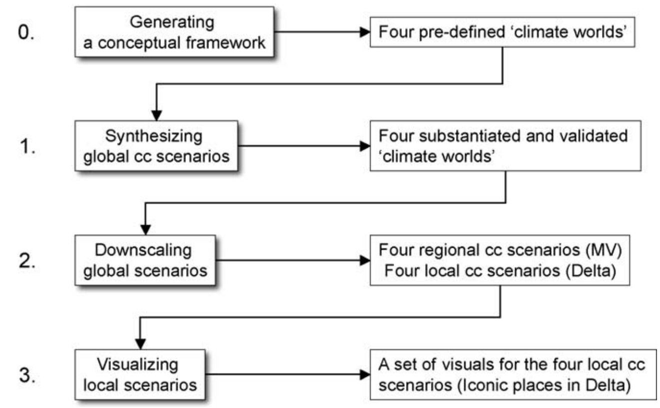

Fig. 1. Procedural steps (on left) and substantive results (on right) of study (cc = climate change; MV = Metro Vancouver).

2.1. Synthesizing global climate change scenarios (Step 1)

Three series of global climate change scenarios, namely the IPCC's SRES scenarios (Nakicenovic and Swart, 2000), the Millennium Ecosystem Assessment (MEA) scenarios (Carpenter et al., 2005), and the Global Scenario Group (GSG) scenarios (Raskin et al., 2002), were used to substantiate, validate, and specify the four scenarios derived from the conceptual framework. Similar to the approach taken by Raskin (2005), correspondences between the 16 global scenarios (6 scenarios in SRES; 4 in MEA; 4 in GSG) and the four conceptually predefined 'climate worlds' were identified. We communicated with a number of IPCC authors and scenario experts including Raskin (pers. comm. 2007) to validate our correspondences.

Based on content analysis of the three reports, we identified a number of aspects of climate change that were addressed as critical in each report and then reduced this to a set of key drivers and impacts. Each report provided qualitative information on the key drivers, while the SRES report provided some quantitative information on emissions and impacts. Corresponding international policies were matched with each scenario. Our scenarios were specified for 2020, 2050, and 2100.

The technical information was 'translated' into iteratively created and reviewed narratives (see Section 2.4). Finally, the qualitative information on the scenarios was transformed into conceptual trend lines (pictographs) in order to guide further

[1] A fourth research question is pursued in another paper (Shaw et al., in preparation). The question is whether and how localized and co-constructed visualizations at the local scale (discussed above) influence the cognitive and affective responses of the public and professionals, and motivate intended behavior change at the local level.

analyses and interpretations in terms of consistency, downscaling, etc.

2.2. Downscaling global climate change scenarios (Step 2)

The four climate worlds were 'contextualized' in national, regional, and local contexts to specify climate change impacts in 'people's backyards'. In contrast to numerical downscaling, we employed a two-step *qualitative* downscaling approach, applying the identified global trends to the regional and local scale (Jacques, 2006).

The first step downscaled qualitative trends from the global to the regional scale, where regional is defined as the metropolitan scale (Metro Vancouver). Metro Vancouver includes 21 municipalities on the southwest coast of Canada and manages water supply, wastewater, and solid waste, as well as coordinates municipal land use, air quality, and greenhouse gas mitigation, following sustainability guidelines. As Metro Vancouver's infrastructure is vulnerable to climate change impacts, it is a suitable case study area for climate change impacts and response options on the regional level. To ensure internal consistency the qualitatively downscaled information was corroborated with an existing regional socio-economic model.[2] It was assumed that the federal government would not play a major role in the scenarios beyond enabling high-level policies, and that most policies influencing the downscaled local scenarios stem from regional and local land use decision-making and governance.

The second downscaling step used the regional information as a marker for trends at the local scale (Municipality of Delta), but was supplemented by available quantitative local information (e.g., population projections and downscaled sea level rise data). The Corporation of Delta is a municipal government serving the growing communities of Ladner, North Delta, and Tsawwassen. Land-uses include agricultural, residential, and commercial areas. The average elevation is only 0–2 m above mean sea level. Its vulnerability to storm surge has been demonstrated during numerous storm events in the past, most recently in 2006. At the beginning of this project (2006), storm events had begun to infiltrate municipal politics. For these geographical and political reasons, the municipality of Delta provided a suitable case study to examine potential climate change impacts on sea level, agricultural production, and current spatial development patterns (NRCan, 2007). An additional rationale for selecting Delta was the unusual availability of local data. Baseline data were collected for Delta (reference year 1990), then projected for each scenario. Supplementary local-scale data, such as data on vehicle travel and settlement densities, were added to each scenario.

While a comprehensive vulnerability assessment was not undertaken, the guiding principles of a participatory vulnerability assessment were used (Smit and Wandel, 2006). Critical biophysical and social sensitivities were identified through the best available data and local/expert knowledge and participation (cf. Watson et al., 1998) (see Section 2.4). As such, the vulnerability information reflects the risk perceptions of the local stakeholders and expertise on the working group (see Section 2.4). For instance, regional temperature and precipitation data was used to consider critical regional and local vulnerabilities to agriculture in the region, and local experts were consulted to elaborate on the anticipated impacts (crop shifting, foreclosure, etc.) and response options under the four scenarios. Similarly, population projections were used to consider different land-use changes in the community, and city planners helped to extrapolate and spatialize these findings. Capacity building was emphasized in the exchange and deliberation with local experts. In addition, inclusion of local experts and stakeholders in the scenario development and visualization design process was used to build credibility and ownership throughout the process.

Considerable effort went into weaving disparate data and types of information including threats and responses to climate change into coherent narratives of the four scenarios. This information included biophysical impacts (e.g., sea level rise, crop failure, etc.), possible responses (raise sea wall, retreat, increased density, etc.), socio-economic change (peak oil, societal value change, environmental refugees, etc.) and governance issues (e.g., breakdown, incremental versus abrupt regulation, etc.). Consistent with the overall scenario framework and given the spottiness of available data, especially for socio-economic and governance issues, a simplistic guideline was used that assumes local responses are equivalent to responses at the global scale. For instance, local mitigation was assumed to match global efforts and outcomes. It is clear that under the four scenarios, the federal, provincial, and municipal governments will need to cope with changes and restrictions in their respective jurisdictions and either independently or collaboratively determines appropriate adaptation and mitigation (cf. Biggs et al., 2007). Yet, a systematic exploration of these socio-political cross-scale issues was beyond the scope of this study.

Concurrently, we collected impacts estimates and potential policies for key iconic locations from documentation and in consultation with regional and local experts (the iconic locations were collaboratively identified in an initial workshop). We combined all this information to create draft versions of coherent local narratives for each scenario. In final form, the narratives and data were used to support the production of visualizations.

2.3. Visualizing local climate change scenarios (Step 3)

We visualized the local scenarios based on decision rules addressing data availability, clear and compelling visual information, and fit with the local narratives. These visualizations were created to test whether defensible, compelling depictions of climate change and responses to it would add value to existing approaches to climate change communication and planning (Nicholson-Cole, 2005; Sheppard, 2005a).

The scenarios were designed to be used in subsequent perception studies (e.g., Shaw et al., in preparation); therefore emphasis was placed on providing a range of common styles, levels of realism, and types of imagery that have been shown to be effective in previous participatory studies (e.g., Tress and Tress, 2003; Sheppard, 2005b). A deliberate decision was made to reduce the realism of the developed areas in close-up views, in order to avoid possible adverse reactions from participants and potential legal repercussions around individually recognized property in the area (cf. Méndez, 2008). The spectrum of visual media was also influenced by, available data, and constraints of time and budget.

Two- and three-dimensional landscape visualizations were supported by Geographic Information Systems (GIS) and climate/environmental modeling. We applied visualization tools ranging from 2D photorealistic graphics editing (*Photoshop*) to 3D tools including *ArcSCENE*, *Google Earth*, *SketchUp*, and *Visual Nature Studio*. We processed a high-resolution 3D dataset (*LiDAR* data) for accurate visualization of the shorelines. We followed a set of visualization standards to ensure defensibility (Sheppard, 2005b). The generated visuals were reviewed by the extended research team as well as by the local working group and were subsequently revised by the core research team, in an iterative process (see Section 2.4). The visual materials (which also included GIS mapping, charts, and photographs of precedent response options elsewhere) were finally combined with data and narratives to produce 'visioning packages'; these were used in testing sessions in the second phase of this project (Shaw et al., in preparation).

[2] Details about the downscaling to the regional level and the use of QUEST modeling are spelled out in Appendix.

Table 1
External groups involved in the research process and their respective primary activities (M = meeting of the LWG).

	1. Synthesizing	2. Downscaling	3. Visualization
Extended research group (ERG)	Review global storylines	Review regional storylines	Review visuals
Local working group (LWG)	–	Input impacts (M 2) Input Adaptation/Mitigation (M 2) Review local storylines (M 3)	Review visuals (M 3)

2.4. Participatory approach

The scenario study was conducted in a participatory manner similar to other land use studies (Tress and Tress, 2003; Wiek et al., 2006; Patel et al., 2007), and integrated assessment studies (Cohen et al., 2006; Robinson, 2008). Different external groups were constituted and involved in different functions and at different stages of the research process (Table 1) (Wiek, under review).

The *core research team* (CRT) consisted of 5 persons (principal investigator, co-principal investigator, 2 research associates, and a doctoral student) from the University of British Columbia. The CRT formed an extended research team as well as a local working group for different periods of collaboration. For the local working group sessions, facilitators with climate change knowledge were hired and instructed by the CRT.

The *extended research group* (ERG) included 14 university researchers and 17 federal and provincial government researchers (with background in climate change modeling, impacts, responses), 7 local and regional practitioners (planning and engineering), and 5 non-governmental experts (e.g., David Suzuki Foundation). The CRT collaborated with the ERG to receive reliable inputs, to access technical data, to vet and approve the information and underlying assumptions for the global and regional scenarios (particularly for the "Deep Sustainability" scenario). The collaboration varied with respect to medium (in person, via e-mail, or telephone) and participants (plenary meetings, sub-groups) depending on availability.

The *local working group* (LWG) included 2 provincial government scientists, 4 practitioners from the municipality (planning and engineering), 5 local committees members (including agriculture and community advisory), and 2 private sector representatives (from the Port of Vancouver). The LWG was assembled to provide inputs for contextualizing the regional information by suggesting and reviewing local scenario content, to advise on visualization priorities, and to review the generated results (narratives and visuals). The participants had experiences in local climate change projects and/or were members in community groups. Three working group sessions were held in form of workshops (Table 1).

3. Results

The conceptual framework outlined four alternative global change scenarios based on GHG emissions and response options, from a 1990 baseline over the time steps 2020, 2050, to 2100 (Sheppard et al., 2009). The first scenario entitled "Do Nothing" is a high emissions scenario with no effective adaptation or mitigation activities. The three other scenarios implement different proactive response strategies with different effects on emission profiles. The 'pure' adaptation scenario entitled "Adapt to Risk" still remains a high emissions scenario (no significant effect on emissions). The scenario entitled "Efficient Development" employs adaptation but also moderate mitigation measures resulting in a moderate emissions profile. Finally, the fourth scenario entitled "Deep Sustainability" is based on the assumption that strong mitigation responses, coupled with adaptation, would significantly reduce the emissions trajectory over time and lead to stabilization of climate change.[3] When, where, and how these response strategies are employed and when their effects will be 'visible' is specified in the downscaled regional and local climate change scenarios.

3.1. Synthesized spectrum of global scenarios of climate change

GHG emissions and seven emission drivers are consistently addressed in the IPCC's SRES scenarios, the MEA scenarios, and the GSG scenarios (see Section 2.1). The drivers are: economic and social development, energy and technology, ecosystems, agriculture, land use, transportation, and population. Based on similarities regarding emissions and drivers, Table 2 groups various scenarios of the three global scenario series to the four 'climate worlds'.

To enhance the coherence of the 'climate worlds', some adjustments and assumptions were required. First, while economy and energy use increase linearly to 2100 in the SRES A1/A2 scenario, a linear increase is assumed for the "Do Nothing" and "Adapt to Risk" scenarios only until late-century. Literature regarding 'peak oil' suggests that we are facing diminishing returns not only on non-renewable oil and gas deposits and supply but also on its low cost (Hirsch et al., 2005). Therefore, the two high emissions scenarios assume a linear increase in economy and energy use in the early part of the century but both begin to slow and then decline by late century. Possible effects could be that without cheap energy sources, the economy begins to decline and GHG emissions begin to slow. Second, the high emissions "Adapt to Risk" scenario assumes that particular adaptation strategies could either increase or decrease GHG emissions since there is as yet very little information on this topic (Klein et al., 2007; Yohe et al., 2007). We assume that adaptation would not have net gain in reducing emissions. Therefore, the GHG emissions in the "Do Nothing" and "Adapt to Risk" scenarios are considered to be the same (both aligning with the SRES A1 scenario). Third, the low emissions scenario "Deep Sustainability" represents a scenario where climate change is stabilized within this century as a result of strong mitigation policies. In this regard, the scenario goes beyond SRES, which does not explicitly include mitigation policies (Nakicenovic and Swart, 2000; Pielke et al., 2008). Corresponding to a Post-SRES B1 scenario, the "Deep Sustainability" scenario assumes 450 ppm CO_2 concentration and an average temperature below the +2 °C marker, above which is considered to be dangerous anthropogenic interference (by 2100) (IPCC, 2007a).

Table 3 summarizes the qualitative assumptions made in explaining the different quantified GHG emissions trajectories and the associated quantified impacts of the four 'climate worlds' over the three time steps (2020, 2050, 2100). The table focuses on a reduced set of climate change impacts, namely population, economy, energy use, and land use (subsuming biodiversity, transportation, etc.) as key drivers, as well as atmospheric CO_2 concentration, temperature change, and sea level rise as key impacts.

[3] Stabilization refers to remaining under a 450 ppmv atmosphere CO_2 concentration by 2100 (and subsequently remaining below a projected 2 °C global average surface temperature warming), considered the threshold of dangerous anthropogenic interference (IPCC, 2007a,b).

Table 2
Correspondence between ‘climate worlds’ and global scenario series.

‘Climate world’	IPCC SRES/Post-SRES scenarios	MEA scenarios	GSG scenarios	Selected corresponding key features (with sources)
“Do Nothing”/“Adapt to Risk”	A1/A2	Order from Strength	Breakdown/ Fortress World	Lower trade flows, slow capital stock turnover, and slower technological change (A1, SRES). Low average per capita income (A2, SRES). Ensconced in protected enclaves, an elite safeguards its privilege by controlling an impoverished majority and managing critical natural resources (Fortress World, GSG). Protected natural areas are not sufficient for nature preservation or maintenance of ecosystem services (Order from Strength, MEA).
“Efficient Development”	B1/B2	Adapting Mosaic	Policy Reform	High level of environmental and social consciousness combined with a globally coherent approach to a more sustainable development (B1, SRES). Slow transition to alternative energy systems as oil and gas resources decline (B1, SRES). Increasing production and consumption undermines the ability of ecosystems to continuously support themselves, at times having serious consequences (Adapting Mosaic, MEA).
“Deep Sustainability”	Post-SRES B1	Techno Garden	Great Transitions	Proactive local and regional environmental measures and policies lead to relatively low GHG emissions (Post-SRES B1). Resurgence of quality values as a component of human welfare, high valorization of nature, equitable wealth distribution, and strong social solidarity (Great Transitions, GSG). Annex 1 countries take greater responsibility (70% more) for reducing GHG emissions (Great Transitions, GSG).

The “Do Nothing” and “Adapt to Risk” scenarios follow continued rapid growth in global population, economic, GHG emissions, and land use trends until late century when abrupt change occurs (e.g., decline of cheap energy supply). The main differences between these scenarios exist in the land-use driver. Expansion continues in both but climate change impacts (such as rapid immigration and thus population growth from environmental refugees) are not planned for in scenario 1 and are anticipated in scenario 2, avoiding unplanned settlement areas and shifting away from the development in highly vulnerable areas assumed in scenario 1.

In the “Efficient Development” scenario the population and energy use grows at a slower rate while the energy sources incrementally diversify over time. Fossil fuels are still dominant

Table 3
Qualitative trends of drivers and associated quantified emissions and impacts of the four ‘climate worlds’.

‘Climate world’	Drivers				Emissions and impacts											
	Trends to 2100				2020				2050				2100			
	Population	Economy	Energy use	Land use	CE [%]	CO_2 [ppmv]	TC [°C]	SLR [m]	CE [%]	CO_2 [ppmv]	TC [°C]	SLR [m]	CE [%]	CO_2 [ppmv]	TC [°C]	SLR [m]
“Do Nothing” (1)/ “Adapt to Risk” (2)	Increasing	Increasing	Increasing	Urban expansion	+57	410	+0.45	n/a	+144	550	+1.6	+0.16	+175	850	+3.75	+0.42
	Rapidly	Rapidly	Rapidly	Rapidly												
	Steadily	Steadily then sharp decline	Steadily	No climate change planning (1) or proactive adaptation planning (2)												
“Efficient Development” (3)	Increasing	Increasing	Increasing	Complete communities	+38	410	+0.5	n/a	+69	470	+1.5	+0.16	+105	620	+2.7	+0.35
	Moderately	Moderately	Moderately	Mixed use												
	Steadily	Steadily	Steadily	Densely												
“Deep Sustainability” (4)	Increasing	Increasing	Increasing	Integrated, closed loop systems	+15	410	+0.5	n/a	−15	445	+1.35	+0.16	−58	450	+1.9	+0.26[a]
	Slowly	Slowly	Slowly	Slowly												
	Stabilizing	Stabilizing	Stabilizing; rapid transition to alternative energy	Densely												
				District heat and energy												

CE = average change of emissions, reference year 1990 [%]; CO_2 = CO_2 concentration [ppmv]; TC = average temperature change, reference year 1990 [°C]; SLR = average sea level rise, reference year 1990 [m]). Sources: Nakicenovic and Swart (2000), Raskin et al. (2002), Carpenter et al. (2005) and Hirsch et al. (2005).

[a] The reference year for Post-SRES 450 is 2000 (Schlesinger and Malyshev, 2004). Global mean sea level change (for ‘best guess’ temperature sensitivity of 2.5 °C) is very similar through 2050 for all three scenarios (1 and 2 are the same). However by 2100 there is some divergence based on emissions scenario.

Table 4
QUEST outputs for emissions, key drivers and sub-drivers for the "Do Nothing" scenario. (Energy use data for 2000 were used as baseline because data for 1990 were not available.).

"Do Nothing" Scenario	1990	2020	2050	2100
Population [Mio. inhab.]	1.5	1.82 (+82%)	3.0 (+200%) (incl. environ. refugees)	4.8 (+380%) (all developable areas)
Economy [Mio. $]	50	Growth continues but slows as of 2020	Decline with increased rich/poor disparity	As of 2070 economy begins to decline
Land use				
Developable land [km^2]	200	Scarcity (2015)	ALR, marginal coastal, floodplain areas cov.	All developable land area covered
Density [inhab./km^2]	3216	3216 (+0%)	3216 (+0%)	4551 (+41%)
Vehicle km traveled (VKT) [Mio. km/a]	33	49 (+49%)	79 (+139%)	132 (+300%)
Energy use [Mio. GJ]	617 (2000)	808 (+31%)	1249 (+103%)	1522 (+147%)
Per capita [GJ/inhab.]	350	250 (−29%)	275 (−21%)	300 (−14%)
Energy use per GDP [MGJ]	600	786 (+31%)	1218 (+103%)	1482 +147%
Primary energy	Hydro (117), oil (173), gas (324), wood and biofuels (75)	Hydro (174), oil (234), gas (387), wood and biomass (78)	Hydro (175), oil (442), gas (507); wood and biomass (112)	Hydro (until 2060) (43), oil (911), gas (peak in 2070) (394), wood and biomass (144)
CO_2 emissions [Mio. t]	24	35 (+46%)	56 (+133%)	66 (+175%)

but significant energy (and water) efficiency gains are made in individual residential and commercial developments, slowing in GHG emissions but not contributing to absolute reductions.

What the "Efficient Development" scenario lacks in rapid implementation of sustainable energy management is made up for in the "Deep Sustainability" scenario. Instead of an incremental approach to reducing GHG emissions, this scenario assumes a significant social turn leading to considerable GHG emissions reductions early in the century. Population growth slows and there is a more regionalized approach to energy and food production. Mitigation and energy planning become part of political and social consciousness and action. New forms of urban design and land-use planning increase resilience by reducing GHG emissions and including adaptive features that respond to unavoidable climate change impacts. Agricultural lands are protected both for local, organic produce (saving energy from transported imports) and local biomass to be grown. Conservation measures, efficiency gains, and fuel switching contribute to lower energy use with limits on renewable energy supply and a focus on regional production. The economy slows and even declines in mid-century as the turnover to renewable energies occurs and thereafter continues to grow.

3.2. Downscaled climate change scenarios

3.2.1. Downscaled regional climate change scenarios

Based on future GHG trajectories that match those of the four 'climate worlds', the GB QUEST model numerically specified four corresponding regional scenarios for the Metro Vancouver area. The coherence of the regional trends also provides the validity for the assumptions made in the four global scenarios. The GB QUEST data were subsequently visualized in scale-less 'pictographs': Fig. 3 presents on the left side the charts for the GHG emissions (model input) and the four key drivers (model outputs).[4]

The use of GB QUEST provided quantified data not only for the key drivers but also diverse sub-drivers to be used for formulating the regional scenario narratives. Table 4 exemplarily provides data for the core drivers and selected sub-drivers for the "Do Nothing" scenario.

In Fig. 2, the information about key drivers and GHG emissions is combined with data about climate change impacts, namely atmospheric CO_2 concentrations, temperature changes, and regionally specific information on sea level rise; as well as with the 'response repertoire' of existing projects and policies for adaptation and mitigation at national, provincial, and municipal scales. This comprehensive semi-quantitative 'picture' indicates the different potential development paths, their implications, and available response options. Given the lack of data about socio-political developments at the national, regional, and local scales, we used the assumptions from the relevant global scenarios (e.g., MEA, GSG, and IPCC) to map out the equivalent trends at the local level. For instance, in the 'Do Nothing' scenario, breakdowns of institutions, policies, and government occur; whereas, in the 'Deep Sustainability' scenario, social values change quickly partly due to stringent government regulations that encourage citizens to make more sustainable choices.

We present in Table 5 two of the four regional narratives, which were finally created on the basis of the data compiled.

3.2.2. Downscaled local climate change scenarios

Four iconic locations in Delta were used to illustrate the local dimensions of the four scenarios, specifically focusing on critical themes in Delta: (1) land use planning in Tsawwassen, (2) shoreline, dikes, and agricultural lands in Roberts Bank (Brunswick Point), (3) habitat in Reiffel Refuge, and (4) coastal neighborhoods in Beach Grove (Fig. 3).

The community of Tsawwassen lies on the western coast of Delta bounded by water on three sides. It includes agricultural and residential lands, the majority of which lies at 0–2 m above sea level. Without the string of protective dikes and sea walls, these valuable lands would be submerged at high tide on a daily basis. Critical agricultural land in Delta is provincially zoned as part of a 'land reserve' in which farming is encouraged and all non-agricultural uses are controlled. This land currently buffers the community against expansionist population and development pressures. Currently 85% of working age residents commute to work outside of Delta. Private and public transportation, agricultural practices, and both freight (Deltaport) and ferry ports (Province of BC) are the main source of GHG emissions in the area. Current incremental incursions onto the agricultural land reserve highlight the vulnerability of these iconic lands for population growth (e.g., inclusion of environmental refugees from other more vulnerable parts of the world). This area provides an interesting window into current land-use planning against innovative themes such as densification and restructuration of urban patterns to reduce GHG emissions and to increase resilience.

Roberts Bank is a section of the main protective dike (3.48 m height) along the western coastline that runs approximately 15 km

[4] The pictographs were scale-less as they were used for 'visual understanding' with the local working group. The numerical data had been discussed and approved by the extended research group beforehand.

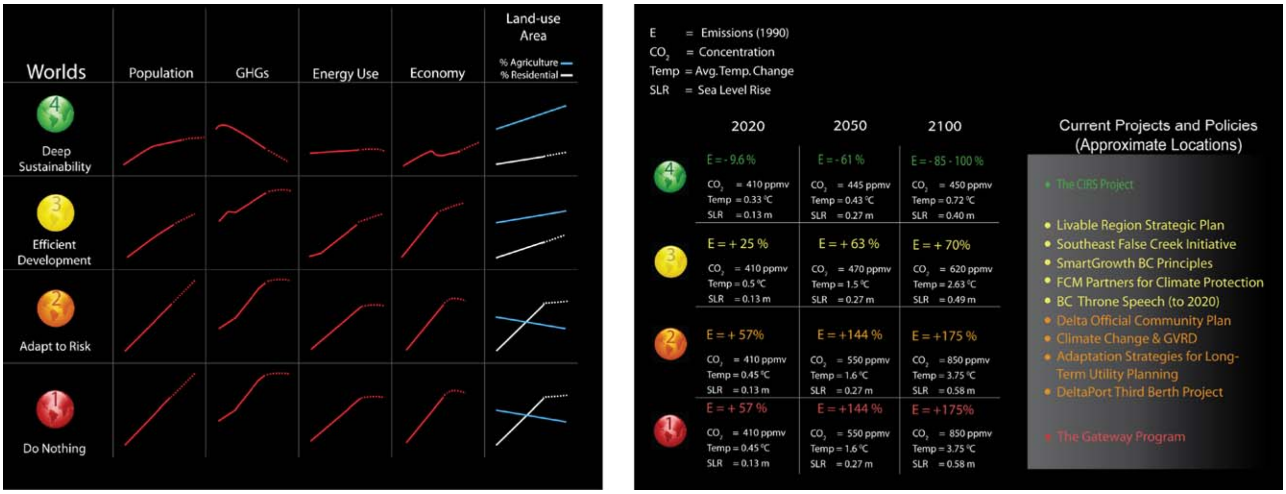

Fig. 2. GB QUEST modeling input (GHG emissions) and outputs (drivers), combined with impacts (partly regionalized) and response adaptation and mitigation measures. (Trend lines depicted by dotted line after 2050 as the GB QUEST models were only tested and verified by sectoral experts for 40-year futures. Trends after this period were extrapolated to be consistent with their corresponding global scenarios.)

from Tsawwassen to Brunswick Point, protecting agricultural and residential lands. The dike continues east up the shoreline of the Fraser River. Brunswick Point is a section of the dike that protects significant agricultural crops including vegetables, berries, and pasturelands. The shoreline, dikes, and agricultural lands associated with the Roberts Bank/Brunswick Point area elucidates the impact of sea level rise and more frequent storm surge events on the coastline of Delta, particularly the dike system that protects agricultural lands at sea level. The Roberts Bank dike has also become a local recreational site. The Corporation of Delta has undertaken a number of engineering and economic studies to determine the feasibility and costs of raising the dike, a proactive adaptation, and is currently looking for cost-sharing mechanisms with the province. There has only been one known breach of the dike (verb. comm. with local engineers).

Westham Island lies in the Fraser River delta north of Tsawwassen. Located on Westham Island is Reiffel Refuge, an internationally protected bird flyway, which is protected by a

Fig. 3. Map locating the four iconic places in Delta: Tsawwassen, Roberts Bank (Brunswick Point), Westham Island (Reifel Refuge), and Beach Grove (1:24,000-scale).

Table 5
Exemplary narratives for two of the four regional scenarios (scenarios 1 and 4).

Regional scenario 1—Do Nothing: React Locally!	Regional scenario 4—Deep Sustainability: Think Climate Change Globally, Be Proactive Locally!
Per capita greenhouse gas emissions increase with the population of Metro Vancouver and the economic growth [GB QUEST]. All orders of government have abandoned issues relating to climate change in order to focus on more pressing issues of housing, economic growth, and security. Long-term plans such as the Livable Region Strategic Plan (LRSP) are ignored in favor of Gateway-style projects that react to the effects of traffic congestion from population growth and economic expansion by building, on a project-by-project basis, infrastructure such as roads, bridges, and trucking transport routes. The two cement plants in Metro Vancouver account for 58% of industrial greenhouse gas emissions (GVRD, 2006). One of the largest emitting sectors in the region, the transportation sector, continues to grow as large-scale transport projects expand road networks and as residents, pushed further from the downtown core, take to their cars to commute to their workplaces. New transportation and housing developments begin to encroach onto the ALR in the Lower Mainland and Fraser Valley, eroding it 53% by 2040 [GB QUEST]. These plants use large quantities of heat energy fuelled by emission-intensive coal that contribute to greenhouse gas emissions and poor air quality. Metro Vancouver mirrors the national trend which more than doubles greenhouse gas emissions by 2050, placing growth pressures on ecosystems and increasing hospital visits for respiratory ailments. Effects from warmer temperatures on Metro Vancouver differ seasonally. Wet winters become wetter while summers become drier and longer. A warmer minimum temperature in winter causes the snowbelt to climb higher to colder elevations reducing the snowpack on the North Shore mountains reducing the volume of snowmelt captured for water storage in the Capilano, Seymour and Coquitlam reservoirs. Less snowpack melts quickly and leads to an earlier spring freshet, which alters ecosystem dynamics (i.e., breeding and feeding cycles of fish and amphibians) and, combined with a longer growing season (due to higher summer temperatures), amplifies water scarcity problems in the region (Greenhouse Gas Reduction Plan for the GVRD, 2006). Winter precipitation increases, causing more frequent storm surges that place pressure on infrastructure and structures leading to increases in insurance payouts and omission of high-risk areas from insurance altogether. The accumulated greenhouse gas concentrations combined with the climate lag of the previous century contributes to a faster rate of temperature increase in the second half of the century. The combination of west coast subsidence and sea level rise inundates coastal developments, destroying estuarine environments, and forcing salinization of previously fertile agricultural lands. Rising shorelines impact the stability of dykes, sewage outfalls, and fundamentally alter the estuarine habitat in low-lying areas such as Delta and Richmond forcing many residents to abandon damaged houses, farms, and businesses. Water scarcity and saltwater intrusion (with its impact on groundwater and fertile land) cause break down in the ecology, commerce, and society of Metro Vancouver. Scarce resources are sequestered by a minority elite leading to poverty and social unrest among the majority. By 2100, GHG concentrations triple to 850ppmv lead to an average surface temperature 3.5 °C greater than 1990 temperatures while sea level rise indefinitely continues centuries into the future (IPCC SYR, 2007a,b).	The original $1.1 million spent on the 2010 Olympics hydrogen highway, built to link the Vancouver International Airport to Whistler, is raised to $4–5 billion. This federal and provincial commitment sends the necessary signal to the private sector, and kick starts exponential growth in investment for alternative energy. Government procurement policies and transport fleets (GVRD, 2006) (and an increase in the number of corporate fleets) secure a demand for alternative fuels and technologies, decreasing prices of alternative technologies, while also increasing the available number of fuelling stations. People willingly work fewer hours and spend more time in creative pursuits. New communication technologies and increased transport options reduce vehicle-hours traveled per capita, limiting large-scale infrastructure projects and their encroachment on agricultural and natural lands bordering urban areas. A carbon tax imposed on Metro Vancouver, targeting both commercial and household emissions, accelerates greenhouse gas reducing projects throughout the 21 communities in the region. Development permits are concentrated in areas where climate impacts are smallest; restrictions apply to climate and biodiversity-related sensitive areas. A carbon tax begins to internalize environmental costs into the pricing of goods (i.e., greenhouse gas emissions caused by transport of goods), considerably increasing the price of imported goods (that travel a long way), and creates incentives for consumers to buy goods locally. Due to a revitalized demand for local foods, the agricultural land reserve becomes viewed as a vital resource, contributing to jobs, agricultural products, and food security. New sources and different qualities of energy are matched with end-uses. Metro Vancouver modular and integrated energy framework supplies energy as a coordinated whole, capturing and reusing transformed energy such as steam and biomass to supply other end-uses. Energy planning at all scales from a collaborative energy team including all orders of government and BC Hydro and Terasen to community energy planning to fulfill energy requirements throughout the century (despite an expanding population). Efficiency improvements in residential and commercial design were augmented by changes in electricity supply at the regional level. Significant energy demand management combined with incentives for alternative energy technologies such as geothermal energy, biofuels, photovoltaic, wave, micro-wind, and hydro turbines rapidly reduces greenhouse gas emissions below 1990 levels. The energy producing Centre for Interactive Research and Sustainability (CIRS) building [www.cirs.ubc.ca/] becomes a prototype for neighborhood design and development. Buildings are not only designed to reduce water consumption and are linked into highly efficient transportation options, but buildings are able to generate their own energy supply (energy surpluses are sold to the BC Hydro grid providing energy conservation incentives). Buildings are utilized as energy producing sites using micro-wind turbines, and embedded solar photovoltaics. Bright roofing materials increase radiative reflectivity, while overall greening of the city including rooftop and community gardens improve radiative absorption, rainwater capture, and local food security (DCS, 2006). Community development focuses on ways to produce energy, food, green space, and other necessities to live within the ecological limits of the region. One in every two people has a job within 8 km, all new developments have 10 min access to transit, and telecommuting for work becomes common (DCS, 2006). By 2020, The conversion of valuable parking lot real estate into residential and commercial developments in Metro Vancouver municipal centres increase high density residential and commercial space while promoting car-free and walkable downtown cores throughout Metro Vancouver. Per capita vehicle kilometers, the main emission source at the turn of the century, declines as residents begin to work and live within more self-sufficient communities reducing the need to commute for work and services. Overall transport energy is reduced and per capita emissions per year decline from 7 t at the beginning of the century to 1 t by the end of the century. Water demand management programs slow per capita water use. The combination of increasing water storage (via Enchantment Lake in the Capilano watershed), increasing residential water efficiency (i.e., low-flush toilets), introducing demand management programs, and dividing residential and commercial/agricultural water supply generates a surplus volume of high quality drinking water. Pre-emptive efforts to minimize climate impacts and to curb the rate of greenhouse gas accumulation, decreases community vulnerability in the region. Accumulation of greenhouse gases slows, stabilizing concentrations at 450 ppmv (1.5 times 1990 levels) at the end of the century leading to less than a 2.0 °C increase in average surface temperature and slows the rate of sea level rise (IPCC, 2007a,b). Adaptations to these changes are made if and only if they do not contradict mitigation efforts.

substandard dike (2.9 m height). The area illustrates how sea level rise not only threatens manmade structures and assets but also impacts on critical mudflat habitat that is a crucial feeding ground for more than 230 bird species. Recent local data shows that the high marsh habitat is dependent on specific hydrologic regimes and exposure/submersion patterns, and given projected local sea level rise estimates and observed increases in storm surge events, this coastal habitat has been identified as vulnerable to climate change (Hill, 2006).

Beach Grove is a coastal neighborhood located on Boundary Bay and renowned for its ocean views. Many of the 3–4 bedroom houses lie at sea level and are protected by a sea wall (2.9 m height). In 2006, this protection was brought into question when a storm surge event crested the sea wall, resulting in 50 homes being flooded and millions worth of damage (Spencer, 2007). This confined event foreshadowed the significance of sea level rise impacts on current development patterns in this area where property and significant assets are located in vulnerable areas without adequate consideration of different forms of neighborhood resilience.

An exemplary set of data collected for the "Do Nothing" scenario at these iconic places in Delta is presented in Table 6.

3.3. Visualized local climate change scenarios

Table 7 gives an overview of the visuals created for the four iconic places in Delta. The first set of visuals illustrates the four scenarios separately at the four iconic locations (Section 3.3.1), providing an understanding of what each of the four scenarios look like in one location. However, when the scenarios become the focus, the effects of each scenario are illustrated linking the four iconic places (Section 3.3.2). The former, visual focus was used for different community engagement activities in the subsequent phase of the project (Shaw et al., in preparation).

Table 6
Data matrix for iconic locations under Scenario 1 "Do Nothing" (over time steps).

Scenario 1: "Do Nothing"	Current	2020	2050	2100
1. Tsawwassen	Area: 364 km^2 Population: 102,655 (2005), 89,400 (1991) Density: 282/km^2; 70% single family dwellings; 3 people/household Elevation: 0–10 m Agriculture: 50% protected Commuting residents: 85% car ~50 min	Population: 109,919 Early examples of development in the agricultural land reserve Highway expansion, poor public transportation, carbon-based import and export industries, and high-carbon agricultural practices	Population: 263,805 25% environmental refugees Development in the Agricultural Land Reserve increasing faster due to unplanned development from environmental refugees	Population: 457,262 75% environmental refugees Agricultural Land Reserved completely lost to planned and unplanned development
2a. Roberts Bank	Dike height: 3.48 m Freeboard: 0.75 m PSE[a] = MSL + NHT + SS (+SLR) = 2.9 m	SLR: 0.13 m PSE = 3.03 m; no breach	SLR: 0.27 m PSE = 3.17 m; overtopping and pressure from storms	SLR: 0.58 m PSE = 3.48 m; breach (1 m) shapes into 300 m wide gap (verb. comm. Delta engineer)
2b. Brunswick Point	Westham Island substandard dike (2.9 m) Combination of normal high tide and storm surge would overtop dike (verb. comm. provincial scientist) Brunswick Point standard dike (3.5 m)	Early sea level rise results in a rising saline water table, which is diluted sufficiently through rainwater, irrigation, and pumping	Increasingly saline (spedifore) soils; salt wedge spreads further inland Abandonment of coastal farmlands	Farm fields infertile; saltwater intrusion Farm abandonment in Delta (due to population and salinity)
3. Reifel Refuge on Westham Island	Significant mudflat habitat Wintering grounds for over 230 species of migratory birds	Coastal squeeze begins to affect upper mudflats	Coastal squeeze occurs; certain high quality vegetation and biofilm nutrients are submerged (Hill, 2006)	Regular inundation; no stable wintering grounds for birds reduces bird numbers, increases intertidal disturbance, shifts species composition between mudflats and sandflats (Hill, 2006)
4. Beach Grove	Coastal community with valuable homes infrequently damaged due to storm events Non-standardized dike height: 3.48 m Freeboard: 0.75 m	Neighborhood trees, particularly hardy Willows, are able to withstand early sea level rise and storm surge impacts	Storm events will increase by approximately 25% (McBean and Henstra, 2003; Lambert and Fyfe, 2006) Saline-sensitive coniferous trees perish and are replaced with ornamental species following increased frequency and intensity of storm surge events	Insurers become sensitized to the risks; residents are either forced to pay 4–5 times on their insurance premiums or abandon their properties altogether late in the century (ABI, 2004) Insurance losses double due to growing populations and increasing assets at risk (ABI, 2004) River and coastal flooding increase by a factor of 14; intra-urban flooding costs by a factor of 20; costs of subsidence increase by 50% (ABI, 2004) Storm events increase by 60% (McBean and Henstra, 2003; Lambert and Fyfe, 2006) All ornamental trees must be replaced with saline-tolerant willows San Fransisco Bay: a 0.3 m SLR makes 100-year storm surge event a 10-year event (Miller, 2003)

[a] Perfect storm event (PSE) = Mean Sea Level (MSL), 0 m; Normal High Tide (NHT), 2 m; Storm Surge (SS), 0.9 m; Sea Level Rise (SLR), changes over time and under different development paths.

Table 7
Visuals created for the iconic places in Delta, indicated by theme, type, and time steps.

	Current	Scenarios 1–4
1. Tsawwassen	Elevation (map)	Land use (layered map) Land use 3D build-out and landscape model (Coastal LiDAR—aerial) Population (pie chart) Current; 2100
2. Roberts Bank (Brunswick Point)	Sub-standard versus standard dike protection map Photo/Lidar comparison (Roberts Bank)	2D maps of coastal morphology Sea level rise 3D landscape model (coastal LiDAR—specific) Current; 2100
3. Reiffel Refuge		Mudflat habitat Lidar (specific) Current; 2100
4a. Beach Grove (Neighborhood)	Storm surge photo Photo/Lidar comparison	Coastal neighborhood (3D landscape model—aerial) Current; 2100
4b. Beach Grove (Backyard)		Sea level rise; various themes (3D landscape model—southern/western view) Current; 2100

3.3.1. Visual focus: iconic location

The first set of visuals illustrates the four iconic places separately (focal point) under the four alternative climate change scenarios, focusing on different themes as indicated above. For lack of space, we present selected visuals indicating the spectrum spelled out in Table 7.

3.3.1.1. Land use planning in Tsawwassen. An aerial image of Tsawwassen establishes current land use patterns in the area such as sprawl, density, and green space (i.e., biodiversity) (Fig. 4). Much of the surrounding area is protected agricultural land (iconic and valued land in Metro Vancouver).

3.3.1.1.1. Do Nothing. Scenario 1 assumes that current patterns are extended into the future with 70% of Delta residents living in single-family dwellings (3 per household) in suburbs that foster car dependency and commute trends upwards of 82% of the working population. New residential developments (and/or planned golf course development) encroach upon a small fraction of the agricultural land reserve by 2020. By 2050, the global average surface temperature has risen over 2 °C and the frequency of storms has increased resulting in water scarcity and natural hazard impacts on more vulnerable nations. Migration dynamics accelerate, leading to environmental refugees who seek refuge along the Delta coastline, contributing to an additional 20–25% population increase in Delta by 2050, thereby surpassing current population projections. By 2100, both planned residential developments and unplanned settlements expand across all developable land areas including the agricultural land reserve (see Fig. 5a). The temperature increases to 3.75 °C and the combination of increased storm surge, 0.58 m sea level rise, and increased development in the area exacerbates estimated damage and losses due to flooding (see Fig. 5b).

3.3.1.1.2. Adapt to Risk. Scenario 2 has the same set of drivers as scenario 1 but planners begin to anticipate an influx of environmental refugees by 2050. This anticipation increases adaptive capacity of the government, minimizing the encroachment of unplanned settlements in vulnerable coastal areas. While the agricultural land reserve is still built over in the corresponding visual imagery, managed retreat and setbacks from the coastline are implemented later in the century.

3.3.1.1.3. Efficient Development. In scenario 3, emphasis is placed on ‘smarter’, denser development, walkable communities with commercial amenities, and access to alternative transport. Mixed residential and commercial density is visualized showing that of most of the agricultural land reserve is protected. Efficient development slows (but does not reduce) emissions, temperature increases and ultimately sea level rises to 0.49 m by the end of the century.

3.3.1.1.4. Deep Sustainability. Scenario 4 assumes significant social change occurs early in the century. A carbon tax results in energy conservation measures and fuel switching initiatives. A slowly increasing population is housed in dense, complete (commercial, residential, and efficient public transport), walkable communities, allowing for combined heat and power initiatives and alternative energy systems, e.g., wind, solar (Fig. 6). Local food and energy

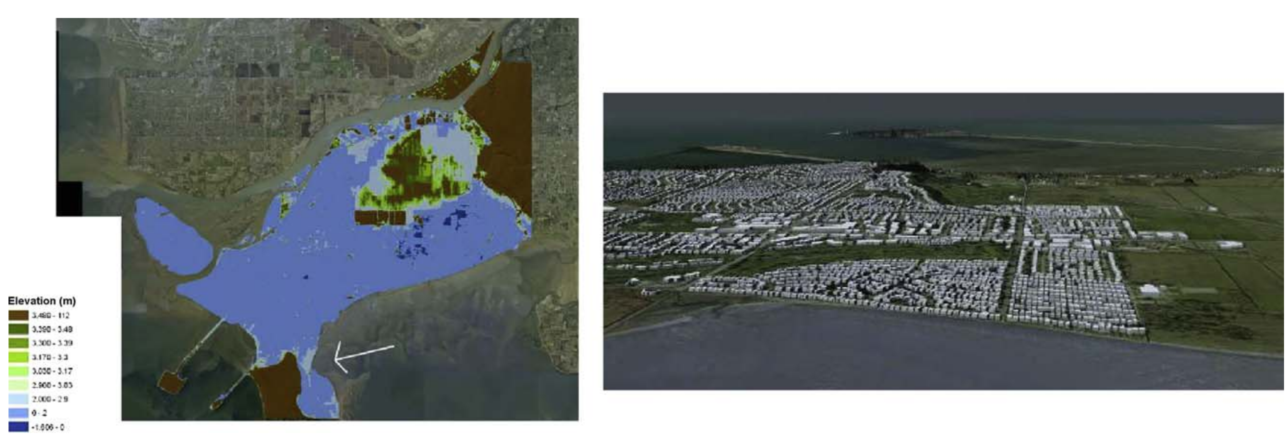

Fig. 4. Current topography shows majority of Delta (in dominant light blue) lying 0–2 m in elevation above sea level (left, arrow showing viewpoint for image on right), and current build-out (right) in Tsawwassen and surrounding agricultural area (Credit: David Flanders, CALP/DCS, UBC).

(a)

(b)

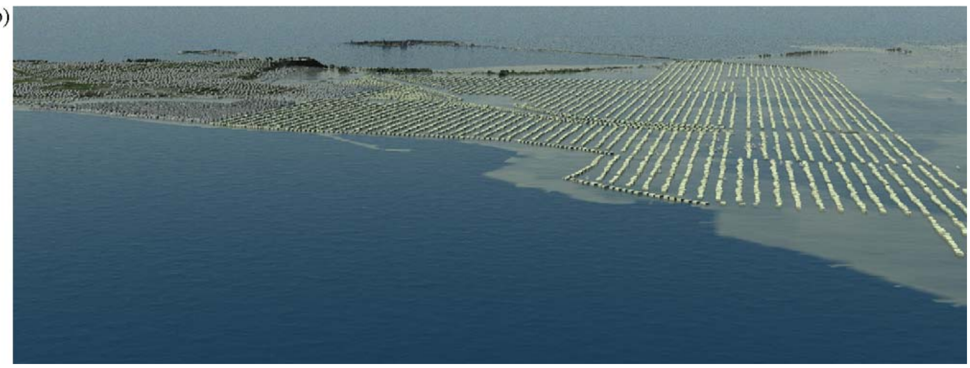

Fig. 5. (a) Tsawwassen and surrounding area under scenario 1 ''Do Nothing'' by 2100. Current (white), planned (yellow), and unplanned (beige, top right) development of residential buildings (Credit: David Flanders, CALP/DCS, UBC). (b) Tsawwassen and surrounding area under scenario 1 ''Do Nothing'' by 2100. Increased development in vulnerable areas increases cost of flood events. (Credit: David Flanders, CALP/DCS, UBC). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

production (biomass crops) on agricultural lands are maintained. Decreased emissions keep temperatures below the dangerous threshold of 2 °C and sea level rise is slowed to 0.4 m by the end of the century.

3.3.1.2. Sea level rise on Roberts Bank dike. Roberts Bank protects significant agricultural land and provides adequate protection for the perfect storm under current conditions (normal high tide + storm surge) (Fig. 7a). However with the addition of sea level rise projections in 2100, scenario 1 would overtop and likely breach the current dike damaging residences and crops, increasing salination of productive agricultural soils (Fig. 7b). The likely adaptation strategy in scenario 2 would be to raise the dike to account for normal high tide, storm surge, sea level rise, and raising the current 0.75 m freeboard (projected clearance) for additional security (Fig. 7c).

3.3.1.3. Coastal squeeze on mudflat habitat of Reiffel Refuge/Westham Island. Exposure and submersion patterns on the Reiffel Refuge mudflats determine the extent of high quality vegetation and biofilms that are nutrient rich sources for 230 species of migrating birds. In scenario 1, coastal squeeze occurs (Fig. 8a and b) with sea level rise and more frequent storm surge events. Regular inundation increases intertidal disturbance, shifts species composition between mudflats and sandflats (reducing stable habitat and wintering grounds for birds).

3.3.1.4. Sea level rise in Beach Grove neighborhood. Despite the significant property and landscape damage caused in the 2006 storm surge event (Fig. 9a), residents of Beach Grove are strongly attached to their oceanfront properties and have opposed municipal attempts to raise the sea wall for greater protection. For them, there is a trade-off between protection and the ocean views associated with their desirable real estate and life-style (Fig. 9b). No systematic adaptations have been made in the neighborhood so far to protect existing assets from future storm surge events with sea level rise.

Fig. 6. Tsawwassen and surrounding area under ''Deep Sustainability'' scenario 4 by 2100. Complete, walkable communities with combined heat and power systems fuelled by alternative energy sources (e.g., a biogas facility, biomass crops), increase density, mixed-use, and local jobs resulting in less commuting (Credit: David Flanders, CALP/DCS, UBC).

Fig. 7. (a–c) (From left to right). (a) Current mean sea level illustrates the dike with extensive mudflats on left side, with trees and protected agricultural land on right side; (b) in scenario 1, by 2100 the dike is breached and agricultural lands are flooded; (c) in scenario 2 (adaptation), by 2100 the dike is raised (Credit: David Flanders, CALP/DCS, UBC; all sea level and LiDAR data provided by Natural Resources Canada).

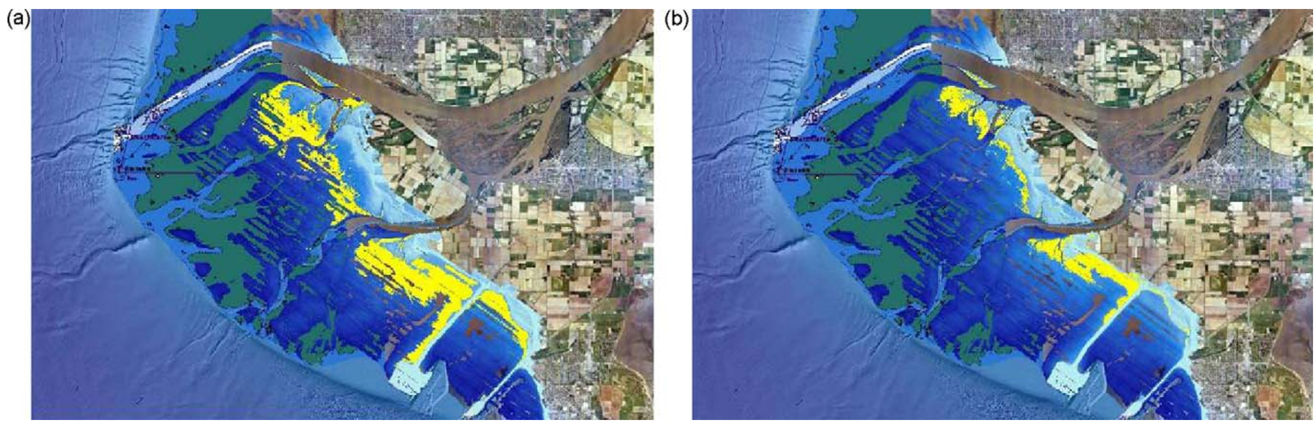

Fig. 8. (a and b) (From left to right). (a) 2D maps of coastal morphology with current mean sea levels; (b) by 2100, mean sea level in scenario 1 is 0.58 m higher, resulting in a squeezed intertidal zone (yellow) (Credit: Hill, 2006; David Flanders, CALP/DCS, UBC). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Fig. 10(a–d) depicts the four alternative climate scenarios in the Beach Grove neighborhood by 2100. Scenario 1 assumes frequent storm surge events and flooding. By 2100, some coastal homes are abandoned due to insurance agencies withdrawing from homeowners with assets located in highly vulnerable areas. The visual imagery for scenario 2 shows an alternative adaptation strategy to raising the dikes. The berm acts to protect against increased flooding while providing public green space, and prompting a managed retreat of development away from the coastline. The visual for scenario 3 illustrates the incremental retrofit of individual homes that is not complete until late in the century, resulting in the integration of alternative energy and development such as photovoltaic panels to offset household energy requirements and stilts to minimize flood damage. The visual for scenario 4 depicts a different urban design retrofit by 2100 where multiple forms of alternative energies are brought in much earlier in the century and resilience is built into the community design. Neighborhoods cluster with local food and energy production systems to share heat and power and derive additional heat and electricity from micro-wind turbines and solar photovoltaic

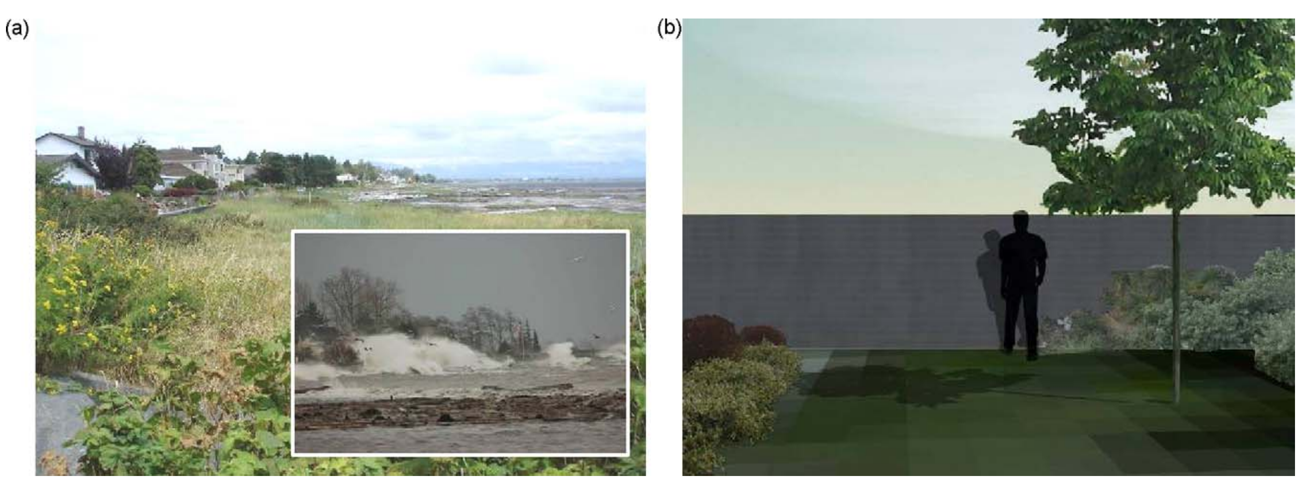

Fig. 9. (a and b) (From left to right). (a) Current conditions on Beach Grove coastline (insert of 2006 storm surge event) (Credit: Corporation of Delta); (b) scenario 2 illustrates the visual influence of the raised sea wall on ocean front property (backyard, view West) (Credit: David Flanders, CALP/DCS, UBC).

Fig. 10. (a–d) (From top left to right, to bottom left to right). (a) Scenario 1 illustrates more frequent flooding and abandonment of houses in Beach Grove neighbourhood; (b) scenario 2 shows a berm as an adaptation strategy; (c) scenario 3 includes incremental retrofits of stilts and solar panels; (d) scenario 4 depicts a new urban design with low-carbon, energy and food producing clusters with integrated resilience to projected impacts. (Credit: David Flanders, CALP/DCS, UBC).

paneling. Housing materials, orientation, and vegetation are used to maximize passive lighting, heating and cooling throughout the year. Amphibious residential design (raft clusters) increases resilience in the face of continued sea level rise. As in scenario 2, both scenarios 3 and 4 require a raised sea wall as an adaptation to projected sea level rise (which continues beyond 2100), however these expenditures are delayed in scenarios 3 and 4.

3.3.2. Visual focus: scenario

The set of visuals presented in Section 3.3.1 illustrated the four scenarios separately at the four iconic locations. The subsequent section focuses on the scenarios and the visuals provide a more comprehensive capture of each scenario by combining views from the four iconic places.

For instance, the compiled visuals for scenario 4 illustrate how mixed land-use, changes in urban patterns, and creative design can reduce vulnerability to climate change impacts (Fig. 11). This scenario also emphasizes issues of energy and food security as a way of contributing to community resilience to overall climate change impacts.

4. Discussion

We critically reflect on the strengths and weaknesses of the presented scenario study against the three challenges outlined in Section 1.

4.1. From global to local

While there is far reaching support for downscaling climate impacts from global to regional and local, few attempts have been made to downscale comprehensive scenarios to the local (neighborhood) level (cf. Biggs et al., 2007; Fowler et al., 2007). Part of the difficulty relates to the fact that climate change downscaling usually does not include downscaling of social, economic, political, and other aspects. This would enable a more comprehensive exploration of the social vulnerabilities as well as action and behavioral change at the local scale.

The presented study is an attempt to piece together diverse and often disparate forms of data at both the regional and local scales to construct credible and relevant local future Pictures—scenarios that are defensible and matter to local stakeholders (cf. Cash et al., 2003). In the process of doing so, three areas of challenges were recognized that deserve discussion, namely new data on emissions and impacts; effects of adaptation and mitigation; and compatibility with other studies and frameworks.

The first challenge is to balance the time- and cost-intensive procedures of a participatory multi-scale scenario study with the rapidly evolving research on emissions and climate change impacts. During the final project stages and the writing of the present article, various new data and insights, for instance, on sea level rise and on emission trajectories, have been published that would be relevant for the synthesizing and the downscaling

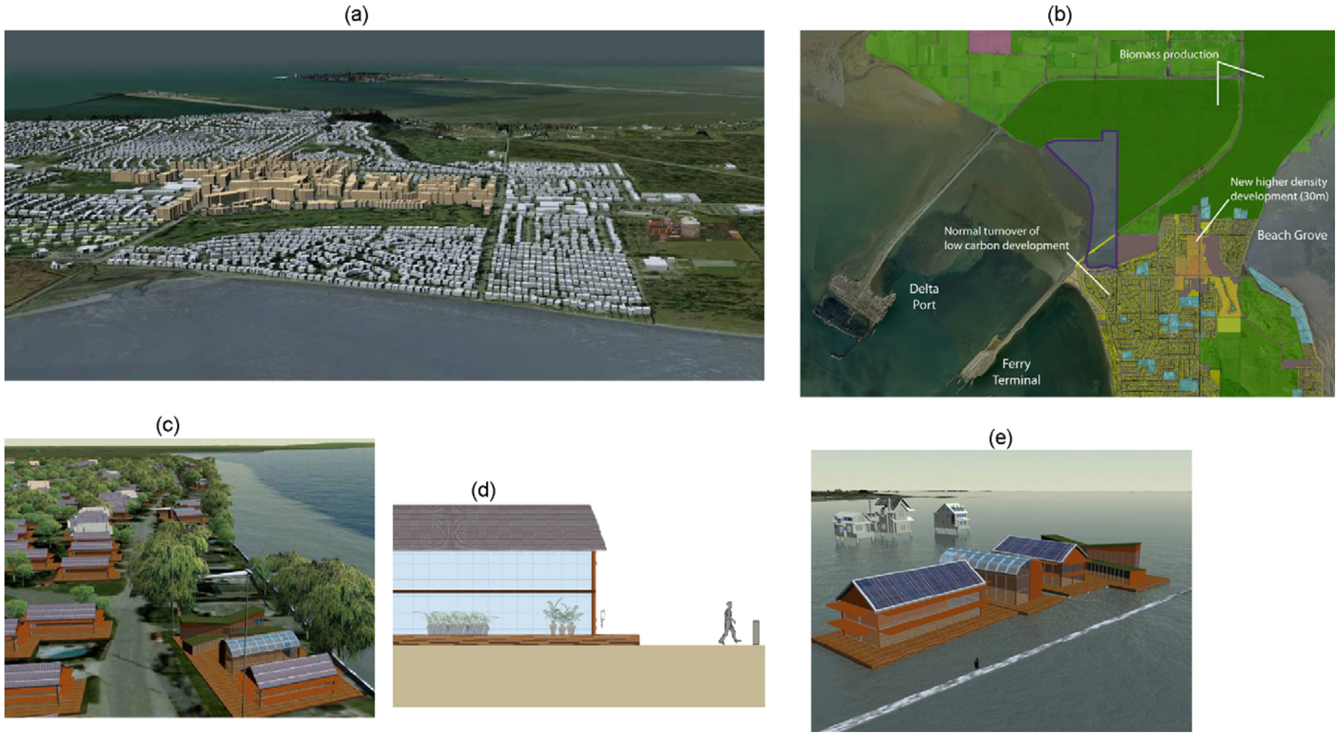

Fig. 11. (a–e) (Clockwise from top left). Scenario 4 visuals for 2100 include: (a) urban containment via complete, integrated communities protects agricultural land for food and energy production (on right: closed loop bioenergy system for residential and agricultural), (b) strategic high density development and mixed use, low carbon development occur (purple in centre: Tswassessen First Nation territory), (c) neighborhood form changes to include alternative energy clusters (wind and solar) and adaptations (raised sea wall) for increased resilience, (d) residential design uses orientation, shading, passive heating and cooling systems to conserve energy, and (e) projected sea level rise slows however residential designs build-in adaptive resilience (stilts, raft underlay) (Credit: David Flanders, CALP/DCS, UBC). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

module of our scenario study (a.o., Vafeidis et al., 2008; Pielke et al., 2008). At the local scale, the Corporation of Delta released a long anticipated dike breach analysis (Spencer, 2007). These contributions draw attention to a continuous revision of the underlying sets of data for further applications.

The second challenge is to accurately deal with adaptation and mitigation strategies in the scenarios. This is partly due to scale effects of the different response strategies and partly due to the underlying assumptions made in the SRES scenarios. On the one hand, adaptation is widely considered a local response and therefore little information exists on the ways adaptation can affect, positively or negatively, global emissions and thus global climate change. Yet, one could argue that adaptation strategies could have adverse side effects (additional emissions). More research is needed to specify these effects. On the other hand, mitigation is viewed as a global response to climate change. However, mitigation strategies vary considerably between different regions of the world (IPCC, 2007b). There are no models available that spatially specify mitigation strategies and their contribution to global reductions. An additional challenge was posed by the fact that the SRES scenarios do not incorporate explicit mitigation policies (Pielke et al., 2008). Finally, a coherence or 'robustness' analysis between national, regional, and local responses could enhance the overall credibility of this multi-scale type of scenario study (cf. Wiek et al., 2006).

The third challenge is the compatibility with other scenario studies and data frameworks. A complementary study could compare our results with sophisticated regional emissions modeling that bridges socio-economic factors, emission trajectories, and the influence of climate policy to interrogate, approve, and specify our findings (e.g., quantified uncertainty ranges). Moreover, recent quantitative downscaling studies (e.g., van Vuuren et al., 2007) could be used to specify certain aspects of our study. Finally, the design of the study is compatible with the DPSIR and similar frameworks in that it synthesized key *drivers* of climate change, additional *pressures* on the environment, current *state* of the environment, projected *impacts*, and the societal *responses* (OECD, 2004). This compatibility allows for integrating DPSIR data sources, to apply the approach to a broad variety of regions worldwide, and to collaborate with scenario work at national and local scales (Helweg-Larsen and Bull, 2007).

4.2. From enhanced understanding to effective involvement

Literature on behavior change with regard to issues of climate change call for a more comprehensive and emotionally engaging science communication (Moser and Dilling, 2007). While systemic perspectives are important to increase cognitive understanding of climate change, visual imagery elicits affective responses (Nicholson-Cole, 2005). We used two main science communication techniques, narratives and visuals, to make the climate change scenarios accessible to decision-makers and public audiences. The regional narratives create distinct but holistic future 'images'. The narrative format was chosen to explicate key trends and interactions while the benefit of using *local* narratives is that they create the space for people to imagine how the dynamics would transpire in their local area. The narratives could have been further elaborated in this project by moving beyond the science narrative into stories or other creative possibilities. The 2D and 3D visuals generated more specific images for identified iconic places, communicating a large amount of information without fully guided direction to key drivers and assumptions. The project followed ethical guidelines for using emotionally charged imagery (Sheppard, 2005b) that suggest that key descriptions of the substantive information should accompany imagery, enabling the viewer to triangulate and judge the validity of the imagery. Yet, the

representation of uncertainty in this type of scenario development is an incommensurable task given the multiplicity of possible futures, discontinuity, and surprise (Robinson, 2003). The specific *effects* of imagery versus narrative were teased out in a separate study (Shaw et al., in preparation).

4.3. Participatory approach

The form of participation in this research contributes to emerging models for participatory scenario development and capacity building, moving beyond the unidirectional or transmissive model of science communication (e.g., Wiek et al., 2006; Patel et al., 2007). Including participants from different stakeholder groups in the scenario development expanded the information that was included at the local scale (integrating local expertise) but also made the future-oriented information more relevant (futures that matter) (Cash et al., 2003). The co-production of knowledge embedded scientific perspectives within local meaning contexts, creating useful information to both researchers and participants (Wiek, under review). Three challenges deserve further exploration, namely the ethics of using visual imagery in a way that is both defensible and dramatic; the need to include all key stakeholders in the participatory process; and ways to link the research outcomes to municipal and other decision-making.

The ethics of using visual communications was recently raised in a lawsuit threat against Greenpeace (Méndez, 2008). Greenpeace was using computer simulation to illustrate potential impacts of sea level rise on communities in Spain (Saramago et al., 2007, pp. 58–79), which were allegedly not based in science, but rooted in scare-mongering, and therefore might reduce real estate values. This issue was also discussed in the case of the Delta case study and the Beach Grove simulations in particular. Anticipating similar reactions led to the applied participatory scenario design, namely to involve stakeholders as much as possible, and to generate alternative climate futures in order to avoid the messaging that the most dire future is the most likely.

Identifying key stakeholders and ensuring their representation and participation in such research is fundamental. The Tsawwassen First Nation was a key stakeholder group that was – despite considerable efforts – *not* involved in the project. For this reason, their territory was not included in the final product of this research. However, understanding that there is a need to become innovative in ways of engaging First Nations (cf. McDaniels and Trousdale, 2005), in future, we hope to use imagery as an innovative tool for this type of cross-cultural engagement (as demonstrated by Lewis and Sheppard, 2006).

The value of the participatory process to municipal decision-makers could be increased with the inclusion of economic experts to perform analyses (direct and indirect) costs and benefits associated with, for instance, raising a dike versus building a berm, or providing appropriate public transit versus expanding highways. These economic analyses are not trivial. For instance, what is the estimated benefit of more integrated and complete communities? How does one account for the time and carbon savings associated with reduced emissions, or with the local economic and community benefits associated with buying food locally? Scale dimensions and time horizons become critical in these estimations, requiring new, more holistic econometric concepts that account for intangibles (e.g., the Genuine Progress Indicator).

5. Conclusions

Recent studies have paved a way to anchor climate change action in regional and local contexts. The scenario study presented here was a collaborative effort by the University of British Columbia, communities within Metro Vancouver, and numerous agencies and organisations, utilizing participatory methods of capacity building for climate change. Emphasis was placed on closing the gaps between global climate change on the one hand and local impacts and action on the other, by integrating global climate science, different scales of governance, local planning, and public engagement. A key component was to visualize climate change scenarios and response options at iconic places, offering a new way of enhancing relevance to decision-makers and community interests. This study illustrates that addressing climate change in a participatory way, with credible but easily accessible visuals, and at a scale that matters to people, may be critical in building capacity for climate change action. The effects of visualizations on increasing understanding, emotional engagement, and motivating behavior change have been tested with community members in a separate study (Shaw et al., in preparation).

Efforts to link participatory scenario building more directly with decision-making are underway. The World Bank is currently including this participatory capacity building approach in their Economics of Adaptation to Climate Change project, providing a chance to gain experience in applications at the national scale in several developing countries. This resonates with the link to the DPSIR framework of the OECD. There is an opportunity to pursue a comprehensive vulnerability assessment, building from the approach used here, in order to better understand how vulnerability is both perceived and managed locally and perhaps to strengthen the methodology in a critical area. Based on the developed and further assessed scenarios. It would be valuable to perform a backcasting analysis that would reveal possible barriers and pathways to the most desirable future for the community and would evaluate the appropriate scales of institutional actions.

Lastly, this research opens the door to further innovation by delving into the science–art interface, potentially involving artists in the creation of scenarios, visuals, and narratives on climate change. At this point in climate change communication, there is a need to explore all such avenues available to address climate change in a credible and compelling way—to overcome the dominant behavior and politics 'as usual'.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2009.04.002.

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