LifeCycle Assessment of a Land Management

The PlaNYC Afforestation Initiative in the Kissena Corridor Park, New York

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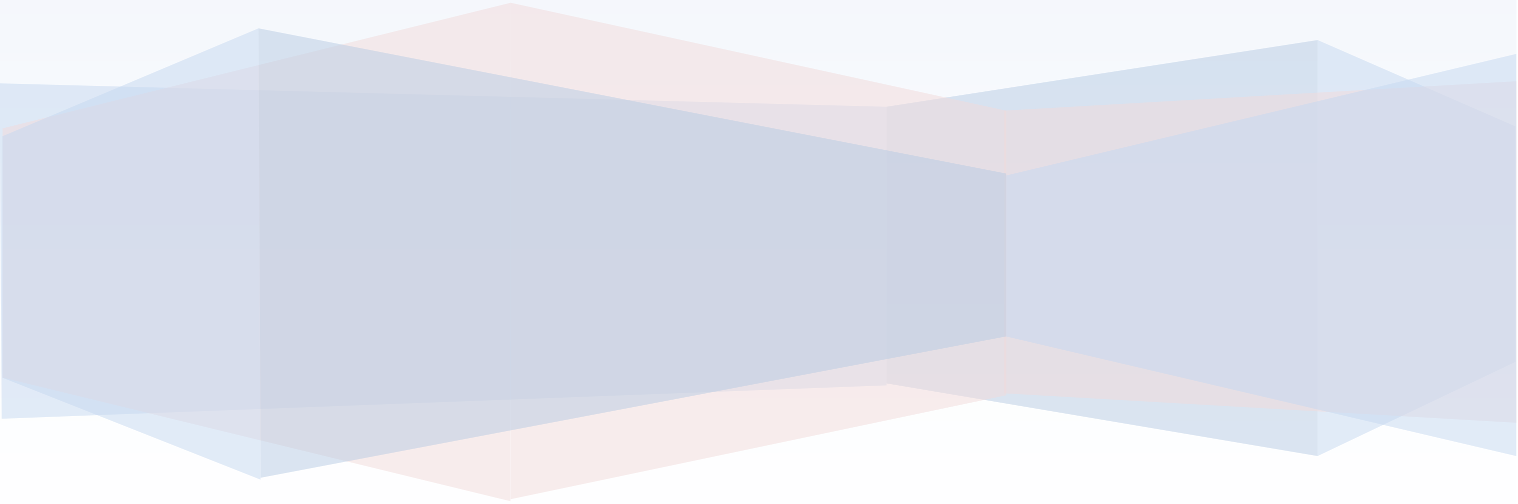

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Acronyms, Abbreviations and Glossary

B&B	Trees or shrubs to be “balled and burlapped”
B.R	Trees or shrubs to be delivered “bare root”
Cal.	The caliper of the trunk of the tree
CH_4	Methane, the major constituent of natural gas and biogas, a potent greenhouse gas
C-eq	Carbon equivalent, used in climate science to measure total impacts; one unit of C-eq corresponding to 3.67 unit CO_2-eq
CO	Carbon monoxide
CO_2	Carbon dioxide, the major greenhouse gas that causes climate change.
CO_2-eq	Carbon dioxide equivalent, used in climate science to measure total impacts of all greenhouse gases relative to the most common, Carbon dioxide. For example, methane (CH_4) has a radiative forcing (over a 100 year time scale) that is 21 times that of CO_2, which is expressed as a greenhouse warming potential of 21, so 1g of CH_4 has a CO_2-e value of 21g
DBH	Diameter at Breast Height, a standard method of expressing the diameter of the trunk or bole of a standing tree
Gal	Size of container in nursery gallons
GHG	Greenhouse gas, a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range
GJ	Giga-Joule (10^9 J)
GWP	Global Warming Potential, a relative measure of how much heat a greenhouse gas traps in the atmosphere. A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years.
HHV	High Heating Value
Ht.	Overall height of tree
J	Joule, unit of energy (International System of Units)
kW	Kilo-Watt (10^3 watt)
kWh	Kilo-Watt-Hour, equivalent to 3.6 MJ
L	Liter
LCA	Life Cycle Assessment, or Life Cycle Analysis
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LHV	Low Heating Value
MJ	Mega-Joule (10^6 Joule)
N_2O	Nitrous oxide
NO_x	A generic term for the mono-nitrogen oxides NO and NO_2
PM10	Larger particulate matters (greater than 10 micrometers in diameter)
sf	Square foot, 0.0929 square meter
t	Metric ton (1000 kg, 1 Mg, or 10^6 g)
tkm	Or t.km – ton kilometer. Used in transport to indicate the movement of one metric ton of freight one kilometer
VOC	Volatile Organic Compounds, the organic chemicals that have a high vapor pressure at ordinary, room-temperature conditions

1 Background and Goals

1.1 Background

Urbanization and environmental deterioration are inextricably linked as two of the most important challenges facing the world today (Hoornweg, Sugar, & Gomez, 2011). Coupled with land use change and urban ecological transitions, urbanization has precipitated a host of environmental problems such as air pollution, water environmental deterioration and climate change. To address these issues, Urban Ecology has a pivotal role to play in finding solutions and navigating a sustainable urban future (Seto & Sanchez-Rodriguez, 2010). A variety of land management projects like urban afforestation programs have been launched in big cities to mitigate negative environmental impacts (Baker, 2008). The New York City (NYC), as the biggest metropolis in US, is actively exploring such solutions (Owen, 2004). For example, the PlaNYC Afforestation Initiative[1], under the MillionTreesNYC program[2], pledged in 2007 to plant more than 370,000 trees in parklands and other public spaces (2021 acres in total over five boroughs) in NYC by 2030. It aims to "enhance water and air quality, mitigate climate change, and increase open space" (Krasny & Tidball, 2009).

Underlying the practice, there is an urgent need to evaluate its environmental merits and the fulfillments of the proposed objectives (Grimm, Faeth, & Golubiewski, 2008). Among current approaches to quantify the impacts, two major ones are often employed: 1) biophysical and ecological studies focusing on ecological dynamics and certain categories of environmental impacts (often for non-urban reforestation programs, e.g. (Lackner, 2003)); and 2) cost-benefit analyses that consider projects' economic meanings (BBOP, 2009; Birch, Newton, & Aquino, 2010). The former fails to consider the role of human induced activities in an urban ecological context; the latter doesn't elaborate the biophysical effects on air, water and soil environment specifically. Furthermore, both of them tend to neglect the full ecological footprints and carbon footprints along the projects' life cycle. Neglecting raw materials and energy used off the site for constructing and maintaining the land management project can rule out more than half of the entire impacts (Baumann & Tillman, 2010a).

In justifying the environmental meaning of such an influential afforestation project, the initiator, NYC's government, and other stakeholders are interested in introducing the Life Cycle Assessment (LCA) analytical tool to evaluate the environmental impacts of altering land use and cover. The LCA method has its unique merits here: the study will lend the life cycle perspective to examine the functional urban forests through adaptive ecological management. By encompassing the off-site resource extraction, transportation, agricultural, manufacturing and end-of-life processes, the environmental impacts can be quantified more precisely; By calculating GHG impacts and energy use as primary metrics and considering water use and criteria air pollutants, the LCA results can lend

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1. For more information about PlaNYC 2030 program, see: http://www.nyc.gov/html/planyc2030/
2. For more information about MillionTreesNYC program, see: http://www.milliontreesnyc.org/

people multiple angles of understanding (Baumann & Tillman, 2010b). As a result, policy decisions can be better substantiated with more information.

1.2 Goals

The Department of Park and Recreation of the City of New York, the administrative branch responsible for the coordination and supervision of the whole PlaNYC initiative, seeks to quantify the environmental advantages associated with the project. This information will be used to strengthen the profile of the project when communicating with the public and the stakeholders.

The commissioner of the study is the Department of Park and Recreation of the City of New York. The study will be conducted by Chen Qian, Master candidate from Yale School of Forestry and Environmental Studies, under the supervision of Professor Alexander Felson. Interested parties include Yale's Hixon Center of Urbanization, Yale students and faculties, project's subcontractors and relevant regulators. Before the LCA results are used for any external purposes, this study needs to be reviewed by a steering committee with representatives from the commissioner and the academia.

The primary goals of the LCA study are to 1) understand the material and energy consumption of the project from a life-cycle perspective, and 2) evaluate the life cycle environmental balance of the urban land management project and the corresponding payback periods. The secondary goals are to 1) compare the environmental impacts of different plantation layouts from the LCA lens, and 2) calculate the explicit and implicit economic costs and benefits of the project.

The LCA study at this stage will be focused on one project under the PlaNYC Reforestation Initiative: Kissena Corridor Park.

2 Scope and Methodology

2.1 System boundary

The study chooses the system boundary as the Kissena Corridor Park itself (KCP, in the Borough of Queens, see Figure 1 below): it will calculate the energy and material flows going into and outside this piece of land. This area is bound by the asphalt path connecting New Hyde Park Road and Colden Street adjacent to the Community Garden (east boundary), the asphalt path connecting 56th and Colden Street adjacent to the synthetic turf field (west boundary), Colden Street (north boundary), and 56th Road (south boundary). The entire site is estimated to be 87,120 square yards. The grove areas, which are not to be seeded, are estimated at 20,874 square yards. The researches plots account for approximately 23,833 square yards, and are not to be seeded.

The Kissena Corridor Park is among the first three sites under research and construction of the PlaNYC initiative. It is a pilot site where a spectrum of urban ecological experiments have been conducted by Professor Alexander Felson, including site entity analysis, soil sampling, existing plant species recognition, invasive plant management and so on (Felson, Palmer, & Pouyet, 2009). For the site preparation and plantation, the contractor (including tree nurseries) will be working on construction the park from 2010 to 2012.

2.2 System Functions

LCA results are calculated relative to the fulfillment of proposed function, usually a product or a service. Most product systems are focused around a primary function while, along the way, contributing to other product systems or providing other utilities that can be seen as secondary functions (Grant, Beer, & Campbell, 2008).

The PlaNYC initiative claims its goal as to "enhance water and air quality, mitigate climate change, and increase open space" (Krasny & Tidball, 2009). Accordingly, the study here defines the following primary function of the Kissena Corridor Park Afforestation Project as "to provide open, afforested space in highly dense urban area, the Borough of Queens, NYC." In this sense, the study is actually providing information about how well, in environmental terms, the project will fulfill this function: provision of urban afforested space.

2.2.1 Functional Unit

The functional unit in LCA quantifies the system functions and defines the basis for comparison of systems alternatives. The functional unit should incorporate all the services provided by all the scenarios (Grant, et al., 2008). As this study is centered on the primary function of the KCP project, the functional unit (and of the alternative scenarios systems as described below) is the **provision of 1 square meter open, urban, afforested space.** To make the study's results have broader, if not universal, implications, the study will treat the entire KCP as homogeneous: all the materials, energy and environmental contributions will be equally distributed within the system boundary, no matter the grave area or research area.

2.3 Time horizon

The complete provision of the functional unit shall be understood as the open, afforested space is fully utilized. However, as long as the park is standing there, it will not cease to offer the function. As it is technically not realistic and practically not sound to cover the "eternality", it chooses time horizons corresponding to the common time horizons considered for climate change researches instead. First, the study defines the point of time when the construction of the park is completed and the commissioner approves the project as the time 0; Second, the study will take into consideration all production, plantation, transportation processes associated with the KCP project before time 0, outside the system boundary; Third, it will also evaluate all the construction processes before time 0, inside the system boundary (as shown in the contract, the duration of the construction is about 27 months); Finally, the study will project the environmental impacts after time 0 when the newly built KCP starts function. For the final step, 30-year, 50-year, 100-year time horizons will be selected, to roughly represent short-term, medium-term and long-term situations. Since there are super uncertainties for the extremely long condition (i.e. in 100 years; see further discussions below), the study will not attempt to predict longer-than-100-year situation.

2.4 Scenario simulation

In order to compare the environmental impacts of different plantation layouts, the study chooses three scenarios to simulate and evaluate: 1) the current mix of tree species, 2) low diversity coverage (LDC), and 3) high diversity coverage (HDC). The low and high diversity scenarios are considered “alternative layouts”, for that the study is more focused on the evaluation of the current plan. These scenarios will be further explained in the coming lines.

2.4.1 Current Plan

The current plan is represented by a certain mix of plantation and auxiliary infrastructures. Since the KCP project plays an important role of research site, multiple layouts have been applied simultaneously in different plots. Basically, two typical plot layouts are designed based on the preliminary research on the soil condition (including pH and moisture) and plant domination (including the invasive species investigation): 1) low diversity plots and 2) high diversity plots. Besides, among the 48 plots within the park, there are some other types of experimental plot so that more species will be introduced to the site. The following table illustrates the 12 types of trees totaling 5,151.

Table 2.1 Species mix of the current layout

Item	Species name	Common name	Abbreviation	Number
1	Carpinus Caroliniana	American Hornbeam	CC	127
2	Garya Species	Hickory	CS	487
3	Celtis Occidentalis	Hackberry	CO	365
4	Juniperus Virginiana	(Eastern) Red Cedar	JV	113
5	Ostrya Virginiana	Eastern Hophornbeam	OV	136
6	Prunus Serotina	Black Cherry	PS	360
7	Quercus Alba	White Oak	QA	459
8	Quercus Imbricaria	Shingle Oak	QI	118
9	Quercus Phellos	Willow Oak	QP	118
10	Quercus Rubra	Northern Red Oak	QR	1418
11	Tilia Americana	American Basswood	TA	1450

2.4.2 Low Diversity Plan

The major distinction between the current plan and the low diversity plan is the selection and numbers of species. The low diversity plan assumes that only two types of trees are planted on site, associated with designated shrubs and grasses, as shown in the drawing. The following table illustrates the 2 types of trees totaling 5,040.

Table 2.2 Species mix of the low diversity layout

Item	Species name	Common name	Abbreviation	Number
10	Quercus Rubra	Northern Red Oak	QR	2496
11	Tilia Americana	American Basswood	TA	2544

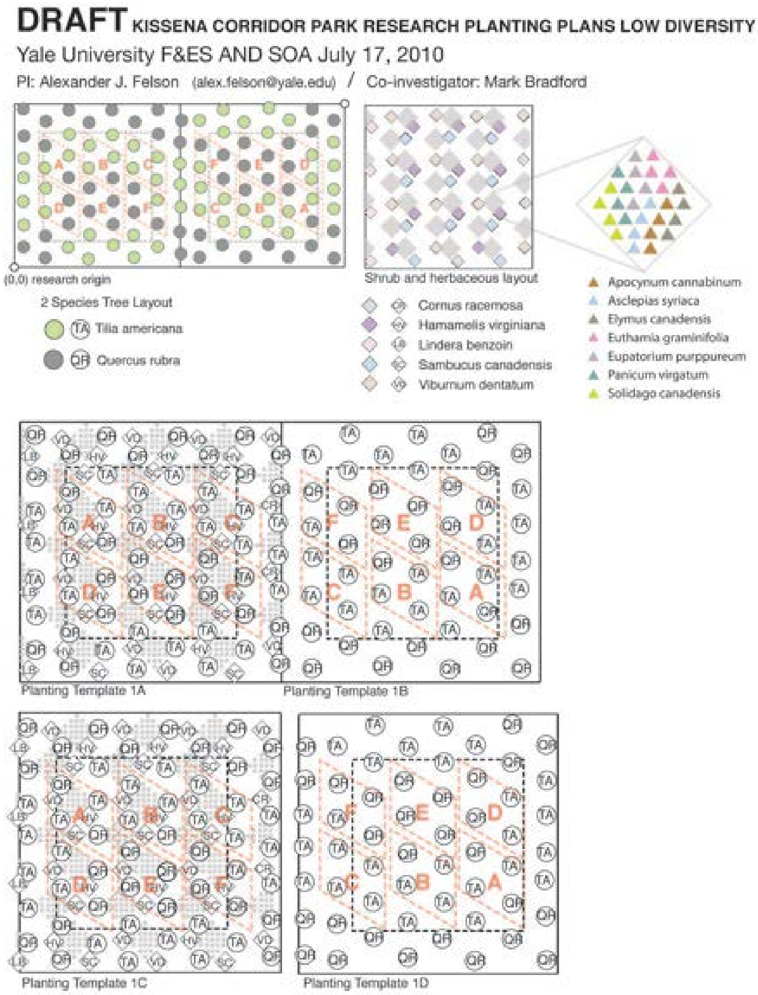

Figure 2.1 Kissena Corridor Park planting plan—low diversity (Felson, 2010)

2.4.3 High Diversity Plan

Similarly, the high diversity plan assumes that only six types of trees are planted on site, associated with designated shrubs and grasses. The following table illustrates the 6 types of trees totaling 5,040.

Table 2.3 Species mix of the high diversity layout

Item	Species name	Common name	Abbreviation	Number
2	Garya Species	Hickory	CS	960
3	Celtis Occidentalis	Hackberry	CO	864
6	Prunus Serotina	Black Cherry	PS	960
7	Quercus Alba	White Oak	QA	864
10	Quercus Rubra	Northern Red Oak	QR	768
11	Tilia Americana	American Basswood	TA	624

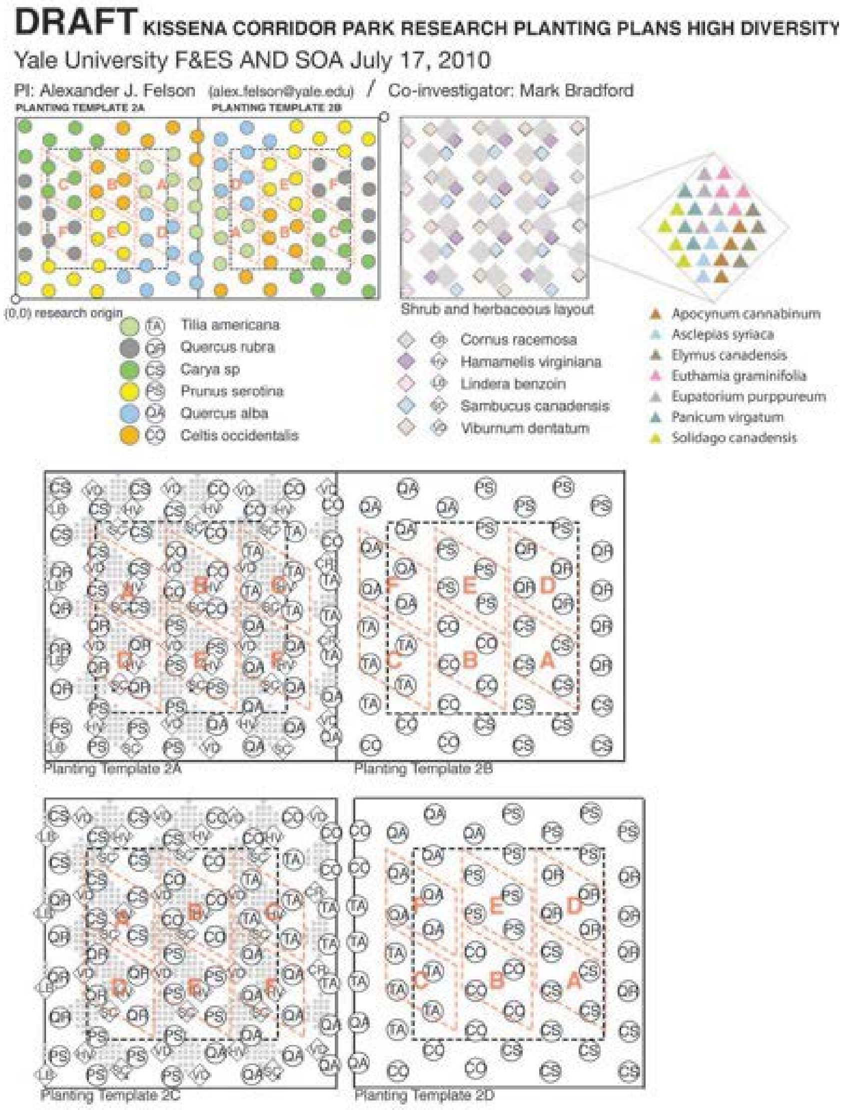

Figure 2.1 Kissena Corridor Park planting plan—high diversity (Felson, 2010)

2.5 Categories of Environmental Impacts

For all waste scenarios, the following environmental impact categories will be considered: (1) greenhouse gas (GHG) emissions, (2) energy consumptions, and (3) water intake.

Two models are introduced to derive the environmental impacts associated with the project. The first one is the EIO-LCA model developed by the Green Design Institute of Carnegie Mellon University (Green Design Institute, 2008):

1. Considering that the entire PlaNYC initiative requires huge fiscal investments and therefore influences economic activities significantly, the LCA will adopt a hybrid EIO-LCA (Environmental Input Output—Life Cycle Assessment) method to evaluate all the materials and energy used to construct the KCP project. The study uses the 2002 Producer Price Database because the value on the contract is engineer's estimate and doesn't include the profit spread between the sellers and buyers. The study procedures will be in compliance with ISO 1404X standards[3]. The impact assessment of these will be made as follows:
2. For analyzing GHG emissions, the IPCC Global Warming Potential (GWP, 30, 50, and 100 years) method is used. It first specifies the GHG types (e.g. CO_2 fossil, CH_4, N_2O, etc.) and finally converts different GHG pollutants into Carbon Dioxide equivalent (CO_2-eq).
3. For assessing energy use, the model calculates the total energy consumption in Joule, and also points out the energy type (e.g. conventional fossil fuel, conventional renewable energy, etc).
4. For evaluating the environmental burden to the regional water use, the model focuses on the water withdrawal with the unit of m^3.
5. In addition, it also provides the data of land use footprint in m^2 for associated activities.

It should be noted that all of these are midpoint methods. The data of upfront materials and energy required to construct the KCP park are highly site-specific (see the section of Data Collection), but the model is generically applicable for the whole economy in the U.S. Therefore, the non-spatial-specific model will weaken the quality advantage of raw, site-specific data.

The second model is the iTrees model (version 4.0) developed by the United States Department of Agriculture and numerous cooperators (United States Department of Agriculture, 2010):

1. The study assumes the environmental advantages will be functioning upon the completion of the construction (i.e. time 0). After that, different species of trees will grow in certain patterns in an urban context and start to sequestrate GHG, avoid energy use, intercept the stormwater, absorb air pollutants, and create ecosystem benefits. The impact assessment of these will be made as follows:
2. For analyzing GHG emissions, the IPCC Global Warming Potential (GWP, 30, 50, and 100 years) method is used. Two mechanisms will lead to GHG mitigation: 1) the trees will sequester ("lock up") CO2 in their roots, trunks, stems and leaves while they grow, and in wood products after they are harvested; and 2) trees near buildings can reduce heating and air conditioning demands, thereby reducing emissions associated with power production. The GHG reduction from first mechanism is called "carbon sequestration" or "direct carbon mitigation"; the other called "carbon avoidance" or "indirect carbon mitigation". They have different magnitude of uncertainties. Summing up two types of CO_2 mitigation, an

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[3] A set of standards about Life Cycle Assessment methodology, from ISO 14040 to 14049, developed by the International Organization of Standardization.

overall number will be given, in the unit of CO_2eq as well. It should be noted that both carbon mitigation mechanisms cover GHG other than CO_2, like CH_4 and N_2O; the detailed breakdown is embedded in the model and invisible to the outside users though.

3. For assessing energy savings, the model assumes the following mechanism for the urban forest to reduce energy use: shading reduces the amount of heat absorbed and stored by buildings; evaporation converts liquid water to water vapor and cools the air by using solar energy that would otherwise result in heating of the air; tree canopies slow down winds thereby reducing the amount of heat lost from a home, especially where conductivity is high (e.g., glass windows).
4. For evaluating the environmental burden to the regional water use, the model makes the following assumptions. Trees act as mini-reservoirs, controlling runoff at the source. Trees reduce runoff by 1) intercepting and holding rain on leaves, branches and bark 2) increasing infiltration and storage of rainwater through the tree's root system, and 3) reducing soil erosion by slowing rainfall before it strikes the soil.
5. The model also provides the information of the economic benefits from reducing certain air pollutants. It suggests trees will 1) absorb pollutants like ozone, nitrogen dioxide and sulfur dioxide through leaves, intercept particulate matter like dust, ash and smoke, 3) releasing oxygen through photosynthesis, 4) lowering air temperatures which reduces the production of ozone, and 5) reducing energy use and subsequent pollutant emissions from power plants.
6. Finally, the model integrates all the ecosystem benefits on annual basis by adding up the economic value, and delivers the yearly "overall benefit" in $/yr.

Unlike the EIO-LCA model, the iTrees model is a model mixing mid-point and end-point method: the GHG mitigation data and energy savings data are mid-point while the overall ecosystem benefit is end-point category for that it converts different types of environmental categories into one single measurement—US dollars based on the specific spatial context. The site-specific model integrates the spatial information (e.g. population density, background environmental information, etc.) according to the zip code. In addition, the iTrees model requires the specification of land setting of the trees such as open area, high/low-density residential area, or industrial area. This species-specific model is capable of outputting environmental impacts according to the DBH, Diameter at Breast Height, of the trees. By accumulating the annual environmental impacts over time, the model is able to run 30, 50, and 100-year simulation.

2.6 Cut-off Criteria and Data Requirements

As a general rule, the cut-off criteria are coverage of 99% for greenhouse gases, and coverage of 95% for all other categories. For the upfront construction process, the cut-off criteria are "coverage of at least 95% of mass and energy of the input and output flows, and 95% of their environmental relevance (according to expert judgment)" (European Commission, 2006).

Spatial and temporal data requirements will be based on typical data for all scenarios. If available, the study will prioritize spatial and temporal specific data over average data. For the upfront construction processes, the data are generally site specific.

2.7 Data Collection and Processing

For the “current plan” scenario, a mix of secondary data (from the two models and literature) and data provided by the client was used. For the high diversity and low diversity scenarios, more projected data were introduced to estimate the environmental impacts hypothetically.

The contract of park construction is among the most important, first-hand data source. It contains information of 1) what types of item will be purchased and used, 2) what kinds of work will be included in the commission, and 3) what the bidding values of them are. The following steps are taken to translate the raw data into LCIA information:

1. Identify each type of work and bridge it with relevant industries and sectors in the EIO-LCA model;
2. Enter the economic value of the work: For those items involving more than two sectors of activities, it will allocate the economic value accordingly. As a general rule, allocation will be based on the system expansion and mass distribution;
3. Record the input-output matrix containing all the intertwined sectors: As a general rule, the cut-off criteria are coverage of top 10 relevant sectors and attempting to reflect the overall interaction;
4. Record the intervention matrix containing environmental impacts of the interested categories: As a general rule, for the upfront construction process, the cut-off criteria are “coverage of at least 95% of mass and energy of the input and output flows, and 95% of their environmental relevance (according to expert judgment)” (European Commission, 2006).

To extrapolate the growth of trees, several silvicultural manuals are referred to (Burns & Honkala, 1990; Ministry of Natural Resources, 2000). Along the 100-year life time that is mostly interested, the DBH growth for every ten years is projected based on the original DBH (at time 0) and either the decade or annual growth rate. If the decade/annual growth rate is not available for a certain species, the study will alternatively use Linear Interpolation (LI method): to select typical DBH data of certain years and assume linear function to describe the DBH change in between. By inputting the information of applicable zip code, tree species, land use type and DBH, the model will output the environmental impacts of several categories of interest.

2.8 Limitation and Uncertainties

As a LCA analysis for a sporadic project, it has the inherent weakness: lack of first-hand data. So the analysis extensively relies on outside database and model to conduct retrospective calculation and prospective estimation. The methodology determines the limitations underlying the LCA results:

1. The EIO-LCA model is a mid-point one with the emphases on interested environmental impacts while the iTrees is an end-point oriented model that translates most of the indicators into monetary results. This makes the data from two sources often incompatible, which limits the abundance of information that they can deliver when combined. For example, the EIO-LCA model specifies the GHG category and primary energy source that iTrees doesn't.
2. For the upfront construction phase, the study assumes the same environmental output for three scenarios. But the fact can be slightly different because of the difference in selecting tree species. The different tree mix can cause different energy input, GHG emissions as well as water intake.
3. Lacking credible information, the study assumes no significant material input in the maintenance phase of the project. But in reality, the maintenance may require the replacement and disposal of dated items as well as dead trees, which can further lead to negative environmental impacts.
4. The study assumes that the environmental credits brought by the shrubs and grasses are minor compared to the trees' contribution. A more practical study should seek the opportunity to integrate the missing part.
5. As a typical LCA study, the analysis does not take into consideration the interaction between items. For example, it does not consider the biological influences between trees in terms of growing pattern and environmental impact contribution. Rather, it regards each item as separated one that can be transferred outside the context but still make the same amount of environmental impacts.
6. When discussing the broader effects for the entire PlaNYC project, the LCA study is no longer site-specified. Instead, it assumes similar surroundings and local environmental conditions for tree growth as the Kissena one. Considering the wide coverage of the project and the variety of the living conditions for 370,000 trees, this assumption should be modified in order to capture more practical situation.
7. Although the longest time horizon is set as long as 100 years, the LCA study does not consider any major disruption for the long existence of the project. Such events can be natural impacts like acid rain, storm and earthquake, or anthropogenic intervention like the close and major re-construction of the park.

According to the limitations discussed above, several potential areas of uncertainty should be noticed, prior to any further explanation of the result:

1. Tree growth pattern is subject to multifold of factors. The reference to silvicultural manuals can only provide the best guess of the average DBH information over time. The uncertainty underlies the estimation of future growing situation. Ongoing monitoring and adjustment of previous projections accordingly is recommended.
2. The discrepancy between real construction practice and designated one lays another uncertainty. As the LCA inventory is mainly derived from the project contract, the study is not capable to investigate the real fulfillment of the project. Some items can be removed while some others need to be added during the construction process.

3. When translating the life cycle inventory to mid-point and end-point results, uncertainties are raised behind the model. Both models provide the best guess results based on massive information collected from all around the country. When relying on the LCA results to guide policy change, the stakeholder should notice the uncertainty inherent in the model.
4. As the project's "life cycle" experiences a very long period, the outside condition can be dramatically changed. For example, the climate change effect, accumulated over 100 years, can influence the marginal environmental contribution of the project. The uncertainty will be enlarged naturally as time runs.

3 Life Cycle Inventory Analysis

3.1 Tree Plantation

3.1.1 Nursery-grown trees

The project purchases young trees directly from nurseries in Pennsylvania, New Jersey and New York. They are (1) Green Plant Center, Staten Island, NY, (2) Pineland's Nursery, Columbus, NJ, (3) Wild Earth, Freehold, NJ, and (4) Sylva Native, New Freedom, PA. The purchase price includes the seed, upfront water, energy input, packaging and transportation fee from the nursery to the project site. The following table shows the plant schedule in accordance with the current plan scenario.

Table 3.1 Plantation schedule of current plan

Item	**Species name**	**Common name**	**Number**
Trees			
1	Carpinus Caroliniana	American Hornbeam	127
2	Garya Species	Hickory	487
3	Celtis Occidentalis	Hackberry	365
4	Juniperus Virginiana	(Eastern) Red Cedar	113
5	Ostrya Virginiana	Eastern Hophornbeam	136
6	Prunus Serotina	Black Cherry	360
7	Quercus Alba	White Oak	459
8	Quercus Imbricaria	Shingle Oak	118
9	Quercus Phellos	Willow Oak	118
10	Quercus Rubra	Northern Red Oak	1418
11	Tilia Americana	American Basswood	1450
Shrubs			
12	Cornus Racemosa	Gray Dogwood	295
13	Hamamelis Virginiana	Common Witchhazel	251
14	Lindera Benzoin	Spicebush	79
15	Sambucus Canadensis	American Elder	272
16	Viburnum Dentatum	Arrowwood Viburnum	361
Grasses			
17	Apcynum Cannabinum	Indian Hemp	3830

18	Asclepias Syriaca	Common Milkweed	3830
19	Elymus Canadensis	Canadian Wild Rye	3830
20	Euthamia Graminifolia	Flat Top Goldentop	3830
21	Eupatorium Purpureum	Purple Joe-Pye Weed	3830
22	Panicum Virgatum	Switchgrass	3830
23	Solidago Canadensis	Canada Goldenrod	3830

Upon the arrival of the baby trees, the contractor will excavate all plant pits and beds and furnish, plant, maintain, water, and replace all plant material, specified in the plant schedule. The plant name, size, and grading standards conform to those prepared by the American National Standards Institute, ANSI Z60.1-2004 American Standards for Nursery Stock. All plants are typical of their species or variety: they will have normal, well-developed branches and vigorous fibrous root systems. All trees and shrubs will have been growing under similar climatic conditions as the project site two years prior to the date of plantation. All balled and burlapped plants will be dug immediately before moving. Container grown trees, shrubs and herbaceous plants will be rooted in the container size indicated on the Plant Schedule.

3.1.2 Mulch

Upon completion of planting, shredded hardwood mulch will be applied to a uniform depth of 2” over the entire planting area. The material will be a natural forest product composed of shredded wood not exceeding 2” in length and 1” in width, which is derived from tree material rather than wood waste or by-products like sawdust or shredded palettes.

3.1.3 Temporary Wooden Tree Guard with Tree Wrap

Temporary wooden tree guards with tree wrap will be erected. The material will be Yellow Pine, Douglas Fir or Spruce. The tree wrap will be snow fencing composed of commercially woven wood slats and wire, which will be carefully wrapped around the trunk of the tree, above the flare and secured with steel or aluminum tie wire.

3.1.4 Landscape Fabric

Landscape fabric will be furnished, placed and stapled on each designated planting bed. The material will be a 100% continuous monofilament polypropylene spun bond fabric with UV inhibitors. Staples will be a least 6” in length and made of a rust-resistant material, such as aluminum or galvanized steel.

3.2 Site Preparation

3.2.1 Construction Fence

An 8’-0’’ high chain link construction fence and gates will be furnished and installed. The materials include fabric (9 Ga., galvanized steel wire woven into 2 inch diamond mesh) line posts, terminal posts, braces and gates. Upon completion of the project, the fence will be removed and become the property of the Contractor.

3.2.2 Range Fence

A range fence 4’-0’’ height will be furnished and installed. The materials include fabric (4’ wide rolls of fuse bonded PVC powder-coated 2”*4” gauge galvanized wire mesh), line posts and tie wire.

3.2.3 Temporary Silt Fence

Temporary silt fence will be installed to prevent excess sediment from leaving the site. The materials include Mirafi Prefabricated Silt Fence with posts. The access sediment accumulations will be disposed after the project completion.

3.2.4 Construction Sign

During the site construction process, construction signs will be furnished, erected, and maintained. The sign will be a vinyl film four-color image photo transfer laminated on M.D.O board. It will be installed on the fence at the Park entrance.

3.2.5 Pre-cast Concrete Plot Marker

Pre-cast concrete plot markers will be furnished, placed, and located on site. The material will be pigmented pre-concrete, 4’-6”*8”*8” as follows: Portland cement, coloring admixture and normal-weight concrete mixtures. The markers will be installed at the center of each rectangular plot. Engraving will occur directly on the galvanized steel plate.

3.2.6 Vehicle (Hybrid SUV)

The vehicle is a compact or mid-sized full Hybrid Support Utility Vehicle, such as Ford “Escape Hybrid”, Mazda “Tribute Hybrid”. It will have an EPA gas mileage of 25-mpg city or better. It will be used for 27 months.

3.3 Compost

Compost will be furnished, spread and incorporated during the project. It will be a well decompose, stable, mature, weed free organic matter source that is the result of the accelerated, aerobic biodegradation and stabilization under controlled conditions. The project will source from WeCare Organics, LLC in the Burlington County Co-compost Facility in Columbus, NJ. The component is tested as below

Table 3.2 Major component and chemical indicators of compost

Item	**Value**	**Recommended Range**
pH	6.3	5.5-7.5
C:N ratio	12.6:1	10:1-25:1
Organic Matter % (dry mass basis)	60	45-55
Bulk Density (lbs/cuyd)	770	800-1000
Moisture Content (wet mass basis)	35	40-50

Soluble Salts (mmhos/cm)	3.87	<2
Nutrient % (dry mass basis)		
N	3.2	1-2.5
P	3.7	1-2
Na	0.44	-
C	1.67	-
Mg	0.36	-

The soil amendment should not be spread across an entire area, but should be used to fill planting holes. The compost will be thoroughly incorporated into existing soil backfill at a rate of 2” per planting hole within the areas.

3.4 Invasive Management

3.4.1 Mow and Spray Phragmites and Mugwort

The contractor will mow and then apply a foliar herbicide to all plants within the areas designated on the plans and repeat as necessary, in order to remove and control the growth of invasive plant. Mechanical removal and weed control herbicide application will be combined to achieve the task. All cut material will be bagged and disposed in a landfill so as not to foster the spread of the invasive species on site or elsewhere. Glyphosate will be used as the active ingredient of herbicide, in a 45-55% formulation. The following equipment will be used:

3.4.2 Vine Treatment

The contractor will cut vines out of trees, apply foliar herbicide, cut stump, or basal bark treatment, chop up, and dispose of dead vines. The herbicide RoundUp (41% Glyphosate) will be used for vine extermination. Herbicide will be marked with sufficient amounts of a color dye to enable inspection of the completed application. The following equipment will be used: cutting equipment, herbicide application equipment, and backpack sprays in some areas.

3.5 Lawn construction

The contractor will construct lawn areas with grass seed, ground limestone, fertilizer, compost, superphosphate, and topsoil and will prepare, plant, and maintain lawn areas.

3.5.1 Grass Seed

Grass seed shall be fresh, recleaned seed of the latest crop, mixed in the following proportions by weight and meeting the following standards of pure live seed content and maximum allowable weed seed content.

Table 3.3 Grass seed composition and major indicators

Percent By Weight	Grass Seed	Purity	Germination	Maximum Weed Seed
60%	Tall Fescue	98%	85%	0.25%

20%	Bluegrass	98%	80%	0.10%
20%	Perennial Ryegrass	98%	85%	0.25%

Prior to seeding, all areas to receive seed will be mown to a height of ¾” and raked clean. Existing topsoil will remain and be supplemented as necessary to ensure the required 6” depth. Compost will be thoroughly incorporated into the top 5” of topsoil. After the compost has been incorporated, limestone, commercial fertilizer will be worked into the top 3” of soil.

3.5.2 Ground Limestone

Ground limestone (Calcium Carbonate) will not be less than 80% total carbonates or 44.8% Calcium Oxide equivalent. The rate of application of limestone per thousand square feet will be as follows, depending on the hydrogen ion concentration (pH).

Table 3.4 Rate of application of limestone per thousand square feet

pH	**Rate/Pounds**
5.0-5.5	100
5.5-6.0	50
6.0-6.8	25
Over 6.8	0

3.5.3 Commercial Fertilizer Low Phosphorus (Slow Release)

The fertilizer will have the following composition: Nitrogen 7%-10%, Phosphorus 1%-2%, and soluble Potash 4%-12%. It will be pesticide free (no weed-and-feed) product. It will be packaged and delivered in standard size bags of manufacturer.

3.5.4 Hydro seeding

The contractor will furnish standard and native grass seeds and prepare soil to accomplish hydro seeding in the area. Grass seed shall be fresh, recleaned seed of the latest crop. Hydro mulch will be a wood fiber product colored with a non-toxic water-soluble green dye. Wood fiber mulch binder will be a semi porous film material capable of binding wood fiber mulch and seed to the soil. The rate of application will be 70 gallons per acre. Fertilizer will be bone meal or a low-phosphorous chemical fertilizer formula. Two parts of work will be associated with the installation: (1) apply seed and 25% of the hydro mulch, and (2) apply 75% of the mulch and wood fiber mulch binder.

3.6 Cleaning and Disposal

After the construction process, the contractor will clear, grub, and remove all objectionable material, such as trees up to and including 6” DBH, all shrubby growth and brush, vines, ground covers, stumps of all sizes, roots and weeds, stones, wood and all trash.

4 Results

4.1 Energy Use

The major energy consumption occurs at the tree nursery and plantation stage (34%), followed by invasive management (29%) and site preparation (21%). The single largest energy consumer is the nursery that prepares the trees in the green houses. The invasive management will also consume considerable amount of energy because of the usage of herbicide. Some items, like construction fence, also contribute to the energy consumption significantly due to the energy-intensive manufacturing process. The on-site vehicle use is moderate due to the strict requirement on the mileage performance of the vehicle. The following table specifies the contribution processes and materials and their energy uses.

Table 4.1 Energy uses of major contribution processes and materials

Process and Material	**Energy Use (TJ)**	**Percent (%)**
Tree plantation	**7.09**	**34.2**
Nursery-grown trees	5.75	27.7
Mulch	0.40	1.9
Temporary tree guard	0.02	0.1
Landscape fabric	0.92	4.4
Site preparation	**4.26**	**20.5**
Construction fence	1.87	9.0
Range fence	0.10	0.5
Temporary silt fence	0.40	1.9
Construction sign	0.06	0.3
Pre-cast concrete plot marker	0.84	4.0
On-site vehicle use	0.99	4.8
Compost	**0.16**	**0.8**
Invasive management	**6.02**	**29.0**
Lawn construction	**1.80**	**8.7**
Grass seed	0.22	1.1
Ground limestone	0.10	0.5
Commercial fertilizer low phosphorus	0.98	4.7
Hydro seeding	0.50	2.4
Clear, grub and disposal	**1.40**	**6.7**
Total Energy Use	**20.75**	**100**

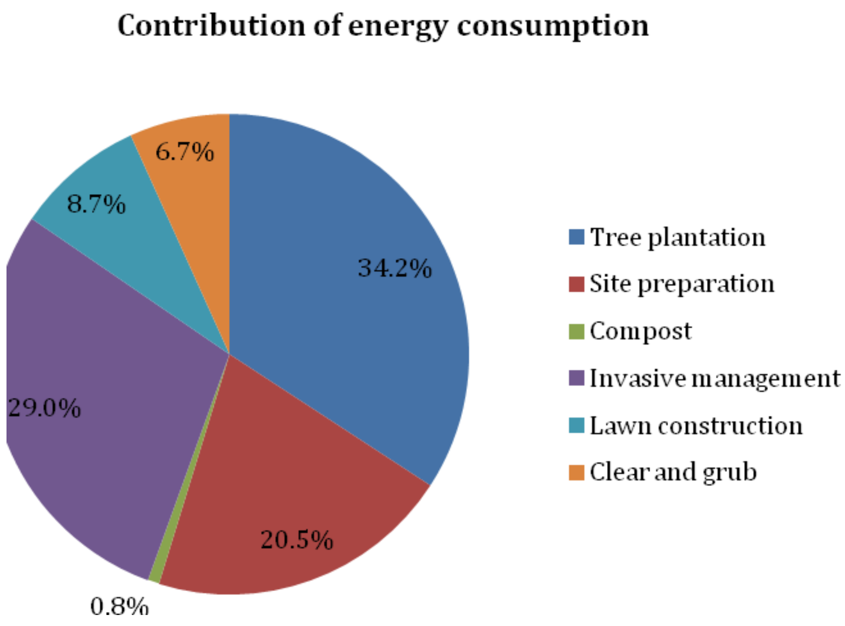


Figure 4.1 Energy consumptions of major contribution processes

The EIO-LCA model categorizes the energy type as coal, natural gas, petroleum, bio-energy and non-fossil electricity. The upfront site construction and preparation will consume positive amount of energy as follows. The most important component is the energy derived from natural gas, followed by petroleum and coal. Fossil fuel contributes to 82.5% of the total energy use.

Table 4.2 Energy use by types for the construction phase

Energy Type	**Energy Use (TJ)**
Coal	4.40
Natural gas	6.80
Petroleum	5.91
Bio-energy/waste-generated	1.39
Non-fossil electricity	2.26
Total Energy Use	**20.75**

Upon the completion of the project, the urban forest will serve to reduce energy use. Incorporating the characteristics of species and the growth trend, iTrees model provides the energy savings information based on different time horizons, shown as follows.

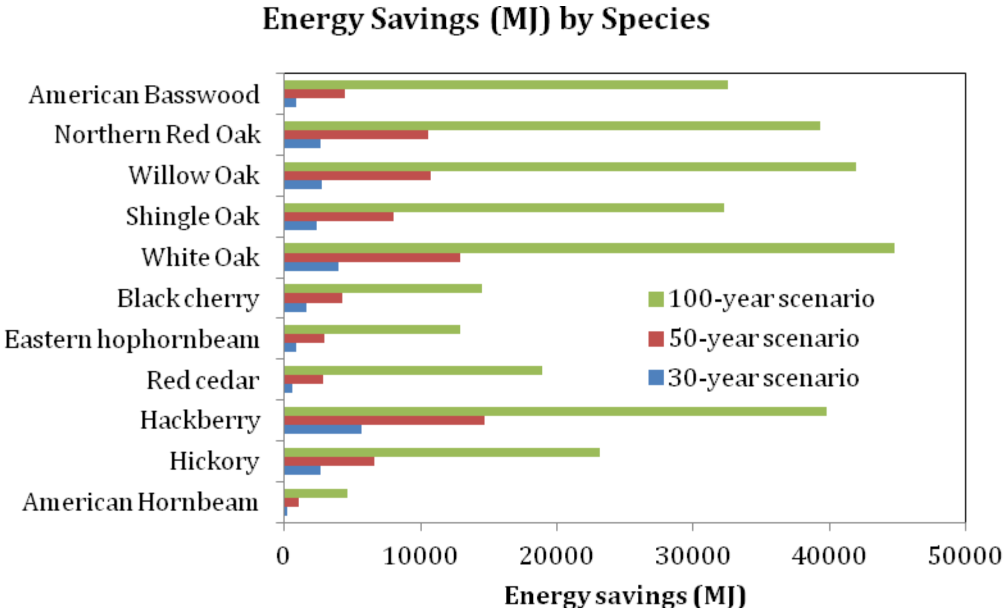


Figure 4.2 Energy savings of each species

For the energy saving function, Oak genus generally performs the best in the 100-year time horizon, averaging 39,555 MJ per oak tree. However, the hackberry outperforms other trees in shorter time horizon (30- and 50-year), with a contribution of 5,688 MJ and 14,562 MJ per tree, respectively, because of its fast growth in the short term. Eastern Hophornbeam, American Hornbeam and Black Cherry save least along their lifetime, especially in the near term.

Multiplying energy saving per tree by the tree numbers, the project-wide energy use and saving balance can be given as follows:

Table 4.3 Energy balance and payback period (current plan)

Time Horizon	**Energy Use (TJ)**
Construction (time 0)	20.75
0-30 year	-7.88
30-50 year	-22.71
50-100 year	-105.09
Energy Use Balance (100-year)	**-114.8**
Payback period	**41.3 years**

The result shows that with the current tree plan, it takes around 41 years to pay back the upfront energy use. After 41 years, net energy credits can be gained. Comparing the project-wide energy performance between different scenarios as below, the high diversity plan takes the shortest time to pay back upfront energy consumption, while the low diversity plan contributes the highest amount of energy savings. This is partly because low diversity plan has the species that grow relatively fast in the short term (i.e. Northern Red Oak and American Basswood), while the high diversity plan is composed of more oak genus trees that will have larger DBH and larger energy saving capacity in the long run. The current plan can be improved to either low diversity or high diversity plan to increase its energy savings.

Table 4.4 Comparison of energy balance and payback period between scenarios

Time Horizon	**Energy Use (TJ)**		
	Current Plan	**Low Diversity Plan**	**High Diversity Plan**
Construction (time 0)	20.75	20.75	20.75
0-30 year	-7.88	-8.76	-15.0
30-50 year	-22.71	-28.77	-30.0
50-100 year	-105.09	-143.44	-114.6
Energy Use Balance (100-year)	**-114.8**	**-160.1**	**-138.9**
Payback period	**41.3 years**	**38.4 years**	**33.8 years**

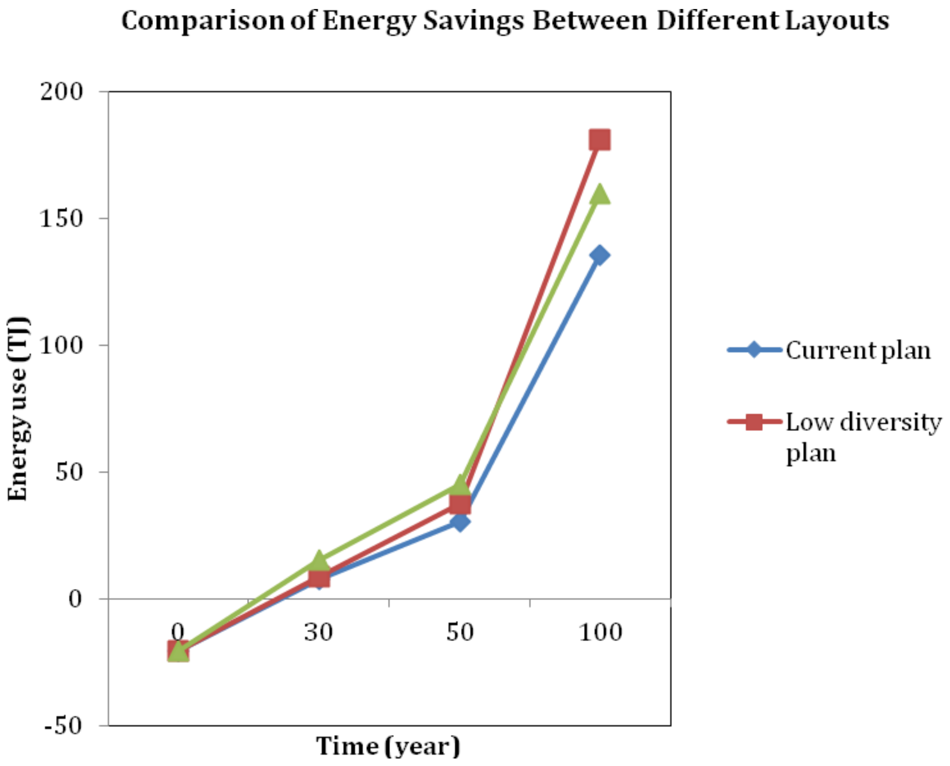


Figure 4.3 Comparison of energy savings between scenarios

4.2 Greenhouse Gas Emissions

The major GHG contributors during the construction process are shown as below. The tree plantation is the single largest stage that emits 38% of greenhouse gas, among which 33% comes from the nursery. In contrast to the energy consumption, the invasive management and site preparation weigh much less in terms of GHG contribution, 20% and 17%, respectively. The cleaning and disposal step also contributes a significant proportion of GHG emission because the assumed landfill process is relatively GHG intensive. The commercial low phosphorous fertilizer will also contribute considerable GHG due to the upstream manufacturing process.

Table 4.5 GHG emissions of major contribution processes and materials

Process and Material	GHG Emission (ton-CO_2-equivalent)	Percent (%)
Tree plantation	**729.2**	**37.9**
Nursery-grown trees	630.1	32.8
Mulch	40.0	2.1
Temporary tree guard	0.89	0.0
Landscape fabric	58.2	3.0
Site preparation	**333.5**	**17.4**
Construction fence	136.1	7.1
Range fence	10.0	0.5
Temporary silt fence	23.0	1.2
Construction sign	3.21	0.2
Pre-cast concrete plot marker	87.8	4.6
On-site vehicle use	73.4	3.8
Compost	**79.7**	**4.1**
Invasive management	**374.2**	**19.5**
Lawn construction	**204.6**	**10.6**
Grass seed	9.0	0.5
Ground limestone	10.0	0.5
Commercial fertilizer low phosphorus	145.6	7.6
Hydro seeding	40.0	2.1
Clear, grub and disposal	**201.0**	**10.5**
Total GHG Emission	**1922.4**	**100**

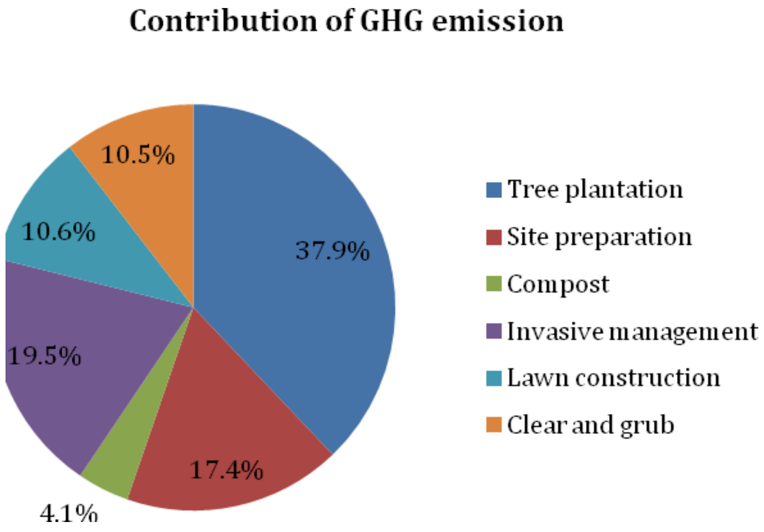


Figure 4.4 GHG emissions of major contribution processes

The EIO-LCA model categorizes the GHG emissions into different types of gases. The Carbon Dioxide from fossil fuel contributes the single largest amount (58.5%) to the total GHG emission, shown as follows. The New York City will emit approximately 58 million tons of CO_2 in one year (World Energy Council, 2009); the project's emission of construction phase accounts for an additional 0.003% emission.

Table 4.6 GHG emissions by gas types

GHG Type	**GHG Emission (ton-CO_2-equivalent)**
CO_2-fossil fuel	1123.9
CO_2-process	196.4
CH_4	238.7
N_2O	342.2
HFC/PFCs	19.9
Total GHG Emission	**1922.2**

Upon the completion of the project, the urban forest will serve to offset GHG emissions. Incorporating the characteristics of species and the growth trend, iTrees model provides the GHG mitigation information based on different time horizons, shown as follows.

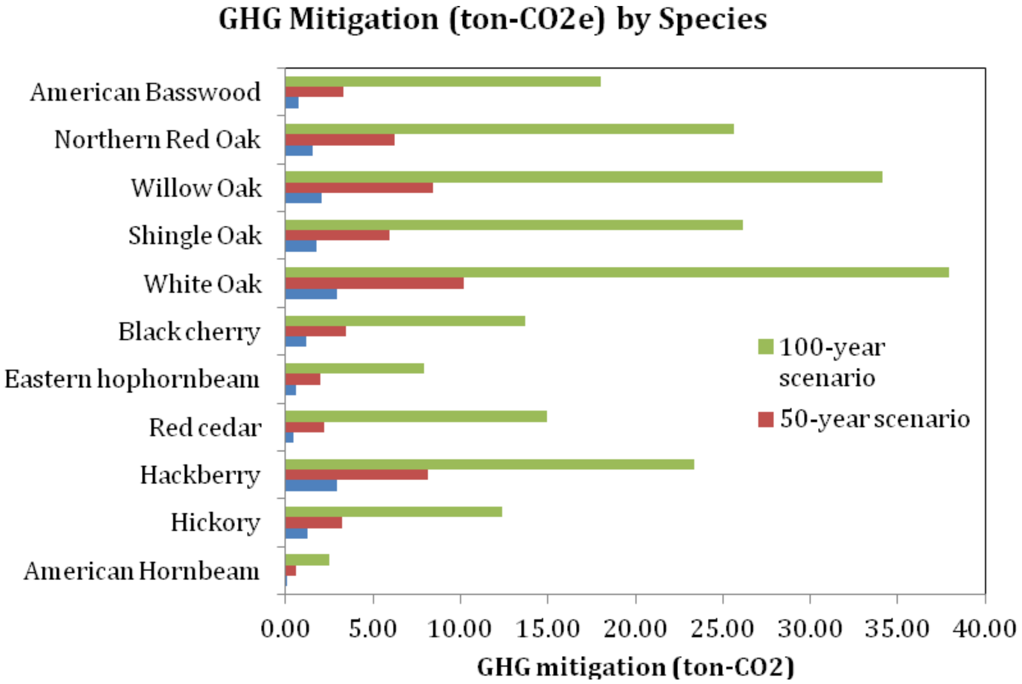
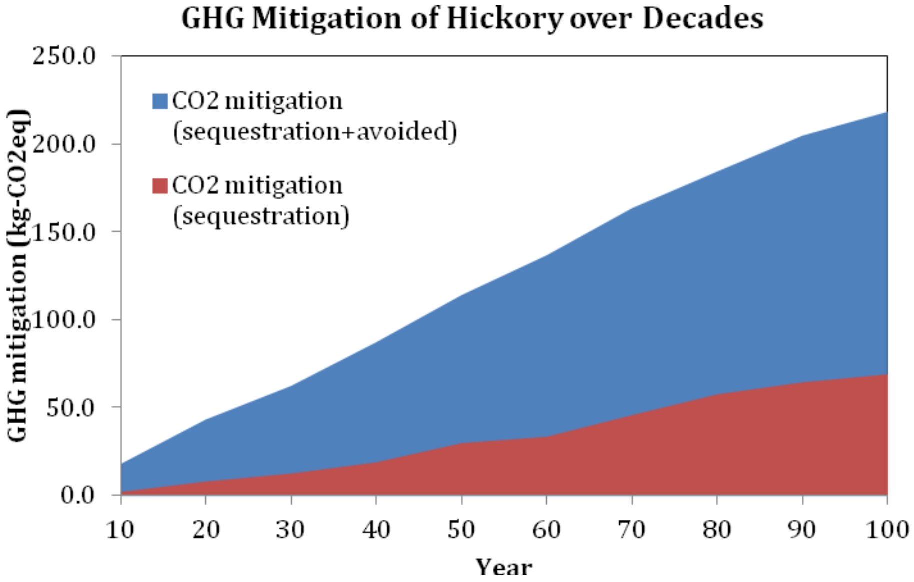


Figure 4.5 GHG mitigation effect of each species

For the GHG mitigation function, Oak genus performs the best in the 100-year time horizon again, averaging 30.6 ton-CO_2eq per oak tree. The second tier is American Basswood and Hackberry. In the short-to-medium term (30- and 50-year time horizon), the Oak trees and Hackberry performs the best.

The GHG mitigation comes from two distinct parts: (1) sequestration for tree growth that will be locked up in the roots, trunks, stems and leaves, and (2) avoided emissions associated with reduced energy production. Based on different growth patterns, the relative contributions from these two mechanisms will vary. The different GHG mitigation footprint over time between Hickory and American Basswood can exemplify how growth pattern will affect the GHG mitigation. For Hickory, the fraction of sequestration over total mitigation remains steady, as the growth rate is stable, though relatively small. On contrary, for the American Basswood, as the growth rate slows down in the long term, the avoided GHG from energy consumption starts to dominate the total GHG mitigation.



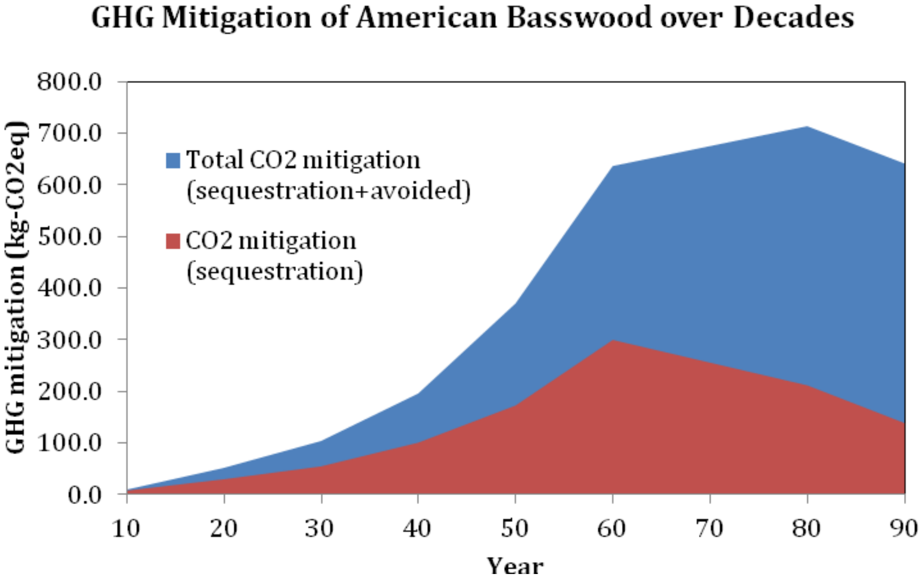


Figure 4.6 GHG mitigation dynamics of Hickory (above) and American Basswood (below)

Multiplying GHG mitigation per tree by the tree numbers, the project-wide energy use and saving balance can be given as follows:

Table 4.7 GHG emission balance and payback period (current plan)

Time Horizon	**GHG Emission (Gg-CO_2eq)**
Construction (time 0)	1.9
0-30 year	-5.4
30-50 year	-15.4
50-100 year	-68.4
GHG Balance (100-year)	**-87.2**
Payback period	**10.7 years**

The result shows that with the current tree plan, it takes around 11 years to pay back the upfront GHG emission. After 11 years, net energy credits can be gained. Comparing the project-wide energy performance between different scenarios, the high diversity plan takes the shortest time to pay back upfront GHG emission. The low diversity plan contributes slightly more GHG credits than high diversity one, but largely exceeds the current plan.

Table 4.8 Comparison of GHG emission balance and payback period between scenarios

Time Horizon	**GHG Emissions (Gg-CO_2eq)**		
	Current Plan	**Low Diversity Plan**	**High Diversity Plan**
Construction (time 0)	1.9	1.9	1.9
0-30 year	-5.8	-5.8	-9.1
30-50 year	-18.2	-18.2	-20.0
50-100 year	-85.6	-85.6	-79.6
GHG Balance (100-year)	**-107.7**	**-107.7**	**-106.9**
Payback period	**10.7 years**	**9.9 years**	**6.3 years**

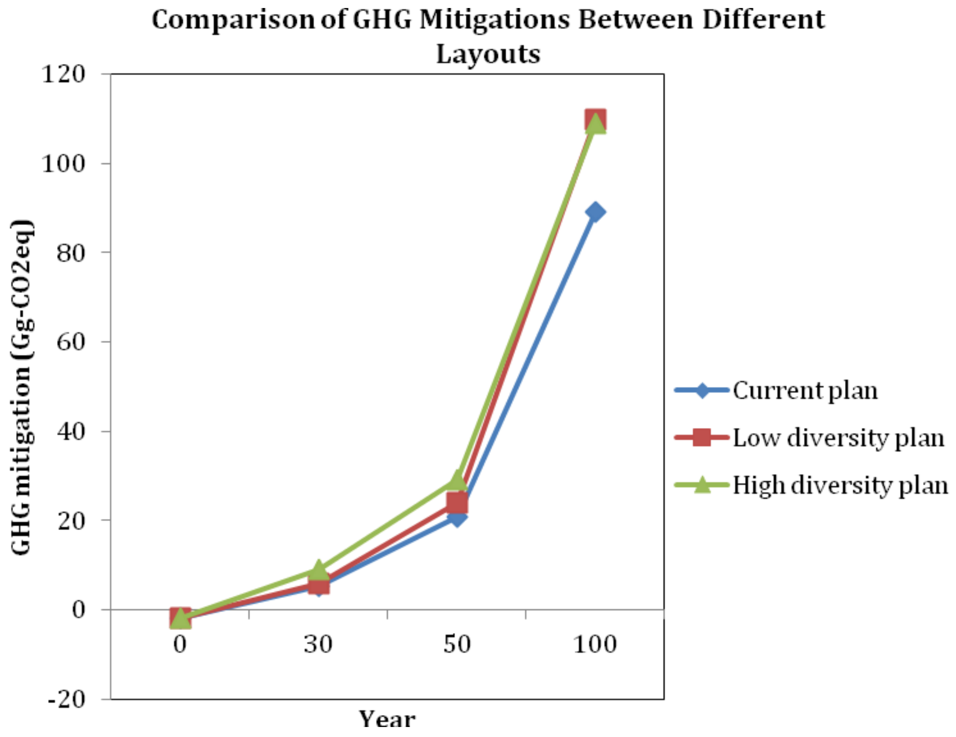


Figure 4.7 Comparison of GHG mitigations between scenarios

4.3 Water Withdrawal

The materials used in project construction will consume considerable amount of water. The table below shows the tree plantation will have the largest water footprint, more than 51%, for which the majority is used in the greenhouse to cultivate the trees. The invasive management process consumes 24% of water, partly because the spray and application of fertilizer requires much water. The landscape fabric manufacturing process accounts for 4.3% due to the high water intensity during the galvanization process. The cleaning and disposal process contributes to 18.5% of water consumption mainly because of processing and disposal of the trash and woody matters.

Table 4.9 Water intakes of major contribution processes and materials

Process and Material	**Water Intake (1000 m^3)**	**Percent (%)**
Tree plantation	**729.2**	**51.1**
Nursery-grown trees	119.5	46.4
Mulch	1.1	0.4
Temporary tree guard	0.1	0.0
Landscape fabric	11.0	4.3
Site preparation	**333.5**	**4.2**
Construction fence	5.7	2.2
Range fence	0.5	0.2
Temporary silt fence	1.0	0.4

Construction sign	0.2	0.1
Pre-cast concrete plot marker	2.8	1.1
On-site vehicle use	0.7	0.3
Compost	**0.6**	**0.2**
Invasive management	**62.5**	**24.3**
Lawn construction	**204.6**	**1.7**
Grass seed	0.8	0.3
Ground limestone	0.2	0.1
Commercial fertilizer low phosphorus	2.3	0.9
Hydro seeding	1.0	0.4
Clear, grub and disposal	**47.7**	**18.5**
Total Water Withdrawal	**257.5**	**100**

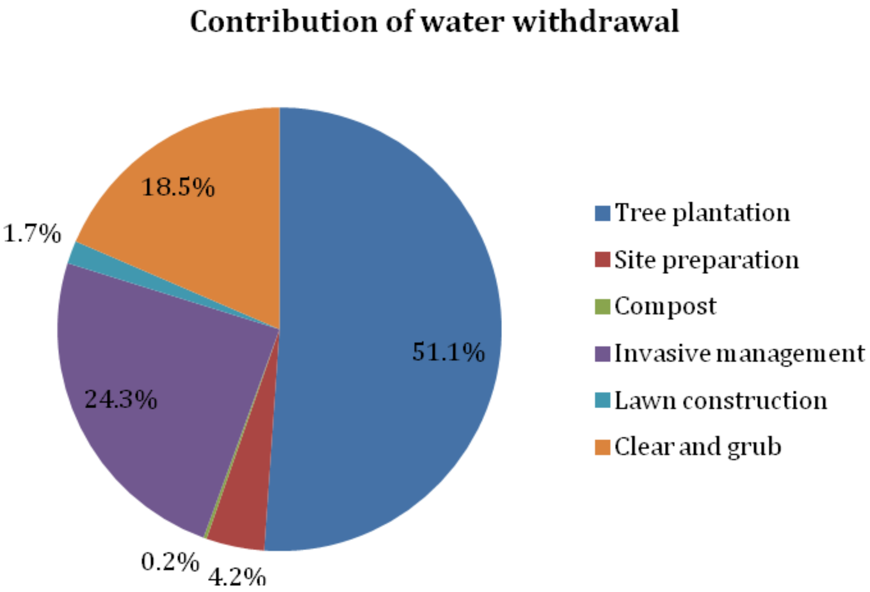


Figure 4.8 Water intakes of major contribution processes

Upon the completion of the project, the urban forest will serve to intercept the water. Incorporating the characteristics of species and the growth trend, iTrees model provides the GHG mitigation information based on different time horizons, shown as follows.

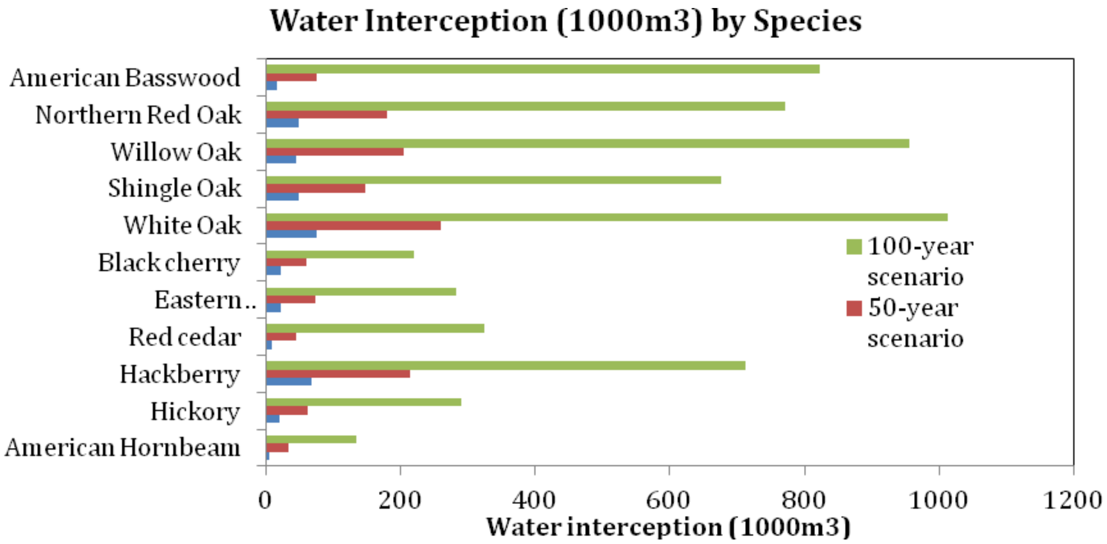


Figure 4.9 Water saving effect of each species

The concept of water interception here is not the counterpart of water withdrawal, because the trees are not “creating” water. Instead, the tree act as natural mini-reservoirs, controlling runoff by intercepting and holding rains on leaves, branches and bark, increasing infiltration and storage of rainwater through the tree's root system, and reducing soil erosion by slowing rainfall before it strikes the soil. So the credits from intercepting runoff can be regarded as a contra account for storm water treatment. Although not strictly consistent by definition, the water balance can be calculated simply by subtracting the water interception from the water withdrawal.

Table 4.10 Water balance and payback period (current plan)

Time Horizon	**Water Intake (1000m^3)**
Construction (time 0)	257.5
0-30 year	-145.5
30-50 year	-398.7
50-100 year	-2448.1
Water Balance (100-year)	**-2734.8**
Payback period	**35.6 years**

The results indicate a 36-year payback period (i.e. it will use approximately 36 years to offset the water withdrawal for the construction). The ultimate water credits can be ten folds larger than the upfront consumption, but the benefit can only be realized after a relatively long period. Further comparison between different layouts in terms of water withdrawal, the high diversity plan shows the shortest payback period, but its water balance is similar to the current plan. The low diversity plan has large but retarded water benefits, around 37% more than current plan’s performance in a 100-year time horizon.

Table 4.11 Comparison of water balance and payback period between scenarios

Time Horizon	**Water Withdrawal (1000m^3)**		
	Current Plan	**Low Diversity Plan**	**High Diversity Plan**
Construction (time 0)	257.5	257.5	257.5

0-30 year	-145.5	-164.4	-213.3
30-50 year	-398.7	-478.7	-500.9
50-100 year	-2448.1	-3377.9	-2372.9
Water Balance (100-year)	**-2734.8**	**-3763.5**	**-2829.6**
Payback period	**35.6 years**	**33.9 years**	**31.8 years**

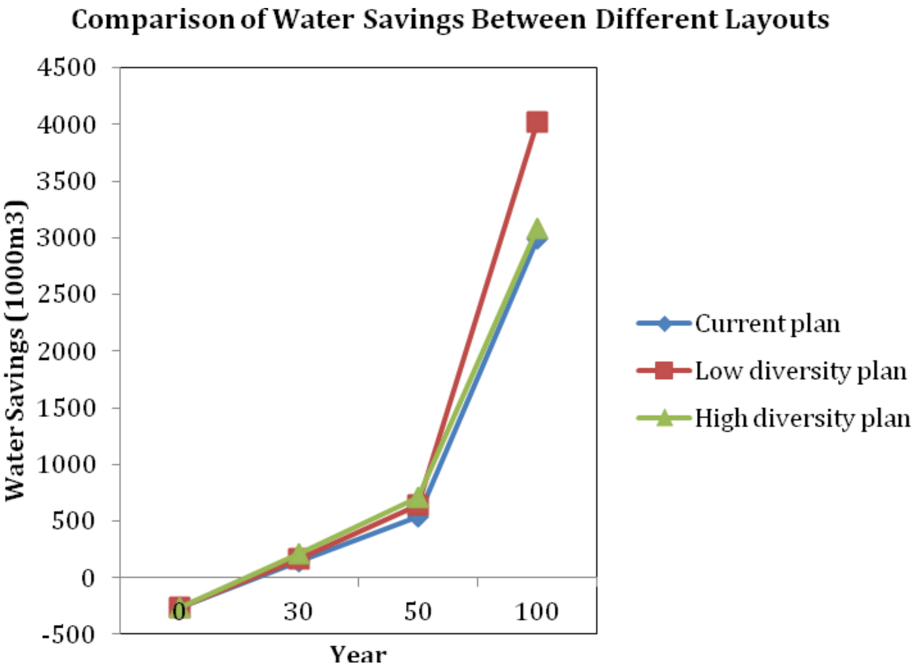


Figure 4.10 Comparison of water saving effects between scenarios

5 Discussion

5.1 Environmental Impacts of Current Plan

For the three environmental impacts of interest, the LCA study shows that the environmental merits are considerable in all aspects but retarded: it takes 10-41 years to offset the upfront energy consumption, GHG emissions and water intake.

Table 5.1 Summary of environmental impacts of the current plan

Time Horizon	**Energy Intake (TJ)**	**GHG Emissions (Gg-CO_2eq)**	**Water Withdrawal (1000m^3)**
Construction (time 0)	20.7	1.9	257.5
0-30 year	-7.9	-5.4	-145.5
30-50 year	-22.7	-15.4	-398.7
50-100 year	-105.0	-68.4	-2448.1
Water Balance (100-year)	**-114.8**	**-87.2**	**-2734.8**
Payback period	**41.3 years**	**10.7 years**	**35.6 years**

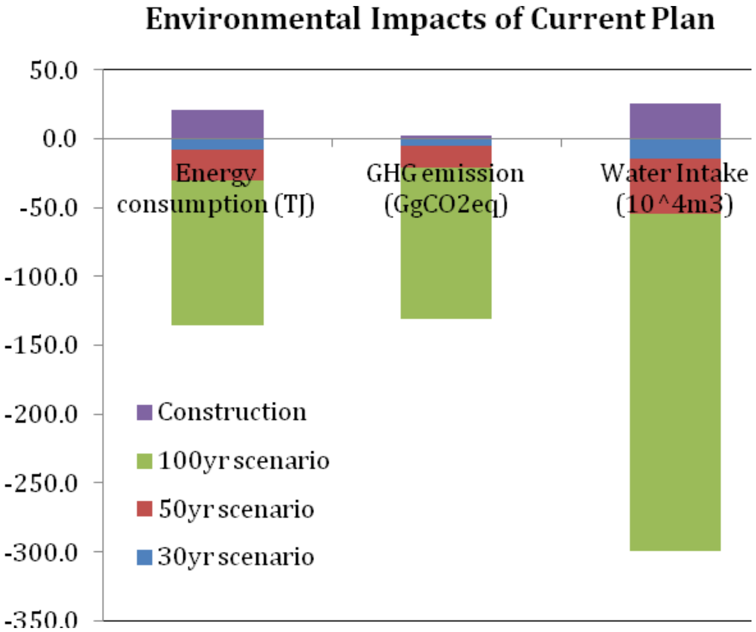


Figure 5.1 Summary of environmental impacts (current plan)

Other than the three environmental categories, the EIO-LCA gives the land use footprint of the construction activity as 2.57kha. Compared to the area of Kissena Park, 95ha, it is about 27 times larger. No comparable result in iTrees model is given.

For the contribution processes, the nursery tree plantation is the most essential step that is energy, water, and GHG intensive. Because of the prevalence of invasive species in the park, the invasive management requires large economic input, as well as energy intake and GHG emissions. The water intake for this step is also considerable due to the application of herbicides. Some seemingly minor items in fact make significant environmental impacts: landscape fabric for water and construction fence for energy and GHG emissions. In addition, the post-construction cleaning and disposal accounts for a large proportion of all three environmental categories.

5.2 Comparison With Alternative Scenarios

From the results above, the low diversity plan is estimated to have the highest environmental credits in the 100-year time horizon; the high diversity plan outperforms the other two in both 30- and 50-year time horizons. This can be explained by the different tree growth patterns in different time periods—the low diversity plan intensively plants Northern Red Oak and American Basswood, which are promising to continue its growth momentum in the long run; the trees selected in high diversity plan are comparatively rapid-growing in the shorter term.

Apparently both alternative scenarios provide higher environmental credits than the current plan, but a comprehensive analysis should be beyond the simple balance of a few environmental categories. The downside of alternative scenarios should also be taken into account: (1) Both alternative layouts own fewer tree species, which can influence the biodiversity of the ecosystem and further temper the symbiotic effects; (2) The insufficient diversity may lead to the ecosystem's vulnerability to outside stress like disease and may make the system not robust in the long run; and (3) As for the function of recreation, more species can provide the park with multiple appearance in different seasons and implicitly increase the ecosystem value.

5.3 The Economy of Urban Afforestation Projects

The explicit economic costs to build up such an urban forest are the construction fee for the project. According to the contract, the total expense including the labor cost and mobilization fee is finally 1.64 million USD, among other bidding prices ranging from 1.64 million to 3.47 million. The implicit economic benefits can only be realized through out the project's lifetime by providing a range of ecosystem services: cooling the urban temperature, providing recreational destination, reducing air pollution (including GHG emissions) and avoiding energy use. The overall ecosystem benefits increase as the time goes, as shown in the following table:

Table 5.2 Comparison of estimated economic benefits between scenarios

Time Horizon	**Economic Benefits (thousand USD)**		
	Current Plan	**Low Diversity**	**High Diversity**
Construction (time 0)	-1638.6	-1638.6	-1638.6
0-30 year	3898.5	4624.3	6613.4
30-50 year	7586.9	9605.3	10273.4
50-100 year	32449.9	43692.8	37303.5
Total Balance (100-year)	**42296.6**	**56282.5**	**52549.2**
Payback period	**12.6 years**	**10.6 years**	**7.4 years**

5.3.1 Valuation of the Urban Forest Asset

Hypothetically using cash flow analysis, the net present value of the asset—urban forest—can be calculated by adding up discounted benefits and costs for each decade. The discount rate will be critical for the final NPV. To test the sensitivity between the NPV with the discount rate, the study uses three different discount rates, 2%, 5%, and 7%. The discount rate not only encompasses the pure value of the time, but also the social capital return requirement.

Table 5.3 Valuation of the project in 100-year time horizon with different discount rates

Discount Rate	**Net Present Value (thousand USD)**		
	Current Plan	**Low Diversity**	**High Diversity**
@2% discount rate	14311.0	8164.0	4330.1
@5% discount rate	3491.3	3124.9	2764.2
@7% discount rate	1453.1	1665.6	1865.4
Non-discounted Payback period	**12.6 years**	**10.6 years**	**7.4 years**

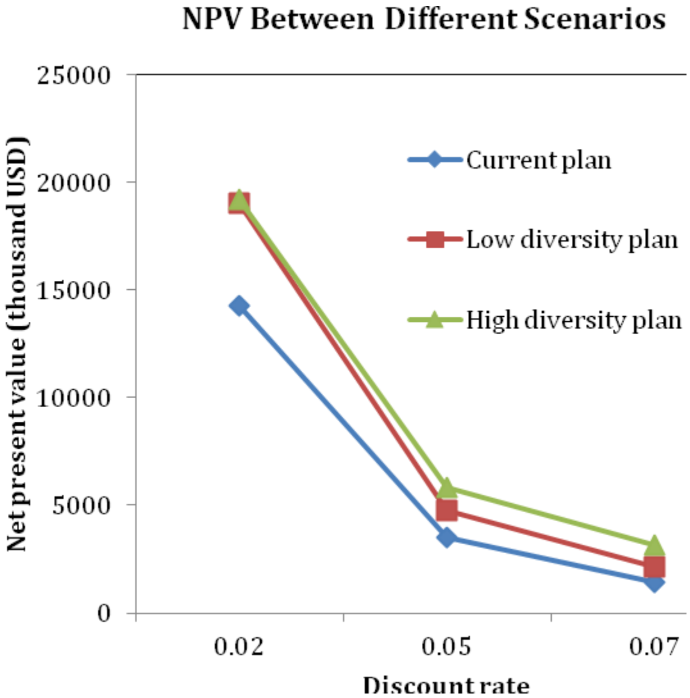


Figure 5.1 NPV valuations between scenarios (100-year time horizon)

The two alternative scenarios also show a better net present value than the current plan. The high diversity plan is more robust in a high discount rate situation. In a time horizon of 100 years, a low discount rate is likely. So if the study chooses the 2% as the long-term discount rate, the net present value of this 95ha urban forest is around 15 million, with a potential up to 20 million.

On the other side, the opportunity cost of the project is harder to capture. It can be the economic benefit of converting the park to other use, for example, industrial use or commercial use. But the environmental benefit is not interchangeable.

5.3.2 Economic Benefits from Mitigating Air Pollutions

Based on the results from iTrees model, the study specifies the economic benefits from mitigating air pollutions, including (1) depleted ozone, (2) avoided VOC (volatile organic compounds) emission, (3) avoided NO_2, (4) depleted NO_2, (5) avoided SO_2, (6) depleted SO_2, (7) avoided PM_{10}, and (8) depleted PM_{10}. The trees can absorb air pollutants like ozone, nitrogen dioxide and sulfur dioxide through leaves, intercept particular matter like dust, ash and smoke, release oxygen though photosynthesis, lower temperature that reduces the production of ozone, and avoid air pollutions associated with energy generation. The following table gives the economic value by mitigating the air pollutions, specified to the local condition and the surrounding environment—open areas and residential communities.

Table 5.4 Economic benefits from mitigating different kinds of air pollutants

Time	**Economic Benefits from Mitigating Air Pollutions (thousand USD)**

Horizon	Depleted Ozone	Avoided VOCs	Depleted NO_2	Avoided NO_2	Depleted SO_2	Avoided SO_2	Depleted PM_{10}	Avoided PM_{10}	**Subtotal**
0-30 yr	49.6	22.0	21.5	91.1	6.1	33.2	44.4	10.8	**278.7**
0-50 yr	193.3	85.7	83.3	336.0	24.0	128.9	173.5	39.4	**1064.2**
0-100 yr	990.4	379.9	421.4	1451.2	122.4	572.3	885.0	169.7	**4992.4**

From the table above, the project can contribute up to 4.9 million economic benefits by mitigating urban air pollutions. The most important parts are the NO_2 emission avoidance, ozone production avoidance and the depletion of particulate matters.

5.4 Broader Environmental Impacts

The project is just one component of the bigger PlaNYC Initiative. When scaling up, the broader urban afforestation endeavor will leave larger environmental impacts and also generate greater economic value. As for this Kissena project, the planted trees are approximately five thousand, occupying an area of 95ha, or 950,000 square meters (functional unit). Each functional unit can contribute 120.8 MJ energy saving, 135.5 kg-CO_2eq GHG mitigation, and 2.73 m^2 water saving, with an ecological footprint of 27 folds at the construction phase, based on current plan in a 100-yr time horizon.

It is informative to estimate the broader environmental impacts upon the fulfillment of the PlaNYC initiative. Assuming the water treatment amount, energy use and GHG emission will remain constant over time, the back-of-the-envelope calculation compares the NYC's environmental burden with the PlaNYC's environmental credits, as shown below.

Table 5.5 Comparisons between citywide environmental burden and program's environmental credits (100-year time horizon)

Boundary	**Functional Unit (million m^2)**	**Energy Intake (TJ)**	**GHG Emissions (Gg-CO_2eq)**	**Water Intake (million m^3)**
New York City	-	~100 million[1]	~5.8 million[2]	~174 thousand[3]
PlaNYC Program	70.3	-8,496	-9,527	-202
Percent	**-**	**0.008%**	**0.16%**	**0.11%**

Note: 1. Energy consumption in NYC averages 1EJ from 2000 to 2005 (Grubler, 2010);
2. NYC emitted 58 million ton-CO_2-equivalent GHG in 2003 (Grubler, 2004);
3. NYC's sewage water system collects and treats an average of approximately 1,260 million gallons per day of sewage (Paolicelli, 2010).

The table above shows that the PlaNYC contributes the most to the GHG emissions and then water intake. The energy saving effect has much lower significance. For the metropolitan city, the 370,000 trees planted in the parkland can compensate around 0.16% of GHG emissions and avoid 0.11% of stormwater treatment workload. But the benefits are mainly realized in the second half of the 100-year horizon. So the scalability should be accompanied with the sustainability of such projects to redeem the proposed environmental impacts.

5.5 Policy Implications

From the quantitative analysis above, several important qualitative policy implications can be drawn. As am ambitious program initiated by current mayor Mr. Bloomberg, the program also requires persistent care and maintenance in the long run. In the near term, the environmental balance for all three categories are negative (i.e. credits do not exceed burden yet), so the longevity of the parklands determines whether positive life-cycle environmental impacts can be ultimately realized. Unless the park can exist for more than 40 years, some of the upfront (environmental) investment will not be paid back.

By examining the contribution processes and materials, some have been identified to leave more important environmental impacts than others.

- The nursery should be placed at the top concern of supervision. This requires better procurement efforts, embracing stricter mandates regarding water saving, fertilizer usage, energy consumption in the screening process.
- The permanently existing auxiliaries should also be paid enough attention: the upfront manufacturing processes of fertilizer, herbicide, fence and fabric are usually energy and water intensive, mainly due to the galvanization and chemical products processing.
- The invasive management is the second largest contributor of the environmental burden. For future operation, this part of work should prefer manual work to herbicide application. The amount of necessary herbicide usage should be carefully calculated to prevent excessive use of chemical products and unnecessary environmental costs.
- Usually neglected, the ultimate disposal technology can largely influence the life-cycle environmental cost (around 15% of construction phase). Landfill is currently the common disposal scenario for the on-site dusts, trash and woody waste (also the underlying assumption in the LCA calculation). But the yard waste could have been fully utilized through advanced technology such as slow pyrolysis to produce biochar (McCarl, Peacocke, & Chrisman, 2009; Roberts & Gloy, 2010). It has demonstrated capabilities to save energy and create global warming credits (Eckelman, 2011). The huge amount of yard waste will be a stable source of starter materials for biochar production. The produced biochar can be reversely applied to the parklands as low-cost soil amendments.

The scenario analysis shows results significantly favoring the alternative layouts. So it lays the question with regard to the selection of tree species: how to balance life cycle environmental merits and the biological consideration when choosing the “right” species and forming the “right” mix. The long-term growth pattern and environmental implications should be considered as equally important as the suitability of the species with the site condition, the ecosystem health, and the recreational functions.

6 Conclusion

According to the results shown above, the Kissena project is proven to have large life-cycle environmental merits in all three interested environmental categories. A range from 11 to 41 years is the reasonable period for the urban forest to pay back the upfront environmental input. The Kissena project can generate an overall ecosystem benefit of 42.2 million USD in a 100-year time horizon; with a 2% discount rate, the valuation of the asset is estimated to be 14.1 million USD without the consideration of the termination value. Alternative scenarios appear to have more environmental advantage than the current plan. However, the LCA results do not embrace the biological consideration like bio-diversity and recreational function. When scaling up, the broader PlaNYC project can contribute significant environmental benefits in energy saving, GHG mitigation and avoidance of stormwater treatment, as well as considerable economic value.

One hundred years are short to a tree, but long for a fast-paced city. A number of limitations and uncertainties face the LCA study. The LCA study is able to provide useful environmental information of the project and informative estimation of the whole program, but it is not capable to predict what will really happen in the coming 100 years, which can leave very considerable effects on the project—it is just based on the current snapshot. The validation and adjustment effort should be paid continuously in an adaptive management manner by ongoing monitoring of the real environmental outputs and adjusting the LCA model. Before using the results to assist any policy making process, the limitations of the study should be fully noticed and a comprehensive consideration including other analytic frameworks than LCA should be favored.

Appendix I. References

Baker, L. (2008). New concepts of manageming urban pollution. In L. Baker (Ed.), *The Water Environment of Cities* (Vol. 5): Springer.

Baumann, H., & Tillman, A.-M. (2010a). LCA in a nutshell *The Hitch Hiker Guide to LCA* (Vol. 1). Berlin.

Baumann, H., & Tillman, A.-M. (2010b). LCA inventory analysis *The Hitch Hiker Guide to LCA* (Vol. 4). Berlin.

BBOP, B. a. B. O. P. (2009). *Biodiversity Offset Cost-Benefit Handbook*. Washington, D.C.: Forest Trends.

Birch, J., Newton, A., & Aquino, C. (2010). Cost-effectiveness of dryland forest restoration evaluated by spatial analysis of ecosystem services. *Proceedings of the National Academy of Science of USA, 107*(50), 21925-21930.

Burns, R. M., & Honkala, B. H. (1990). *Silvics of North America* (Vol. 2). Washington, D.C.: United States Department fo Agriculture.

Eckelman, M. (2011). GHG and Energy Use Implications of Biochar Production. Yale University.

Felson, A. (2010). Kissena Corridor Park Research Planting Plan. Yale School of Forestry and Environmental Studies.

Felson, A., Palmer, M., & Pouyet, R. (2009). Forest restoration in New York City: establishing long-term research activity on parkland across the five boroughs. Unpublished Presentation. Yale School of Forestry and Environmental Studies.

Grant, T., Beer, T., & Campbell, P. K. (2008). *Life Cycle Assessment of environmental outcomes and greenhouse gas emissions from biofuel production in Western Australia*. Sydney, Australia: National Research Flagships.

Green Design Institute, C. M. U. (2008). Economic Input-Output Life Cycle Assessment(EIO-LCA) Database. Retrieved January 1, 2008, from Carnegie Mellon University: www.eiolca.net

Grimm, N., Faeth, S., & Golubiewski, N. (2008). Global change and the ecology of cities. *Science, 319*(758), 754-760.

Grubler, A. (2004). Transition in energy use *Encyclopedia of Energy* (pp. 163-175). Laxenburg, Austria: Elsevier Inc.

Grubler, A. (2010). Energy System Analysis. Yale School of Forestry and Environmental Studies.

Hoornweg, D., Sugar, L., & Gomez, C. L. T. (2011). Cities and greenhouse gas emissions: moving forward. *Environment and Urbanization*(1-21).

Krasny, M., & Tidball, K. (2009). Urban trees for sustainable cities: to develop an integrated social-ecological sciences research agenda. Cornell Urban sustainability Workshop.

Lackner, K. (2003). A guide to Carbon Dioxide Sequestration. *Science, 300*(5626), 1677-1678.

McCarl, B., Peacocke, C., & Chrisman, R. (2009). Economics of biochar production, utilization and greenhouse gas offsets. In J. Lehmann (Ed.), *Biochar for Environmental Management: Science and Technology*. London, UK: Earthscan.

Ministry of Natural Resources, M. (2000). *Forest Operations and Silviculture Manual*. Ontario, Canada: Queen's Printer for Ontario.

Owen, D. (2004, 10.18.2004). Green Manhattan: why New York is the greenest city in the U.S. *The New Yorker*.

Paolicelli, T. G. (2010). *New York City Water & Sewer System*.

Roberts, K. G., & Gloy, B. A. (2010). Life Cycle Assessment of Biochar Systems; Estimating the Energetic, Economic, and Climate Change Potential. *Environmental Science and Technology, 44*, 827-833.

Seto, K. C., & Sanchez-Rodriguez, R. (2010). The New Geography of Contemporary Urbanization and the Environment. *Annual Review of Environment and Resources, 16*(51), 41-51.

United States Department of Agriculture, F. S. (2010). iTrees Model. Retrieved 06/20/2011:

World Energy Council, W. (2009). Energy, the Environment, and Health. In J. P. Holdren (Ed.), *World Energy Assessment: Energy and the Challenges of Sustainability* (pp. 63-110). Madrid, Spain: World Energy Council.