Accepted in IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), 2008 (Singapour, Dec. 8-11, 2008).

Carbon Market Sensitive Green Supply Chain Network Design

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Outline

- Introduction
  - Context
  - Motivation and objective
  - Kyoto protocol
  - Carbon Market
- Literature
  - Limitations
- Model formulation
- Experimentation
  - Managerial insights
- Conclusion

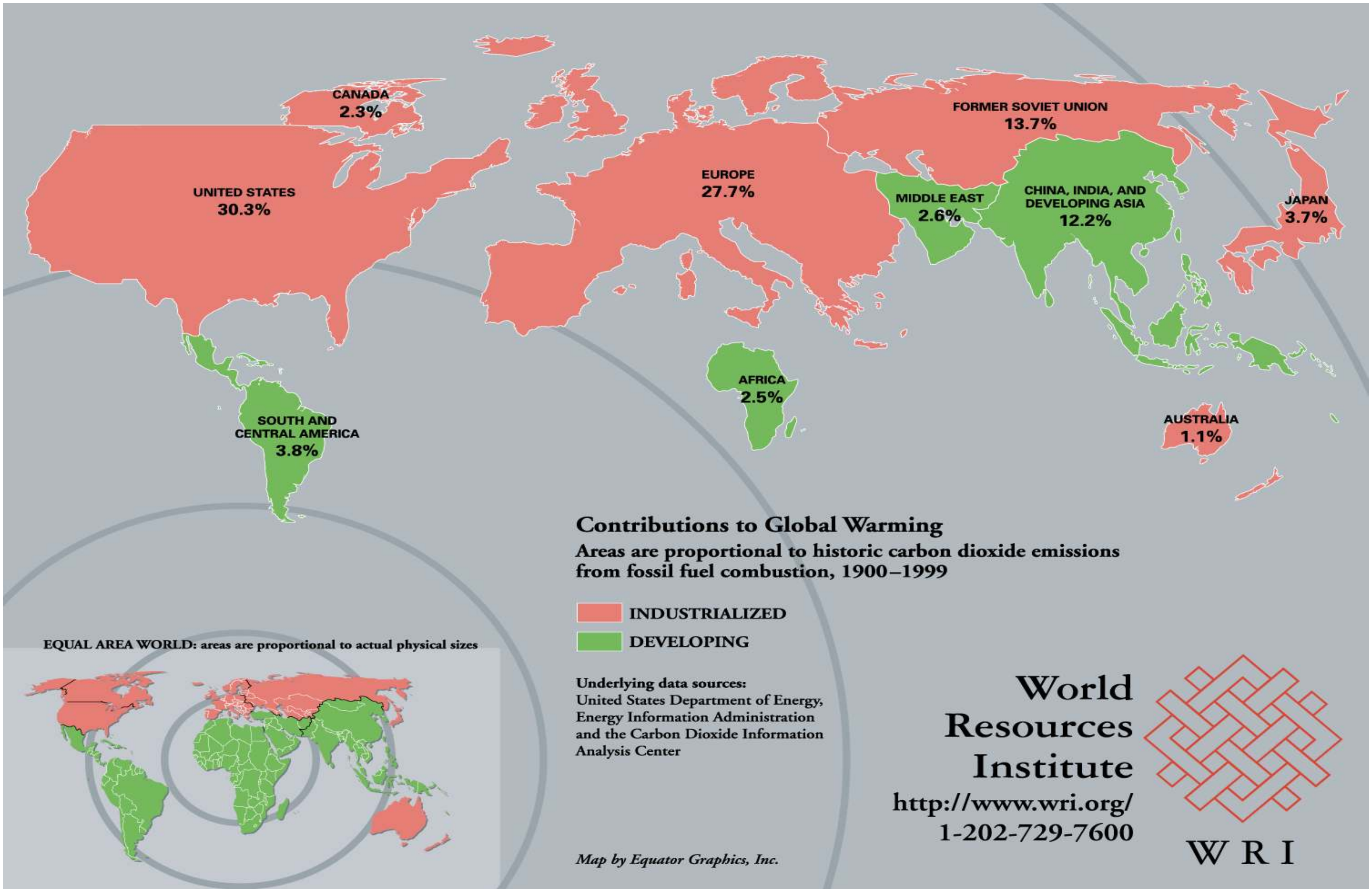
Introduction – *Context*

- Supply chain strategies of last decade :
  - Warehouse consolidation
  - Lean and agile supply chains
  - Just in time
  - Offshore manufacturing
  - Low cost country sourcing

- How green are these strategies ?
- How relevant are they if the carbon trading market became a reality (a price tag for carbon emissions)?

Introduction – *Context*

Climate Change : who is the responsible !!!



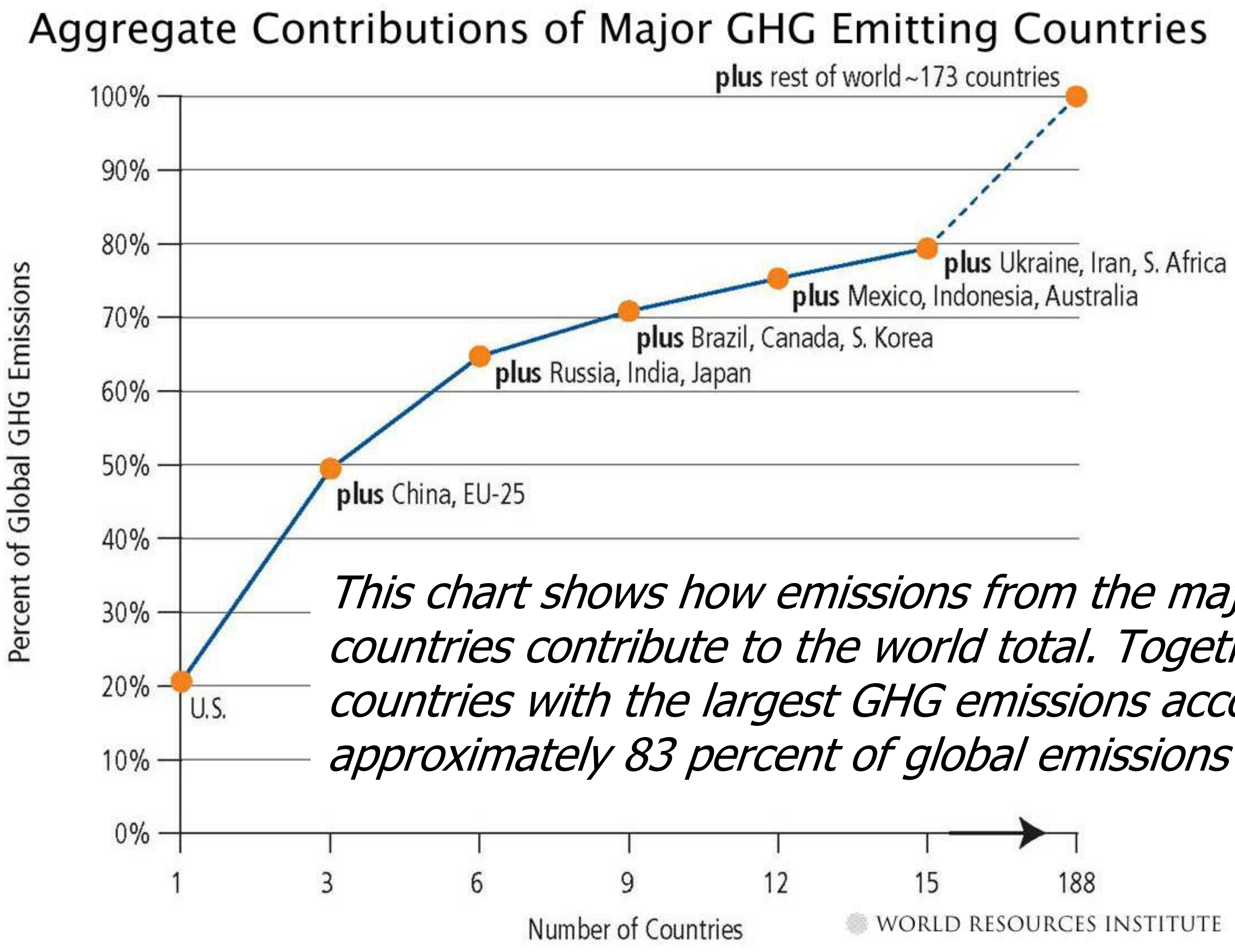
Contributions to Global Warming

Areas are proportional to historic carbon dioxide emissions from fossil fuel combustion, 1900–1999

Underlying data sources:
United States Department of Energy,
Energy Information Administration
and the Carbon Dioxide Information
Analysis Center

Map by Equator Graphics, Inc.

Introduction – *Context*



This chart shows how emissions from the major emitting countries contribute to the world total. Together, the 25 countries with the largest GHG emissions accounted for approximately 83 percent of global emissions in 2000.

The Kyoto Protocol: key features

- Entry into force: February 16, 2005
  - US and Australia did not ratify
- Differentiated commitments:
  - Developed countries and countries with economies in transition agree to quantified legally-binding targets (overall objective leads to a 5% reduction from 1990 levels by 2008-2012)
- **Six gases**,:
  - carbon dioxide (CO2),
  - methane (CH4),
  - nitrous oxide (N2O),
  - Sulphur hexafluoride (SF6),
  - Per fluorocarbons (PFC) and
  - Hydro fluorocarbons (HFC).

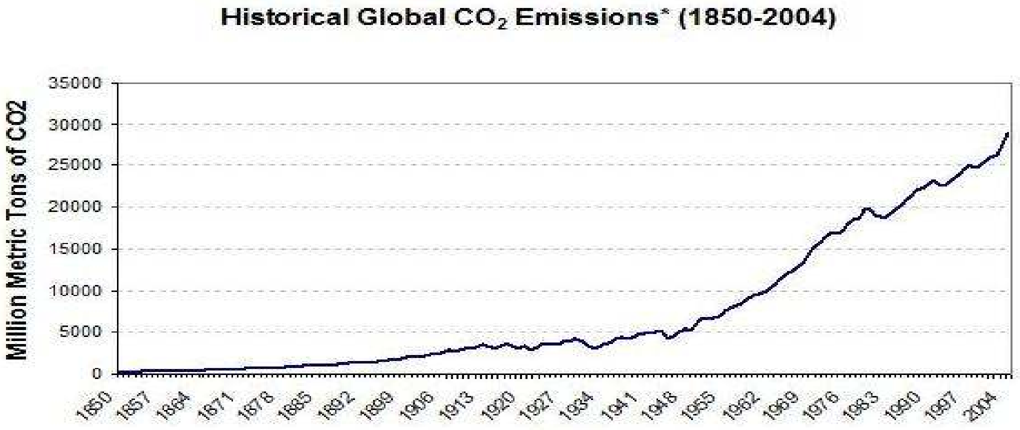
The Kyoto Protocol: key features

- Target should be achieved through:
  - Domestic Reductions
  - Carbon Sinks: direct human-induced land use change and forestry activities
  - International Credits (Kyoto Mechanisms):
    - International Emissions Trading
    - Project –Based: Joint Implementation (in industrialized countries)
    - Project – Based: Clean Development Mechanism (in developing countries)

- Negotiations on next period (post-2012) to start in 2005

Introduction – *Context*

- *Carbon trading markets: a new reality for Green Supply Chain Management*


Historical Global CO_2 Emissions* (1850-2004)

*from Fuel Burning, Cement Manufacture, and Gas Flaring
Source: Marland et. al (2007) Global, Regional, and National CO_2 Emissions. In Trends: A Compendium of Data on Global Change. CDIAC U.S.A.

MCeX Montréal Climate Exchange

13$ per ton
30 may 2008, launched

CCX Chicago Climate Exchange

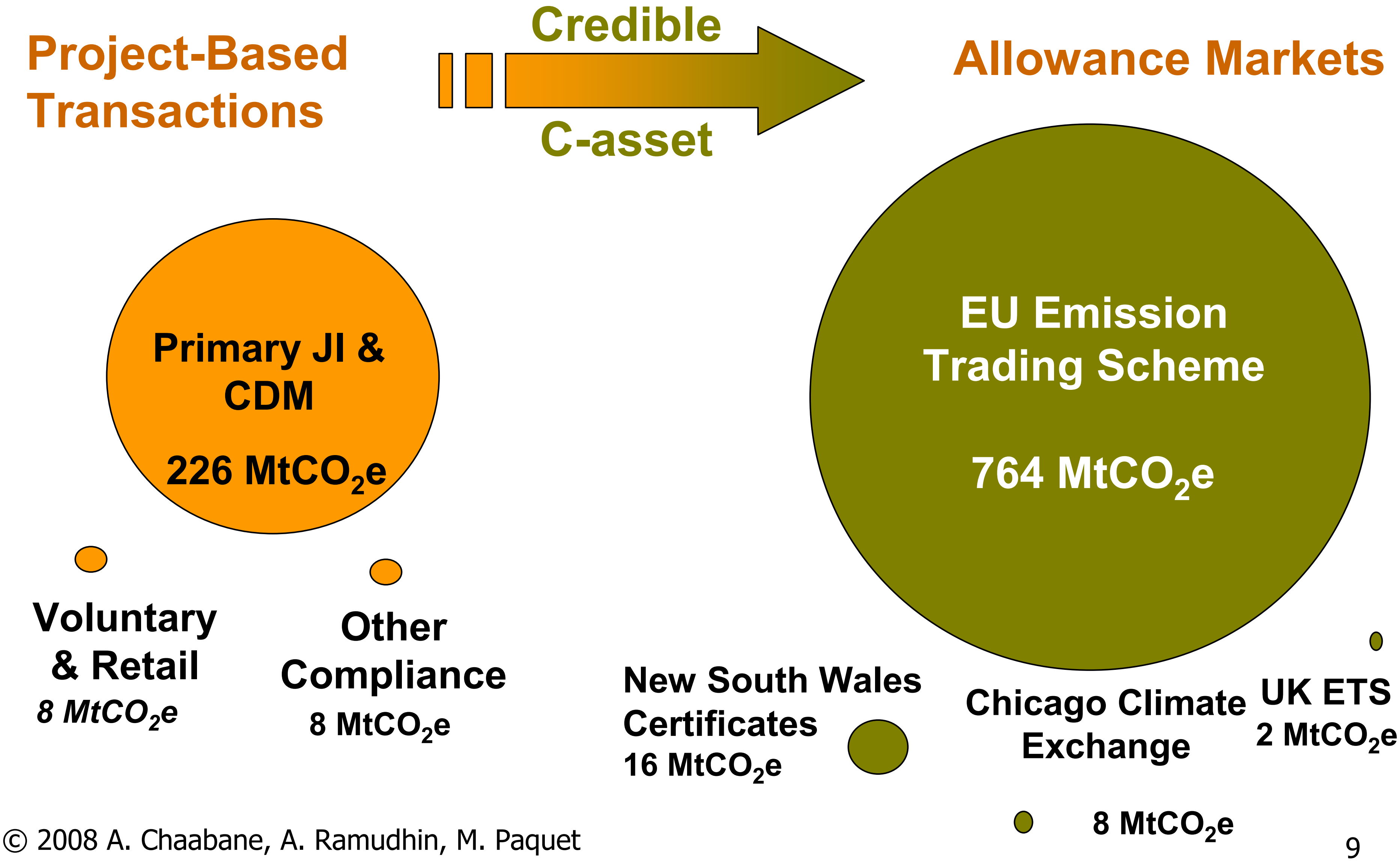
6$ per ton

ECX European Climate Exchange

25€ per ton

Structure of the Carbon Market 2006

(worth close to $22 billion in 2006)



Project-Based Transactions

Credible

C-asset

Allowance Markets

Primary JI & CDM

226 $MtCO_2e$

EU Emission Trading Scheme

764 $MtCO_2e$

Voluntary & Retail

8 $MtCO_2e$

Other Compliance

8 $MtCO_2e$

New South Wales Certificates

16 $MtCO_2e$

Chicago Climate Exchange

8 $MtCO_2e$

UK ETS

2 $MtCO_2e$

Introduction – *Context*

- Trends :
  - ‘Corporate Responsibility’ reporting (green accounts) is on the rise (from 45% of Global fortune 250 companies in 2002 to 67% in 2005)[1]
    - *Texas Instruments saved USD 8 million each year by reducing its transit packaging budget for its semiconductor business through source reduction, recycling, and use of reusable packaging systems*

[1] *Source : KPMG “International Survey of Corporate Responsibility reporting in 2005”*

- Regulations :
  - The government of Canada (ecoAction, 2007) plans to regulate both GHG emissions and air pollutants
    - *“impose mandatory targets on industry to achieve a goal of an absolute reduction of 150 mega tons in GHG emissions by 2020”*
  - The U.S. Environmental Protection Agency’s (EPA, 2006) announced that by 2012, 160 Million Metric Tons of Carbon Equivalent (MMTCE) of emission will be reduced
    - *“99 MMTCE will be reduced in the industry sector and 15 MMTCE will be reduced in the transportation sector”*

Introduction – *Objective*

- Develop a decision support system (DSS) for strategic and environmental supply chain network design analysis :
  - Calculate a supply chain’s existing carbon footprint (calculation of GHG emissions) based on the current supply chain network structure
  - Determine the most cost effective supply chain network design based on user-defined GHG reduction targets
  - Incorporate carbon offsets into cost and footprint calculations to optimize where carbon credits should be purchased and applied: **Environmental Cost**

Literature – *Problem context*

- Green supply chain management (GSCM) and problems context :
  - Green design
    - Environmentally conscious design (ECD)
    - Life-cycle assessment/analysis (LCA)
  - Green operations
    - Supplier selection
    - Green manufacturing and remanufacturing
    - Reverse logistics and network design
    - Waste management
    - Minimize the use of energy

Srivastava, S.K. (2007) Green supply-chain management: A state-of-the-art literature review, International Journal of Management Reviews, 9, 1, 53-80.

Literature – *Methodology*

- Green supply chain management (GSCM) based methodology / approach :
  - Empirical studies
    - Case studies
    - Interviews and surveys
    - Though papers
  - Simulation and game theory
  - Mathematical modelling
    - Non Linear Programming (LP)
    - Multi-criteria decision making
    - LP and Mixed Integer LP

Srivastava, S.K. (2007) Green supply-chain management: A state-of-the-art literature review, International Journal of Management Reviews, 9, 1, 53-80.

Literature – *Limitations*

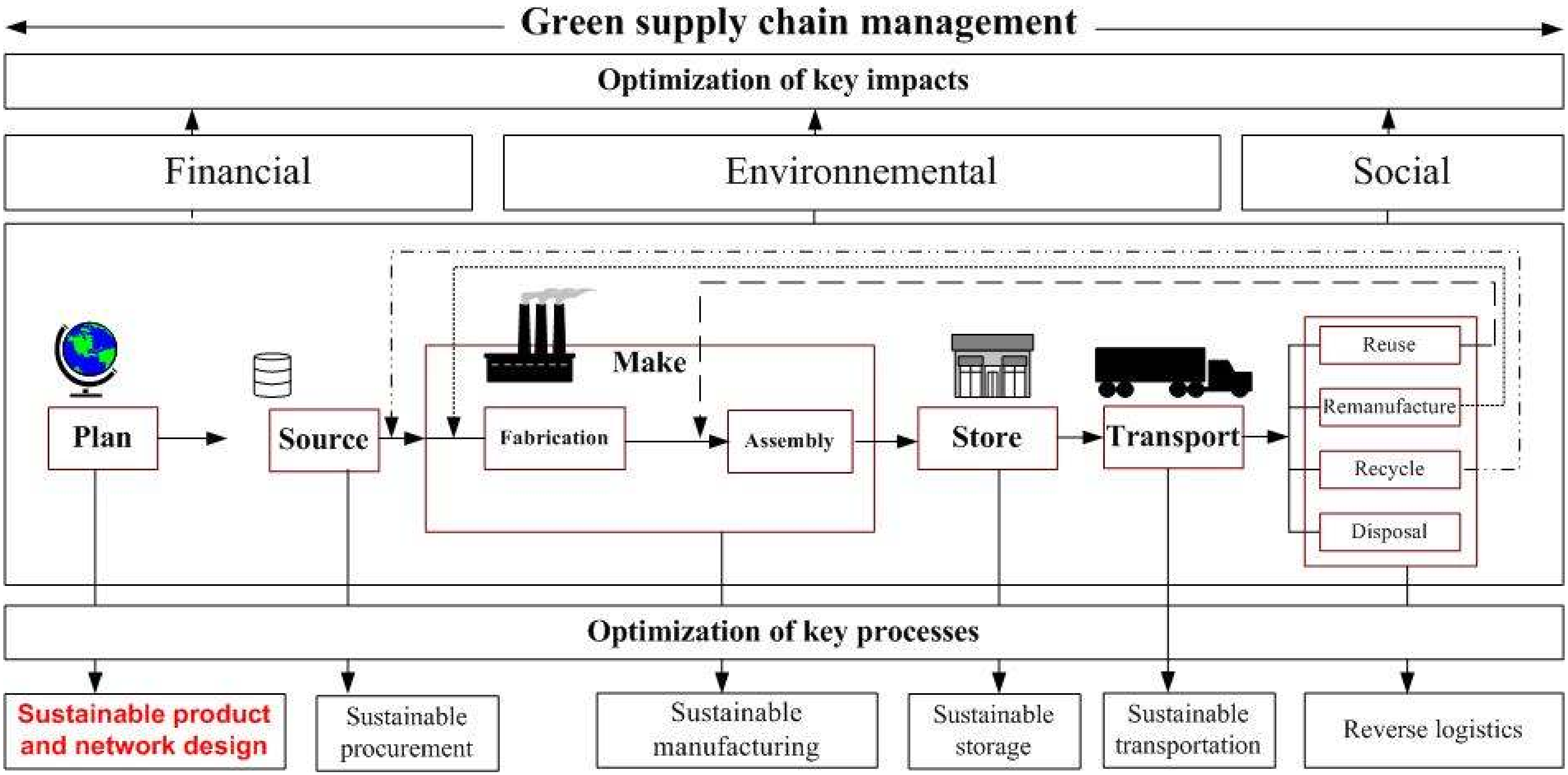
- GSCM studied supply chain problems much more form operational point of view

- For the green supply chain network design
  - The problem is not studied enough
  - Research stress on reverse logistics activities
    - Unable to quantify clearly the real impact of such improvement relative to GHG emission reduction and the supply chain configuration

- Lack of standardized, comprehensive and up-to-date data
  - Industry is struggling to find the right trade-off between
    - Green supply chains
    - Lean supply chains
    - Agile supply chains

A GSCM framework

Environmental conscious supply chain network design



Green supply chain management

Optimization of key impacts

Financial

Environnemental

Social

Plan

Source

Make

Fabrication

Assembly

Store

Transport

Reuse

Remanufacture

Recycle

Disposal

Optimization of key processes

Sustainable product and network design

Sustainable procurement

Sustainable manufacturing

Sustainable storage

Sustainable transportation

Reverse logistics

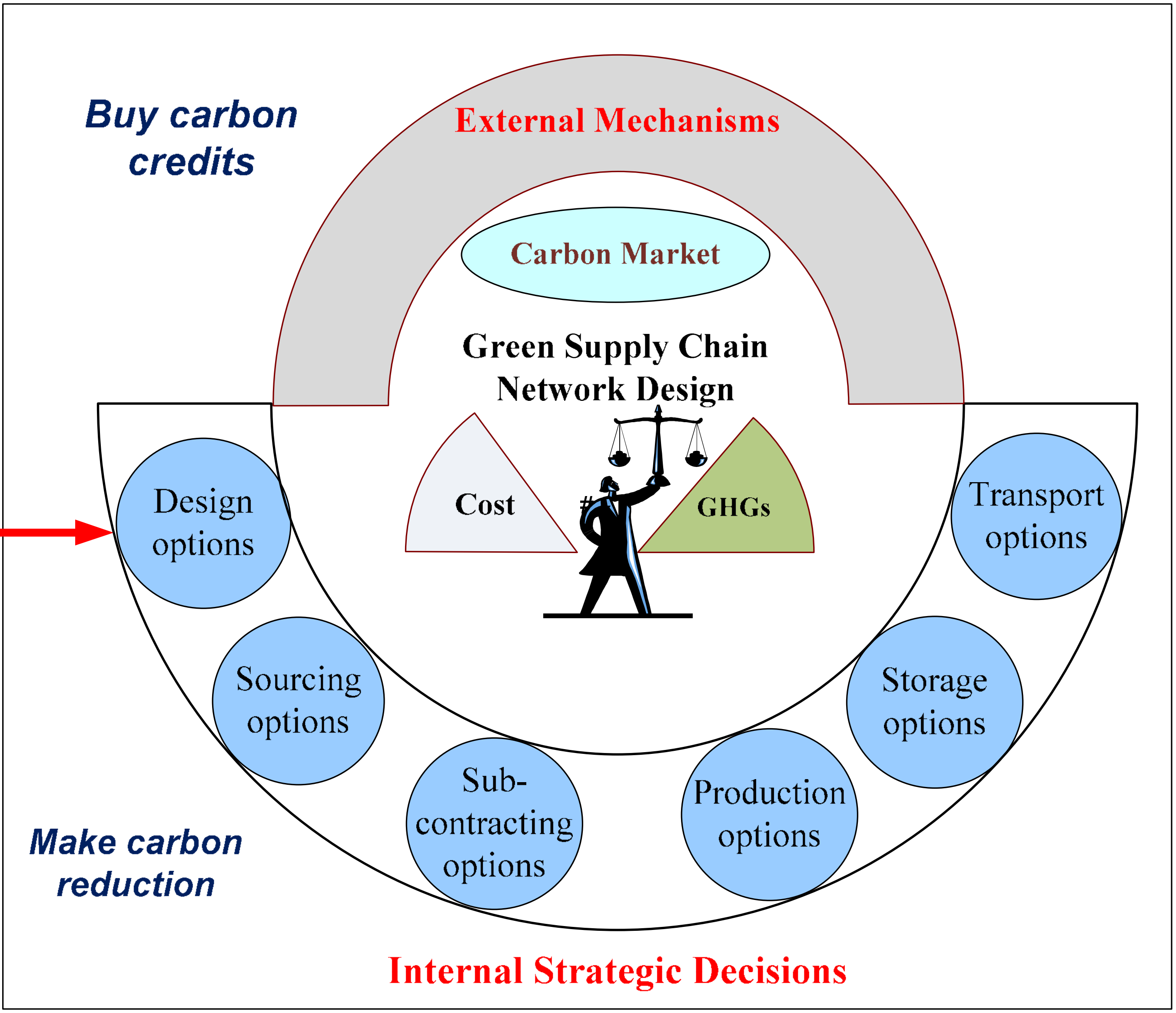
Adapted from the SCOR Model

http://www.supply-chain.org/cs/root/scor_tools_resources/scor_model/scor_model

Methodology: Mathematical programming

Degree of disaggregation

- Country
- Sector
- **Supply Chain**
- Company
- Process
- Activity
- Product



Buy carbon credits

External Mechanisms

Carbon Market

Green Supply Chain Network Design

Cost

GHGs

Design options

Sourcing options

Sub-contracting options

Production options

Storage options

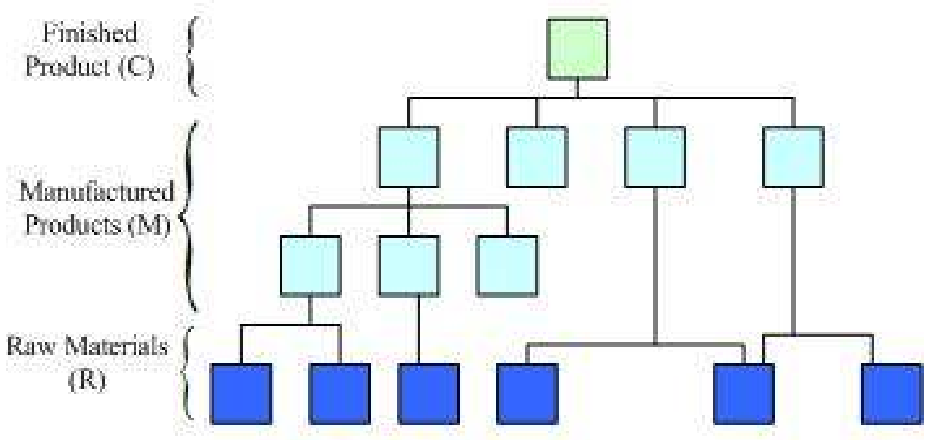
Transport options

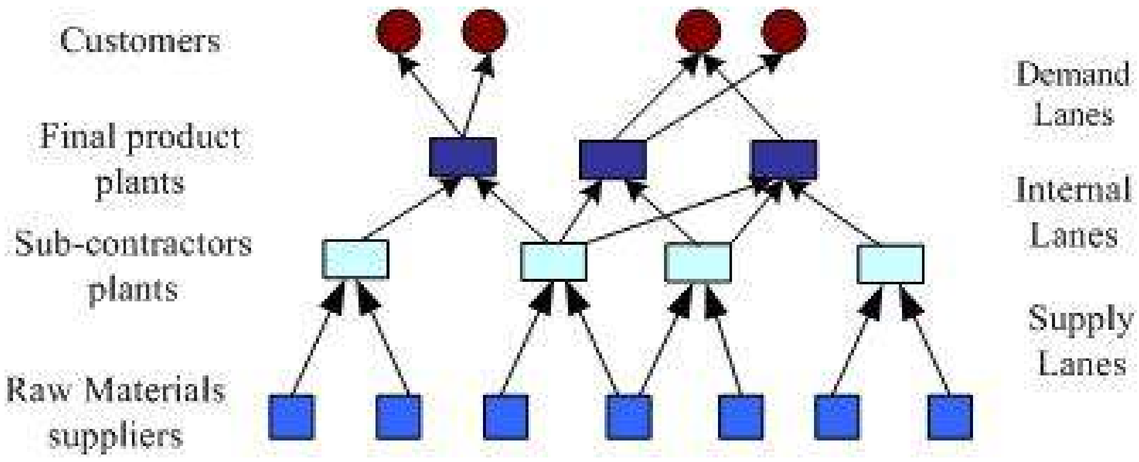
Make carbon reduction

Internal Strategic Decisions

Supply Chain Configuration

- **Products : Bill-Of-Materials**
  - Raw materials
  - Sub-assemblies
  - Finished products
- **Supply Chain Configuration**
  - Potential Suppliers
  - Potential Subcontractors
  - Production plants
- **Transportation modes**
  - Road
  - Rail
  - Air
- **GHG emission**
  - Carbon dioxide (CO_2)



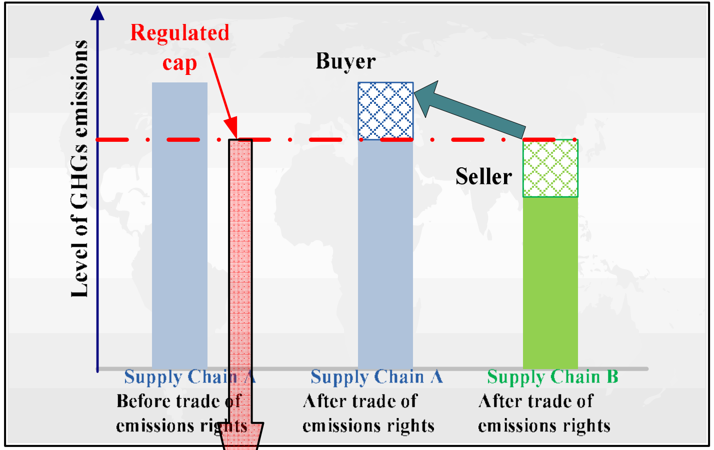


Model formulation

- Minimize the total supply chain cost
  - Majors decisions are:
    - Select
      - Suppliers, sub-contractors and production centers
      - Transportation modes to use between nodes
    - Assign
      - Raw materials to suppliers
      - Sub-assemblies to sub-contractors
    - Determine
      - Products flow between nodes
      - GHG emissions (carbon dioxide equivalent)
  - Subject to
    - Technological constraints

Formulation – *Objective Function*

- The total cost includes fixed and variable costs
  - Fixed costs are:
    - Fixed costs for facilities *(a)*
    - Assignment of raw materials to suppliers and manufactured products to subcontractors *(b)*
  - Variable costs are of five types:
    - Supply of raw materials and manufacturing products *(c)*
    - Shipment costs (related to the number of shipments) *(d)*
    - Transportation costs *(e)*
  - GHG emissions credits *(f)*



$$\text{Min } \mathbf{F}_1 = \underbrace{\sum_{i\in V\cup S}\lambda_i A_i}_{(a)} + \underbrace{\sum_{p\in M\cup R}\sum_{i\in S_p\cup V_p} a_{ip}Y_{ip}}_{(b)} + \underbrace{\sum_{p\in M\cup R}\sum_{i\in S_p\cup V_p} c_{ip}X_{ip}}_{(c)}$$

$$+ \underbrace{\sum_{i\in S\cup V}\sum_{j\in S\cup D}\sum_{k\in K} l_i^k U_{ij}^k}_{(d)} + \underbrace{\sum_{p\in M\cup R}\sum_{i\in S_p\cup V_p}\sum_{j\in S(Suc(P))\cup D}\sum_{k\in K} t_{ijp}^k F_{ijp}^k}_{(e)}$$

$$+ \boxed{\underbrace{\delta\left(\sum_{p\in M\cup R}\sum_{i\in S_p\cup V_p}\sum_{j\in S(Suc(P))\cup D}\sum_{k\in K}\alpha^k \pi_p d(i,j) F_{ijp}^k + \sum_{p\in M}\sum_{i\in S_p}\beta_p \pi_p X_{ip} - L_{\underbrace{Emission}_{Cap}}\right)}_{(f)}}$$

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Formulation – *Constraints*

- Number of operational sites

$$\sum_{i \in S_p \cup V_p} Y_{ip} \leq m_p \; (\forall p \in R \cup M) \qquad (2)$$

- Node capacity

$$X_{ip} - b_{ip} Y_{ip} \leq 0 \quad (\forall p \in R \cup M, \forall i \in S_p \cup V_p) \qquad (3)$$

- Capacity constraints
  - Maximum time capacity use for subcontractors

$$\sum_{p \in M_i} X_{ip} te_{ip} - T_i A_i \leq 0, \forall i \in S \qquad (4)$$

  - Minimum time capacity use for subcontractors

$$\sum_{p \in M_i} X_{ip} te_{ip} - \rho_i T_i A_i \geq 0, \forall i \in S \qquad (5)$$

  - Maximum capacity for suppliers

$$\sum_{p \in R_i} X_{ip} - \left(\rho_i \sum_{p \in R_i} b_{ip} \right) A_i \geq 0 \;\; (\forall i \in V) \qquad (6)$$

- Conservation of flow

$$X_{ip} - \sum_{j \in S(Suc(p)) \cup D} \sum_{k \in K} F^k_{ijp} \geq 0 \quad (\forall p \in P, \forall i \in V_p \cup S_p) \qquad (7)$$

Formulation – *Constraints*

- BOM constraints

$$\sum_{j\in V_p\cup S_p}\sum_{k\in K} F^k_{jip} - \sum_{p'\in Suc(p)} g_{pp'} X_{ip'} = 0 \quad (\forall p \in M \cup R, \forall i \in S(Suc(p))) \qquad (8)$$

- Demand constraints

$$\sum_{i\in S_p}\sum_{k\in K} F^k_{idp} = d_{pd} \quad (\forall p \in C, \forall d \in D) \qquad (10)$$

- Transportation capacity constraints
  - Maximum number of transportation modes that can be used

$$\sum_{k\in K} Z^k_{ij} \le \tau_{ij} \quad (\forall i \in V \cup S, \forall j \in S \cup D) \qquad (11)$$

  - Volume capacity

$$\sum_{p\in R_i\cup M_i} \delta_p F^k_{ijp} - \kappa^k U^k_{ij} \le 0 \quad (\forall\, i \in V \cup S, \forall j \in S \cup D, \forall k \in K) \qquad (12)$$

  - Weight capacity

$$\sum_{p\in R_i\cup M_i} \pi_p F^k_{ijp} - \psi^k U^k_{ij} \le 0 \quad (\forall\, i \in V \cup S, \forall j \in S \cup D, \forall k \in K) \qquad (13)$$

Formulation – *Constraints*

- Logical constraints
  - The number of shipments between two nodes is not nil only if the transportation mode is actually used

$$U_{ij}^{k} - MZ_{ij}^{k} \leq 0 \quad (\forall\, i \in V \cup S, \forall j \in S \cup D, \forall k \in K) \qquad (14)$$

  - A transportation mode is used between two nodes only if the number of shipments is not nil:

$$Z_{ij}^{k} \leq U_{ij}^{k} \quad (\forall i \in V \cup S, \forall j \in S \cup D, \forall k \in K) \qquad (15)$$

  - The number of shipment between two nodes using a transportation mode is nil if there is no flow of products

$$U_{ij}^{k} \leq \sum_{p \in R_i \cup M_i} F_{ijp}^{k} \quad (\forall i \in V \cup S, \forall j \in S \cup D, \forall k \in K) \qquad (16)$$

  - A site is operational if it is open for one product at least:

$$Y_{ip} - A_i \leq 0 \quad (\forall i \in S \cup V, \forall p \in M_i \cup R_i) \qquad (9)$$

Formulation – *Constraints*

- Integer, binary, and non-negativity constraints
  - Transport variables and the quantities supplied are non negative

$$F^{k}_{ijp} \geq 0 \quad (\forall p \in R \cup M, \forall i \in V_p \cup S_p, \forall j \in S(suc(p)) \cup D, \forall k \in K) \qquad (17)$$

$$X_{ip} \geq 0 \quad (\forall (p,i) \in R \times V_p \cup M \times S_p) \qquad (18)$$

  - Binary variables:

$$Y_{ip} \in \{0,1\}, \forall (p,i) \in R \times V_p \cup M \times S_p \qquad (19)$$

$$A_i \in \{0,1\}, \forall i \in S \cup V \qquad (20)$$

$$Z^{k}_{ij} \in \{0,1\} \quad (\forall i \in V \cup S, \forall j \in S \cup D, \forall k \in K) \qquad (21)$$

  - The number of shipments must be integer:

$$U^{k}_{ij} \text{ integer } \quad (\forall p \in P, \forall i \in V_p \cup S_p, \forall j \in S(Suc(p)) \cup D, \forall k \in K) \qquad (22)$$

Parameters – *Data input*

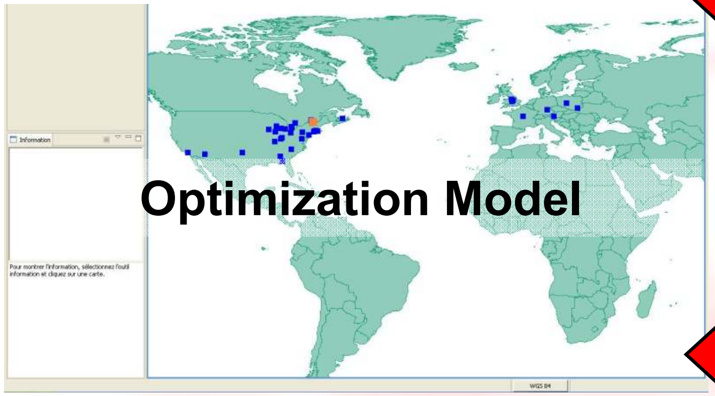
- How to find Emission Factors ?
  - Example: IPCC Emission Factor Database (EFDB)

    http://www.ipcc-nggip.iges.or.jp/EFDB/main.php

Supply Chain Activity	**Data Required**
Transportation	▪ Carbon Emission factor (kg CO_2 per gallon) or **CO_2 per Freight (kg CO_2 per ton-mile)**
Production	▪ Carbon Conversion Factor per kg of Product produced **(kg CO_2 per kg)**
Plant	▪ By plant location, the user enters the Energy Consumption per Space (e.g. kWh per sq. ft.), the Energy Consumption per Capacity (e.g. kWh per production hr) and a Carbon Conversion Factor (kg CO2 per kWh).
Warehouses	▪ By warehouse location, the user enters the Energy Consumption (e.g. kWh per sq ft.), the Carbon Conversion Factor (kg CO2 per kWh) and the Area to Apply (entire size of warehouse, or average inventory volume)

Summary of the model (DSS)

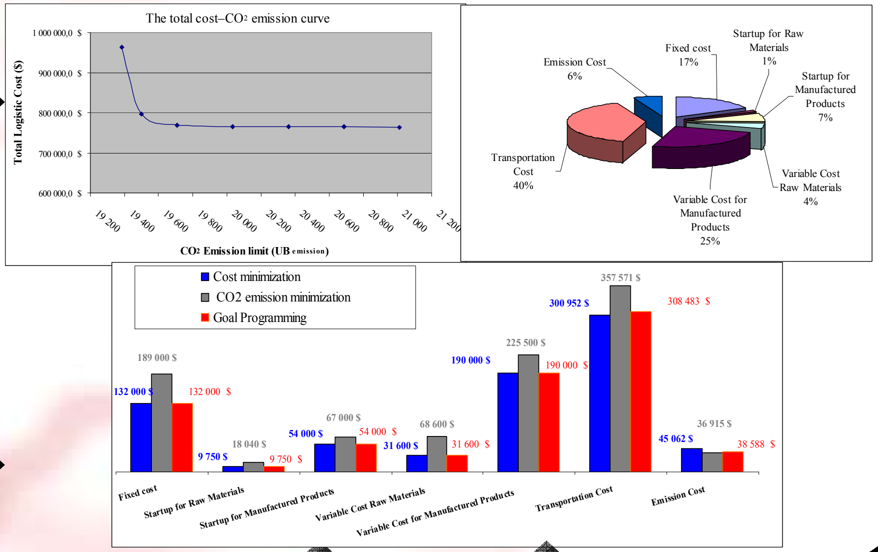
Environmental Conscious and Carbon Market Sensitive Supply Chain Network Design



Pour montrer l'information, sélectionnez l'outil information et cliquez sur une carte.

Optimization Model

GHG Emissions and cost analysis



Environmental data

Actual information system

SAP

Excel

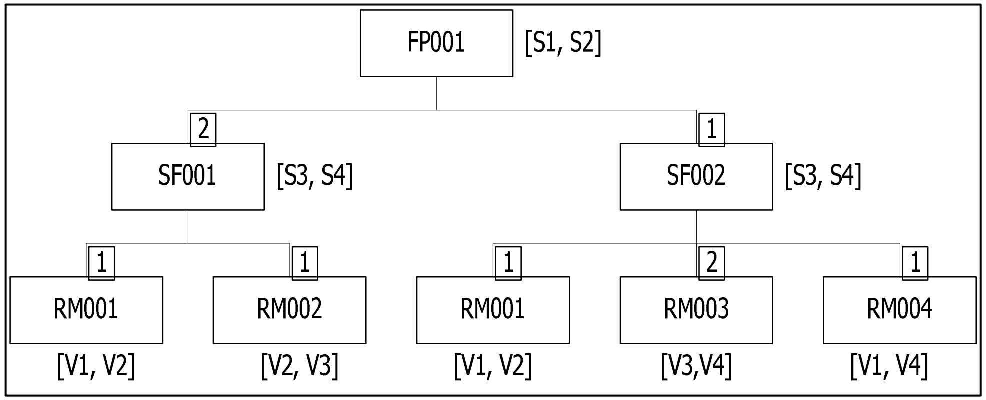
CRM

CATIA

MY SAP SCM

Experimentation – *Example*

- Environmental supply chain network design example



Transportation mode	Type	Payload (tons)	CO_2 (grams/ton-mile)
Road	Class 8b	12.5	187
rail	Intermodal rail	2,093	40
air	Boeing 747-400	70	1,385

Freight transportation emission factors (grams/ton-mile)

	Number of variables	Binary variables	Integer variables	Continuous variables	Number of constraints	Inequality constraints	Equality constraints
MILP statistics	207	64	42	101	232	210	22

MILP model characteristics

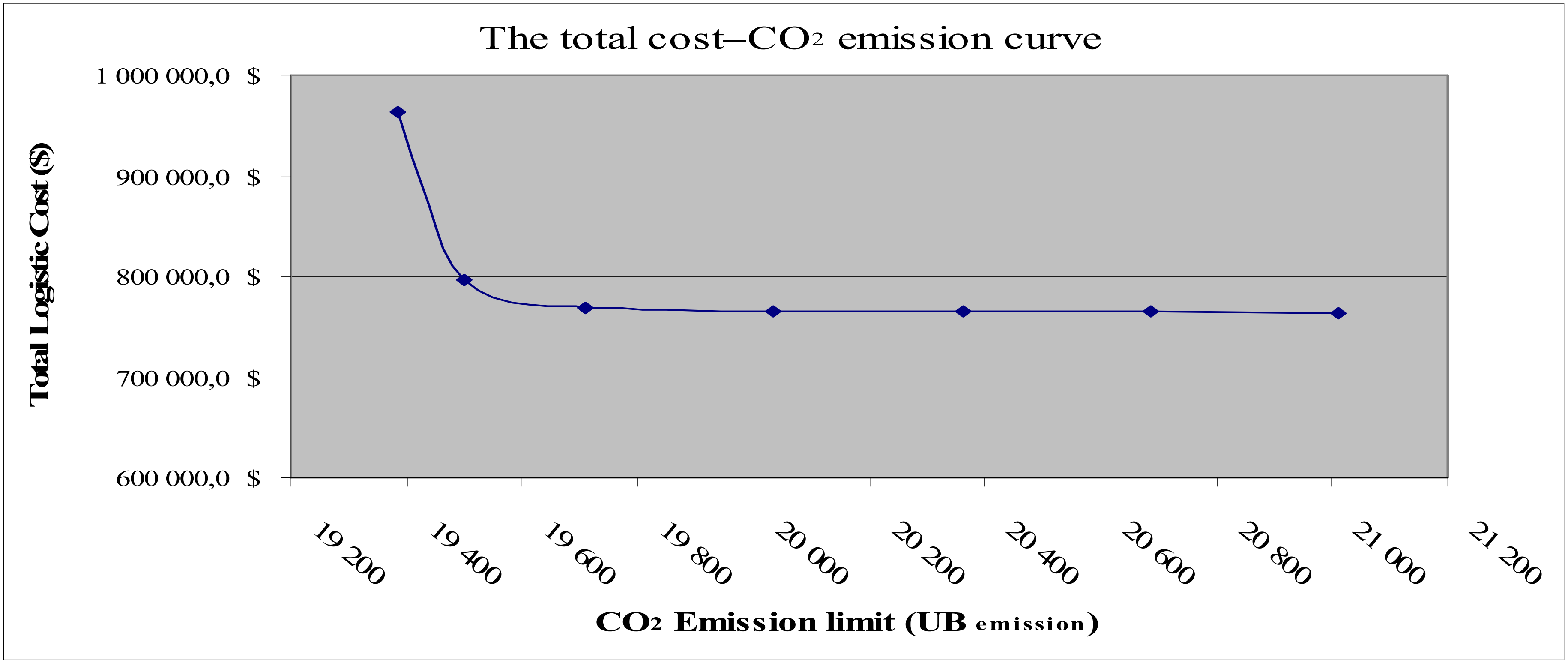
Experimentation – *Results*

- The MILP problem is solved by CPLEX Interactive Optimizer

	GHG emission limit ($UP_{Emission}$) *(in tons)*	Total Cost ($)
Base scenario	21 012	763 364 $
Scenario 2	20 687	764 421 $
Scenario 3	20 361	764 421 $
Scenario 4	20 035	764 421 $
Scenario 5	19 710	768 802 $
Scenario 6	19 709	768 802 $
Scenario 7	19 500	796 032 $
Scenario 8	19 383	962 626 $

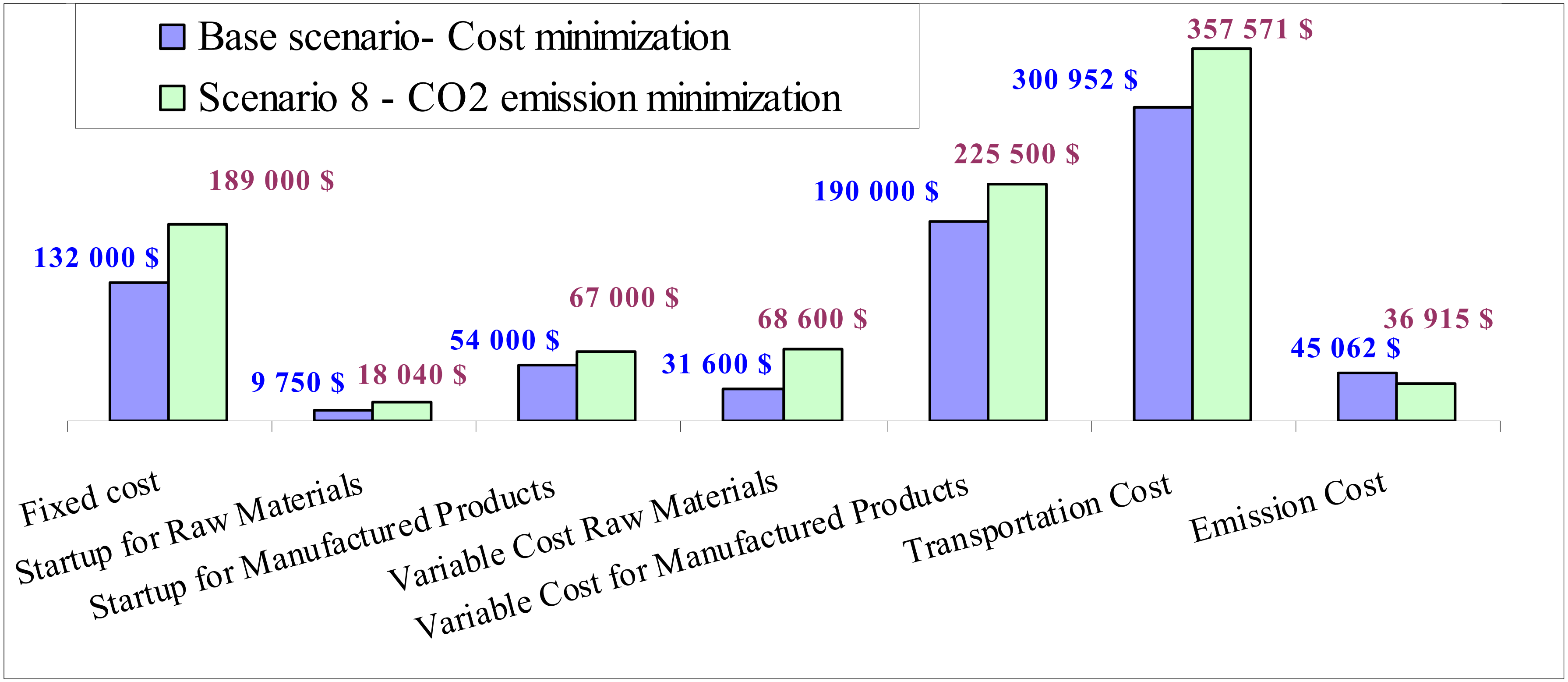
Some managerial insights

- Tradeoffs between cost and CO_2 emissions
- Cost analysis
- GHG emissions assessment



Some managerial insights

Cost minimization versus CO_2 emissions minimization



Thank you

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2. A. Chaabane, A. Ramudhin, M. Kharoune, and M. Paquet. "Trade-offs Model for Carbon Market Sensitive Green Supply Chain Network Design". In Proceeding of the Sixth Annual International Symposium On supply Chain Management, Calgary, Alberta, Canada, October 15th – 17th 2008.

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Questions ?

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