

**Wiley Series in Operations Research  
and Management Science**

# **SUSTAINABLE OPERATIONS AND SUPPLY CHAIN MANAGEMENT**



**Valeria Belvedere  
Alberto Grando**

**WILEY**



# **SUSTAINABLE OPERATIONS AND SUPPLY CHAIN MANAGEMENT**

---

**VALERIA BELVEDERE**

Catholic University of the Sacred Heart, Milan, Italy

**ALBERTO GRANDO**

Bocconi University – SDA Bocconi School of Management, Milan, Italy

**WILEY**



This edition first published 2017  
© 2017 John Wiley & Sons Ltd

*Registered office*

John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ,  
United Kingdom

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at [www.wiley.com](http://www.wiley.com).

The right of the author to be identified as the author of this work has been asserted in accordance with the Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book.

**Limit of Liability/Disclaimer of Warranty:** While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. It is sold on the understanding that the publisher is not engaged in rendering professional services and neither the publisher nor the author shall be liable for damages arising herefrom. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

*Library of Congress Cataloging-in-Publication Data*

Names: Belvedere, Valeria, 1973– author. | Grando, Alberto, 1957– author.

Title: Sustainable operations and supply chain management / Valeria Belvedere, Alberto Grando.

Description: Hoboken : Wiley, 2017. | Series: Wiley series in operations research and management science | Includes bibliographical references and index.

Identifiers: LCCN 2016036070 (print) | LCCN 2016037822 (ebook) | ISBN 9781119284956 (cloth) | ISBN 9781119285366 (pdf) | ISBN 9781119285373 (epub)

Subjects: LCSH: Sustainable development. | Business logistics.

Classification: LCC HC79.E5 B4455 2017 (print) | LCC HC79.E5 (ebook) | DDC 658.5–dc23

LC record available at <https://lccn.loc.gov/2016036070>

A catalogue record for this book is available from the British Library.

Set in 10/12pt Times by SPi Global, Pondicherry, India

Printed in the UK



# CONTENTS

|   |             |
|---|-------------|
| <b>PREFACE</b>  | <b>x</b>    |
| <b>ACKNOWLEDGEMENTS</b>   | <b>xiii</b> |
| <b>1 Sustainability and Future Trends</b>   | <b>1</b>    |
| 1.1 Introduction  | 1           |
| 1.2 Sustainability Before Sustainable Operations and Supply Chain Management                  | 2           |
| 1.3 The Impact of Climate Change  | 7           |
| 1.4 Mega-Trends and Sustainability  | 9           |
| 1.4.1 Demographic Evolution   | 10          |
| 1.4.2 Urbanisation  | 11          |
| 1.4.3 Emerging New Consumers  | 12          |
| 1.4.4 Smart Technologies and the Digital Factory  | 15          |
| 1.5 Mega-Trends, Sustainability and Supply Chain Management                                   | 17          |
| 1.6 Sustainable Development and Corporate Social Responsibility                               | 19          |
| 1.7 The Development of Sustainable Objectives from the Triple Bottom Line Perspective         | 22          |
| 1.8 Sustainability: The Reasons Why   | 23          |
| <b>2 Sustainable Operations and Supply Chain Management as Competitive Factors</b>            | <b>28</b>   |
| 2.1 Introduction  | 28          |
| 2.2 Operations, Logistics and Supply Chain Management in Manufacturing and Service Industries | 31          |



|          |  |            |
|----------|--|------------|
| 2.3      | Operations, Supply Chain Management and Competitive Advantage                | 37         |
| 2.3.1    | Strategic Alignment  | 37         |
| 2.3.2    | Operations, Supply Chain Management and Decision Making                      | 39         |
| 2.3.3    | Operations and Supply Chain Performance Management<br>and Control            | 40         |
| 2.4      | Performance and Trade-Off Management   | 43         |
| 2.5      | Sustainable Operations and Supply Chain Management: A Reference<br>Framework | 44         |
| <b>3</b> | <b>Sustainability and New Product Design</b>                                 | <b>52</b>  |
| 3.1      | Introduction   | 52         |
| 3.2      | The Environmental Orientation Path   | 54         |
| 3.3      | Life Cycle and Cradle-to-Cradle Approaches                                   | 58         |
| 3.4      | Eco-Efficiency and Eco-Effectiveness   | 61         |
| 3.5      | The Design for Approaches  | 64         |
| 3.5.1    | Design for Environment   | 66         |
| 3.5.2    | DFE Principles   | 70         |
| <b>4</b> | <b>Sustainability and Procurement</b>  | <b>81</b>  |
| 4.1      | Introduction   | 81         |
| 4.2      | The Role of Procurement in Delivering Sustainable Solutions                  | 83         |
| 4.3      | Implementing a Sustainable Procurement Strategy                              | 85         |
| 4.3.1    | Identifying Needs and Defining Specifications                                | 87         |
| 4.3.2    | Vendor Pre-Selection   | 88         |
| 4.3.3    | Tender Evaluation and Vendor Selection                                       | 90         |
| 4.3.4    | Vendor Control and Contract Management                                       | 92         |
| 4.4      | Ethics in Procurement  | 94         |
| <b>5</b> | <b>Sustainability and Production</b>   | <b>98</b>  |
| 5.1      | Introduction   | 98         |
| 5.2      | The Design of the Production System  | 100        |
| 5.3      | Leveraging Lean Management for a Sustainable Production                      | 102        |
| 5.3.1    | Overview of Environmental and Social "Wastes"                                | 105        |
| 5.3.2    | The Lean Principles and Toolkit  | 109        |
| 5.4      | Leveraging Six-Sigma for a Sustainable Production                            | 126        |
| 5.4.1    | Six Sigma and Statistical Process Control                                    | 130        |
| 5.5      | Servitisation and Leasing  | 135        |
| <b>6</b> | <b>Sustainability and Logistics, Physical Distribution and Packaging</b>     | <b>136</b> |
| 6.1      | Introduction   | 136        |
| 6.2      | Social and Environmental Aspects in Logistics and Physical Distribution      | 138        |
| 6.3      | Physical Distribution and Sustainability: A Reference Framework              | 140        |
| 6.3.1    | Carbon Footprint Auditing  | 145        |
| 6.3.2    | Eliminating Transportation Waste   | 149        |



|          |  |            |
|----------|--|------------|
| 6.4      | Warehouse Management and Sustainability  | 155        |
| 6.5      | Sustainable Packaging  | 159        |
| <b>7</b> | <b>Reverse Logistics Management and Closed-Loop Supply Chain</b>               | <b>162</b> |
| 7.1      | Introduction   | 162        |
| 7.2      | Reverse Flows and Sustainability   | 164        |
| 7.3      | Reverse Logistics and Closed-Loop Supply Chain: Not only a Semantic Difference | 166        |
| 7.4      | Closed-Loop Supply Chain Management: Integrating Forward and Backward Flows    | 168        |
| 7.5      | Sustainable Supply Chains: Why, Who, What and How?                             | 169        |
| 7.5.1    | Why? Drivers and Reasons in Sustainable Supply Chains                          | 170        |
| 7.5.2    | Who? Main Players in Sustainable Supply Chains                                 | 171        |
| 7.5.3    | What? Products, Materials and Packaging in Sustainable Supply Chains           | 173        |
| 7.5.4    | How? Recovery Options in Sustainable Supply Chains                             | 175        |
| 7.6      | Value Creation Through Recovery Options  | 178        |
| <b>8</b> | <b>Measuring Sustainability</b>  | <b>186</b> |
| 8.1      | Introduction   | 186        |
| 8.2      | Measuring Sustainability in Manufacturing Companies                            | 188        |
| 8.3      | Sustainable Development Measurement  | 189        |
| 8.3.1    | The Measurement of GDP: Limits   | 189        |
| 8.3.2    | Human Development Index  | 191        |
| 8.4      | Sustainability Measurement in Companies  | 194        |
| 8.4.1    | Relevant Profiles  | 194        |
| 8.4.2    | Reference Models   | 197        |
|          | <b>REFERENCES</b>  | <b>204</b> |
|          | <b>INDEX</b>   | <b>224</b> |



# INDEX

- Activity-based approach, 148  
Agenda 21, 194
- Balanced scorecard, 72, 92–93, 188, 198  
Balancing, 118–121  
Benchmarking, 200  
Biofuels, 154  
Biological nutrients, 57–59, 78–79,  
106–107  
Black Belts, 129  
Bottom of the pyramid, 13
- Cannibalisation, 177–181  
CAPS. *see* Center of Advanced Purchasing  
Studies Research  
Carbon dioxide equivalent, 5, 8, 50–51, 66,  
107, 143–145, 148–147, 149,  
153–155, 182, 191, 195, 199, 201  
Carbon footprint auditing, 145–149  
Carbon offsets, 154–155  
Cellular manufacturing, 118–121  
Center of Advanced Purchasing Studies  
Research, 83
- Certifications, 24–26, 44, 56, 72, 89–90,  
106, 108, 157  
Circular economy, 55–59, 63, 78–79,  
163–164  
Climate change, 1–5, 7–9, 18, 53, 75, 107  
Closed-loop supply chain, 162–185  
Code of conduct, 94–97  
CO<sub>2e</sub>. *see* Carbon dioxide equivalent  
Collection, 26, 57, 168–170, 174–175,  
181–182  
Compliance, 24–26, 54–55, 89, 97, 164,  
170–171  
Consignment Stock, 152  
Continuous Replenishment Programs, 152  
Contract management, 86, 92–94  
Control approach, 147  
Control chart, 131–132  
Corporate social responsibility, 19–21, 44,  
48–50, 94, 136  
Corporate sustainability assessment,  
201–203  
Cradle-to-cradle, 47, 54–63, 68, 106, 185  
Cradle-to-gate, 59



- Cradle-to-grave, 54, 59–63, 107  
 CRP. *see* Continuous Replenishment Programs  
 CSA. *see* Corporate Sustainability Assessment  
 Current state, 112–115, 149  
 Customer service, 35, 101, 140–142
- Dashboard, 42, 72, 188  
 Delivery planning, 150–153  
 Dematerialisation, 61, 63, 74–76  
 Deming's cycle. *see* Plan-Do-Check-Act  
 Demographic Evolution, 10–11  
 Design for Environment, 48, 54–55, 65–80, 88, 159  
   for capital protection and renewal, 74–76  
   for dematerialization, 74–76  
   for detoxification, 74–76  
   principles, 70–80  
   for revalorization, 74–76  
 Design for X, 54, 65–66  
 Detoxification, 74–75  
 DFE. *see* Design for Environment  
 Disposal, 57–62, 65, 68, 70, 74–75, 110, 166, 168, 171, 173, 176–178, 182–183, 191  
   with energy recovery, 182  
   without energy recovery, 182  
 Distribution channel, 142–144  
 DJSI. *see* Dow Jones Sustainability Index  
 DMAIC, 128–129  
 Dow Jones Sustainability Index, 201–203  
 Down cycling, 56, 63, 79
- Eco-effectiveness, 54, 61–63, 68, 71  
 Eco-efficiency, 54, 61–63, 66, 68, 71, 182, 198  
 Eco-Management and Audit Scheme, 26, 44, 86, 88–90, 108  
 Education Index, 193  
 EMAS. *see* Eco-Management and Audit Scheme  
 EMS. *see* Environmental Management System  
 Enforcement, 26, 54  
 Environmental management orientation, 54  
 Environmental Management System, 86–89, 92, 195–196
- Environmental Protection Agency, 27, 110, 116  
 Environmental purchasing, 83–86  
 EPA. *see* Environmental Protection Agency  
 E-PRTR. *see* European Pollutant Release and Transfer Register  
 Equity share approach, 147  
 Ethics in procurement, 94–97  
 EU Emissions Trading System, 155  
 EU ETS. *see* EU Emissions Trading System  
 European Pollutant Release and Transfer Register, 145
- Feed-back control, 42, 49  
 Feed-forward control, 42, 49, 142  
 First Time Pass Yield Rate, 128
- 5S  
   set in order (seiton), 125–126  
   shine (seiso), 125–126  
   sort (seiri), 125–126  
   standardise (seiketsu), 125–126  
   sustain (shitsuke), 125–126
- Fleet management, 153–154  
 Flexibility mechanism, 146  
 Flexible manufacturing systems, 102  
 Flow rate, 115  
 FMS. *see* Flexible manufacturing systems  
 Food losses, 6–7  
 Food waste, 6–7  
 Footprint, 5–7, 63, 77, 83, 105, 115, 143–155, 158–159, 191–192  
   Carbon Footprint, 5–7, 77, 83, 145–155, 158–159  
   Ecological Footprint, 5–6, 191–192  
   Water Footprint, 5  
 Forward flows, 169, 172  
 Freight, 139, 140, 148–149, 151–154, 159  
 Fuel-based approach, 148  
 Fuel type, 148  
 Future state, 116, 118
- Gatekeeping, 175  
 GDP. *see* Gross Domestic Product  
 Genuine Savings Indicator, 191  
 GHG. *see* Greenhouse gases  
 Global hectares, 191–192  
 Global Position System, 153  
 Global Reporting Initiative, 27, 71, 200–201



- Global warming potential, 147  
 GNI. *see* Gross National Income  
 GPS. *see* Global Position System  
 Green Belts, 129  
 Greenhouse gases, 4, 8, 26, 85, 90, 130, 140, 146–148, 155  
 Green House Gas Protocol Corporate Standard, 146  
 Green procurement, 83–86  
 Green supply chain management, 165, 167  
 Green Value Stream, 112  
 GRI. *see* Global Reporting Initiative  
 Gross Domestic Product, 138, 189  
 Gross National Income  
   index per capita, 193  
 Gross Vehicle Weight, 151  
 Guidelines  
   prescriptive guidelines, 73  
   suggestive guidelines, 74  
 GWP. *see* Global warming potential  
  
 Handling equipment, 142, 154, 156–158  
 Human Development Index, 191–194  
  
 IFPSM. *see* International Federation of Purchasing and Supply Management  
 ILO. *see* International Labour Standards  
 Industry 4.0, 16  
 Input-output line, 117  
 Inspection, 175, 177, 179, 184  
 Integrated Pollution Prevention and Control Directive, 145  
 International Federation of Purchasing and Supply Management, 95  
 International Labour Standards, 26, 90  
 IPPC Directive. *see* Integrated Pollution Prevention and Control Directive  
 ISO  
   ISO 14000, 26, 44, 86, 88–90, 108  
   ISO 14020, 87  
   ISO 50001, 90  
  
 Just-in-time, 102, 111, 121, 123, 151, 153  
  
 Kanban, 113, 120–123  
 Kanban board, 122  
 Key performance indicators, 18, 38, 42–43, 49, 71–72, 188, 190, 197–199  
 Kyoto Protocol, 145–147, 155  
  
 Labels, 72, 87  
 Landfilling, 177, 182  
 Land take, 109–110  
 Lay-out, 118–121  
 Leadership in Energy and Environmental Design certification, 72–157  
 Lean management, 99, 101–126, 198  
 LEED certification. *see* Leadership in Energy and Environmental Design  
 Life-cycle  
   analysis, 47–50  
   assessment matrix, 45, 54–59, 62, 68–69  
   business life cycle, 60–61, 67  
   physical, 60–61, 70  
   thinking, 67, 70  
 Life expectancy index, 193  
 Local sourcing, 150  
 Logistic network, 142–145  
 Logistic service, 100, 104, 111, 142–1444  
 Logistics management, 31–39, 48, 138–145, 164–166  
  
 Manufacturing recall, 171  
 Marginal value, 183  
 Master Black Belts, 129  
 Materials handling, 141–142, 154, 157  
 Materials line. *see* Input-output line  
 Mega trends, 9–19  
 Metering, 116–117  
 Mixed model approach, 118–121  
 Monstrous hybrids, 79, 174  
 Muda, 103–104  
  
 National accounting systems, 189–191  
 NDDS. *see* Nominated Day Delivery System  
 Network  
   closed-loop, 172  
   open-loop, 172  
 Nominated Day Delivery System, 153  
 Nutrients. *see* Biological Nutrients; Technical Nutrients  
  
 Occupational Health and Safety Assessment Series 18001, 90  
 OEE. *see* Overall Equipment Effectiveness  
 OHSAS 18001. *see* Occupational Health and Safety Assessment Series 18001



- Operations  
 operations management function, 31–33, 36, 38, 44–45, 100\*  
 operations system, 31, 42
- Order qualifier, 30, 38–39, 42–43
- Order winner, 30, 39, 42–43, 89
- Overall Equipment Effectiveness, 123–125
- Packaging, 25, 48, 50, 59, 63, 65–80, 87–88, 110, 142, 159–161, 165, 170–179
- Part harvesting, 55, 179–180
- PDCA. *see* Plan-Do-Check-Act
- Performance  
 external, 41–42  
 internal, 41–42
- Performance measurement system, 42, 72, 188–189
- Physical distribution, 140–145
- Picking, 156–157
- Plan-Do-Check-Act, 86, 89
- PMS. *see* Performance measurement system
- Precision farming, 19
- Process capability, 132–134
- Product Energy Intensity, 116
- Productivity paradox, 100
- Recycling, 26, 44, 51, 55, 60, 62–65, 68–72, 75, 79, 160, 164–166, 171–184
- Remanufacturing, 58, 62, 66, 68, 70, 72, 75, 79, 104, 164, 174, 177–178, 183
- Reporting system, 49, 71–72, 85, 198
- Resale, 177–179, 183–184
- Resource efficiency, 56, 70
- Return  
 asset, 171  
 consumer, 170  
 environmental, 171  
 marketing/distribution, 170
- Reuse, 32, 47, 49, 56–79, 84, 88, 144, 160, 162–185
- Revalorisation, 70, 74–76
- Reverse  
 flows, 36, 55, 164–165, 167–169, 172, 174, 176  
 logistics management, 19, 36, 49, 56, 141, 162–185  
 supply chain management, 162–185
- RFID, 16, 18, 77
- RobecoSam, 201–203
- SA 8000. *see* Social Accountability 8000
- Secondary market, 58, 60, 68, 172, 174–176, 178, 182
- Selection. *see* Sortation/selection
- Service level agreements, 150–153
- Servitisation, 135
- Setup, 120, 123–125
- Single Minute Exchange of Die, 123
- Six Sigma, 99, 101, 130–135
- Smart  
 smart machines, 16  
 smart products, 15  
 smart technologies, 15
- SMED. *see* Single Minute Exchange of Die
- Social Accountability 8000, 26, 90
- Sortation/selection, 175, 177, 184
- SSC Scorecard. *see* Sustainable Supply Chain, Scorecard
- Storage, 34–36, 65, 70, 116, 140–144, 155–159
- Strategy  
 emergent, 37  
 market-based, 37  
 resource-based, 38  
 strategic alignment process, 30, 37–39, 47–48  
 strategy formulation, 37–39
- Supplier-balanced scorecard, 92–93
- Supply chain management, 32–44, 83–85
- Sustainability  
 corporate, 22–23, 44–51  
 environmental, 22–23, 44–51  
 financial, 22–23, 44–51  
 social, 22–23, 44–51
- Sustainable development, 19–23, 189–194
- Sustainable operations, 44–51, 98–135
- Sustainable packaging, 159–161, 173–178
- Sustainable procurement, 83–86
- Sustainable Supply Chain, 44–51, 136–185  
 scorecard, 197–200
- Takt-time, 120
- Technical nutrients, 57–59, 78–79, 106–107
- Tender evaluation, 85–86, 90–92
- Testing. *see* Inspection
- 3D printers, 16
- Time for return, 183



- Time line, 115, 117
- TMS. *see* Transportation Management Systems
- Total Productive Maintenance, 123–125
- Total Quality Management, 126, 128
- Toyota Production System, 102–103
- TPM. *see* Total Productive Maintenance
- TPS. *see* Toyota Production System
- TQM. *see* Total Quality Management
- Trade-off, 38, 40, 43–44, 47, 76–77, 101–102
- Transportation Management Systems, 136–161
- Transportation waste elimination sheet, 149–150
- Triple Bottom Line, 22–23, 47, 49, 54, 64, 70, 182, 194, 200
- UNDP. *see* United Nations Development Program
- United Nations Commission on Sustainable Development, 194
- United Nations Development Program, 192
- Up cycling, 56, 63–64, 68, 78
- Urbanisation, 6, 11–12, 17
- U-shape production line, 118–121
- Value stream mapping, 111–118
- Vendor control, 85–86, 92–94
- Vendor Managed Inventory, 152
- Vendor rate(ing), 85–86, 90–92
- Vendor selection, 85–86, 90–92
- VMI. *see* Vendor Managed Inventory
- Warehouse Management Systems, 143, 155–159
- Warehousing, 141, 155–159
- Waste
- emissions, 17–104, 108
  - energy, 104–105
  - hierarchy, 88
  - land contamination and biodiversity, 104, 109
  - noise, 104, 108–109
  - physical, 104, 106–107
  - water, 104–106
- Water balance, 117
- Wellbeing, 108, 189–192, 196
- WMS. *see* Warehouse Management Systems
- World Bank, 191–192