

Closed circular economy model of the forest sector in the regional aspect

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Abstract. The article presents a model of the circular economy in the context of the forest sector, emphasizing the importance of incorporating forest resources into circular supply chains that extend from the forest to consumers. Based on the logical structure of measuring the development of the circular economy in the forest sector and based on the availability of data, a system for assessing the indicators of the development of the circulareconomy in the forest sector was formulated, including financial, social, and environmental aspects, such as resource efficiency, environmental impact, economic efficiency and social well-being. Based on the results of the study, recommendations for the formation of a circular economy model in the forest sector were formulated.

1 Introduction

The relevance of the study is related to the fact that the forest sector is of key importance for the formation of a global model of a circular economy. By the forest sector, we mean an integrated part of the national economy, consisting of forestry, forest industry complexes, and forest ecosystems. We also pay attention to the fact that the activity of involving wood and non-wood forest resources in cyclical transformation is constantly increasing.

We will consider sustainable forest management the starting point for the introduction of cyclical practices. Because forests perform important ecosystem functions, which include the regulation of water flow, the preservation of biodiversity, and the absorption and retention of carbon. Extensive logging can reduce the ability of forests to act as carbon sinks and mitigate the effects of global climate change. In addition, the destruction of forests can lead to the loss of habitat for wild animals, threatening the preservation of biodiversity.

The second premise is that the harvesting and processing of wood generates a large amount of wood chips, dust, and other waste, which, if improperly disposed of, pollutes the environment. The use of chemicals such as preservatives, dyes, and adhesives can also pollute soil and water bodies, affecting human health and ecosystem safety.

The third component of circulareconomy modeling is the services of forest ecosystems, which can slow the rate of global warming by absorbing carbon dioxide, while wetland

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ecosystems can influence the distribution of precipitation by regulating water cycle. Different species in an ecosystem typically have different biological properties, growth patterns, and species interactions. When one species is exposed to a certain impact, other species can perform their functions for a short period of time, thereby reducing damage to the ecosystem. Thus, more diverse ecosystems can better withstand shocks and mitigate the negative effects of climate change.

This study aims to form a closed-loop economy model for the forest sector on a systemic and comprehensive basis and to determine the inclusion of the value of forest resources in cyclical supply chains from nature (forests) to consumers. The information base for the study was the official statistics of Rosstat and Rosleskhoz. To achieve this goal, general scientific empirical and theoretical methods of system analysis, scientific abstraction, analysis and synthesis, induction and deduction, modeling, and specification were used. Comparative, factor, and correlation-regression analysis were used as specific scientific methods.

2 Methods and materials

The value of forest resources is changing due to the growing attention to environmental protection and sustainable development. Forests are not only a source of raw materials for construction, furniture, and pulp and paper production. Climate regulation policy documents [1-4] emphasize the main ability of forests to regulate climate, sequester and retain carbon. Moreover, it is the boreal forest located in the territory of the Russian Federation that mainly accumulates litter and fixes carbon. Increasing the carbon sinks in forests strengthens the position of the forest sector in the process of achieving maximum carbon neutrality, by absorbing carbon dioxide from the atmosphere through photosynthesis, accumulating carbon, and releasing oxygen. In addition, forests provide a habitat for the conservation of biodiversity and are necessary for maintaining ecosystem balance [5].

At the same time, it should be noted that the forestry sector has a negative impact on the environment, which is expressed in the fact that excessive logging and illegal logging lead to a reduction in forest area, a decrease in the quality of ecosystem services, and a loss of biodiversity. During the harvesting and processing of wood, a large amount of waste and pollutants, including wood chips, dust and chemicals, can be generated in the air [6].

Following the technological chain, wood, as a renewable resource, emits relatively little carbon during processing and use. The use of wood products and wooden structures in the construction of buildings allows to reduce dependence on building materials with high levels of carbon emissions and reduce the total carbon footprint [7, 8].

The closed-loop economy model of the forest sector covers sustainable forest management, deep and secondary processing of wood based on the implementation of the best available technologies. Generally applicable measures of state support for the implementation of the best available technologies in the forestry sector are: inclusion of the costs of their implementation in the fee for negative impact on the environment, provision of an investment tax credit to ensure measures to reduce the negative impact on the environment, introduction of an increased depreciation rate for equipment from a certain list, implementation of special investment contracts, and the use of green financing instruments.

In 2023, the volume of production in the forestry complex of the Russian Federation continued to decline (Figure 1) and amounted to 95.76% of the 2022 volume. The noted negative trend is associated with sanctions pressure and, accordingly, with a ban on export deliveries to European markets. The domestic market was not ready for increased supplies from domestic producers, which led to a drop in prices and profitability for forestry companies.

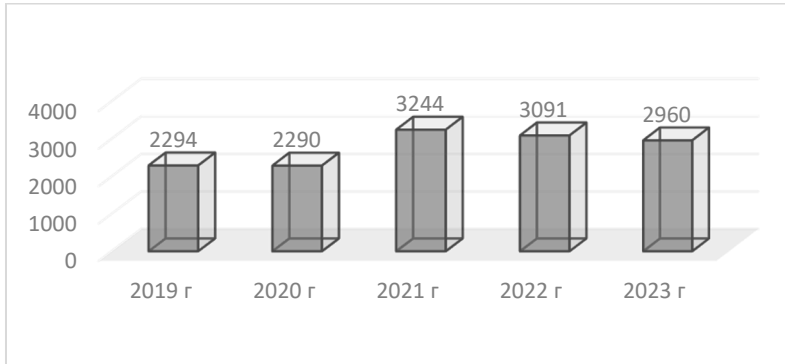


Fig. 1. Volumes of domestic production in all sub-sectors of the forest industry complex of the Russian Federation, billion rubles.

For these reasons, the production of basic types of products, such as logging, production of sawn timber, plywood, paper and cardboard, is declining (Table 1). Against the backdrop of geopolitical events, a new vision of the forestry sector development is being formed, when the main share of forestry products should be sold on the domestic market.

Table 1. Dynamics of production of the main groups of goods of the forest industry complex of the Russian Federation.

Forest industry indicators	2019	2020	2021	2022	2023
		Growth rate 2020/2019,%	Growth rate 2021/2020,%	Growth rate 2022/2021,%	Growth rate 2023/2022,%
Volumes of domestic production in all sub-sectors of the forestry complex of the Russian Federation, billion rubles	2294 100 %	2290 99.82 %	3244 141.66 %	3091 95.28%	2960 95.76 %
Volume of round timber harvesting, million m3	362 100 %	294 81.21 %	233 79.25 %	195 83.71 %	185 94.88 %
Volume of sawn timber production, million m3	44.8 100 %	42.4 94.64 %	32.6 76.87 %	29.8 91.41 %	28.5 95.64 %
Plywood production volume, thousand m3	4081 100 %	4280 104.88 %	4452 104.02 %	3371 75.72 %	3265 96.85 %
Volume of chipboard production, thousand m3	9986 100 %	11211 112.27 %	11410 101.77 %	10420 91.32 %	11603 111.35 %
Fiberboard production volume, million m2	682 100 %	720 105.57 %	740 102.78 %	658 88.92 %	703 106.84 %
Volume of paper and cardboard production, thousand tons	9131 100 %	9860 107.98%	1042 105.7 %	1011 97.02 %	1000 98.91 %
Volume of production of	611 100 %	562 91.98 %	475 84.52 %	408 85.89 %	330 80.88 %

wooden windows, thousand m3					
Volume of production of wooden doors, million m2	20.4	19.8	19.6	21.3	22.8
	100 %	97.06 %	98.99 %	108.67 %	107.04 %

This requires the promotion of wooden housing construction projects, investments in the construction of new and modernized operating pulp and paper mills. In our opinion, the rejection of the export orientation of the forestry complex increases the importance of introducing the principles of a closed-loop economy, sustainable forest management based on increasing forest productivity while preserving biodiversity and performing environmental and social functions. Structural changes in the forestry industry are expressed in the use of environmentally friendly and lean logging technologies, an increase in production capacity for deep processing, including waste and low-quality wood, the development of transport infrastructure for logging, and forestry engineering.

To determine the forecast dynamics of the forest industry complex development, covering the entire process from extraction to processing of wood, we will calculate the average value of the change in indicators and present the data in Table 2.

Table 2. Data for calculating the average value of change in growth indicators.

Indicators of the timber industry	The average value of the change in growth indicators per year, %
Volume of domestic production in all sub-sectors of the forestry industry of the Russian Federation, billion rubles	106.5
Volume of round timber harvesting, million m3	87.81
Volume of sawn timber production, million m3	91.71
Plywood production volume, thousand m3	96.29
Volume of chipboard production, thousand m3	103.34
Fiberboard production volume, million m2	100.82
Volume of paper and cardboard production, thousand tons	82.89
Volume of production of wooden windows, thousand m3	88.65
Volume of production of wooden doors, million m2	102.35

From the data in Table 2 it is clear that average annual growth is observed for the following indicators:

- volume of domestic production for all sub-sectors of the forest industry complex of the Russian Federation;
- volume of chipboard production;
- volume of fiberboard production;
- volume of wooden door production.

Using the calculation of the average annual growth rate, we will construct a forecast growth dynamics of the development indicators of the forest industry complex of the Russian Federation until 2030 (Figure 2).

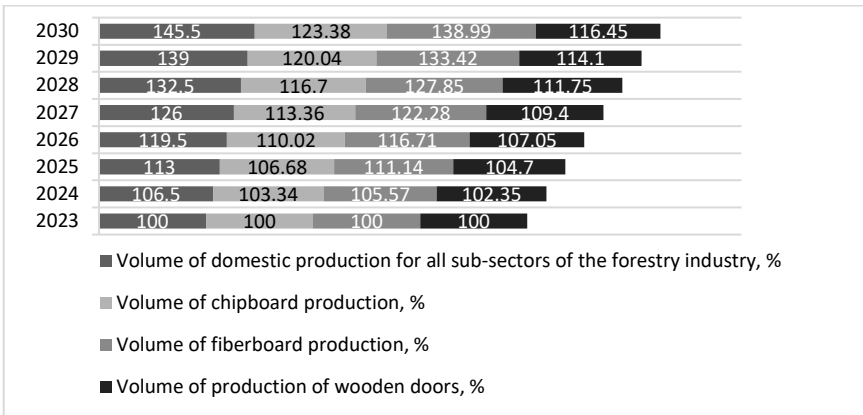


Fig. 2. Forecasted growth dynamics of forest industry development indicators until 2030.

As we can see, we expect an increase in the volume of domestic production in all sub-sectors of the forest industry complex, as well as an increase in the production of wood boards and a decrease in the share of pulp and paper products.

Krasnodar Krai, which belongs to the category of medium forest zone, was studied as a model territory of the closed-cycle economy of the forest sector. The tree species composition is represented by hardwoods (88.4%), softwoods (5.0%) and conifers (6.6%) [9]. The regional timber industry includes pulp and paper industry, woodworking and furniture industry. The Krasnodar Region is the leader of the Southern Federal District in terms of forest resources, with forest vegetation covering more than 90% of the land. Forests located on forest fund lands account for 74.5% of the region's forest area. of the region's forests. The total timber stock is 223.54 million m³.

A characteristic feature is the absence of clear-cutting of mature overmature forest stands, which determines such main categories of the forest regeneration fund lands as clearcuts after clear sanitary cuttings, glades, radinas and heaths. The complex of reforestation measures in the Krasnodar Region forest fund is carried out in accordance with the national project «Ecology» and the regional project «Forest Conservation (Krasnodar Region)».

Incorporated into the circular economy model, Krasnodar Region's forestry solves the tasks of calculating the cutting area, reforestation, afforestation, forest care, and providing forest industries with raw materials for deep processing. The increase in the volume of forest resources involved in closed supply chains is influenced by rational forest management through timely agro-technical and reclamation works, cutting of forest plantations of main and intermediate use. The process of extraction of valuable tree species is hampered by mountainous terrain, which determines the specifics of timber skidding and its delivery to processing plants.

Closed supply chains in the Krasnodar Region's forestry sector depend on the degree of development of deep processing of wood raw materials and wood waste, including the production of paper and paper products, particleboard and fiberboard, furniture, LVL timber, glued laminated timber and OSB panels. The production of sawn timber, moldings, parquet, door and window units is sufficiently represented in the territory. However, in 2023 as compared to 2022, production growth is registered only in the segments of process wood chips (140.5%), wooden pallets, including pallets with sides, and other wooden loading boards (108.2%), and furniture (104.6%). The remaining segments related to wood processing, wood products, paper and paper products manufacturing saw a significant decrease, which indicates the instability of the processes of forming a circular economy model in the Krasnodar Region's forestry sector and the relevance of introducing innovative forestry, logging and wood processing technologies.

3 Discussion

The inclusion of the forest sector in the cyclic economy is not only related to the sustainable development of the forest industry complex, but also closely interacts with global environmental protection and rational use of resources. The cyclic economy offers an effective solution to reduce the negative impact of the forest sector on the environment. The fundamental principles of the circular economy are "reduce, reuse and recycle waste", and by implementing these principles, the forest sector can build more sustainable production and consumption patterns [10, 11]. By following the principle of minimizing and optimizing forest management and timber harvesting methods, the forest sector reduces the scale of damage to forest resources. For example, the implementation of sustainable forest management strategies such as mixed forests and natural reforestation can ensure a stable supply of timber while protecting biodiversity. The circular economy emphasizes the rational use of resources and therefore the long-term supply of wood resources is linked to the implementation of sustainable forest management, including measures such as rational planning of harvesting volumes, promotion of forest restoration and conservation of biodiversity. In addition, wood processing companies can implement the circular economy by improving production processes, rational use of raw materials and reducing waste. The reuse principle encourages the secondary use and refurbishment of wood products [12,13]. Wood products such as furniture, flooring and building structures can be repaired or reconfigured to extend their service life. For example, old furniture can be restored to its appearance and functionality by repainting or replacing components, while old wooden floors can be sanded and polished for reuse. In consumer behavior, it is important to create value for the reuse of wood products by creating recycling networks and second-hand markets.

The principle of transforming waste into new resources in the forestry sector is realized by using waste in the production of products with high added value. For example, by-products of processing, such as wood chips and wood flour, can be used as biomass energy sources for electricity or heating, and wood chips can also be used to produce new products, such as artificial boards. The recycling of wood waste and wood products is also an important manifestation of the principle of resource use. With the help of specialized recycling technologies, wood waste can be transformed into paper, biomaterials or other useful products [14].

The impact of the forestry sector on the environment is multifaceted and includes both positive effects, such as carbon storage and biodiversity conservation, and negative effects, such as deforestation and pollution problems. Sustainable development of the forestry sector requires finding a balance between environmental protection and resource use. The authors' systemic view of the construction of the value chain of the use of forest wood resources in the model of a circular economy in the forest sector (Figure 3) covers the entire process from the collection and processing of raw materials to the distribution and consumption of final products, which not only increases the efficiency of resource use and reduces production costs, but also prevents environmental pollution and promotes the sustainable development of the forest sector. As we can see, the optimization of the value chain of the use of forest wood resources begins with the introduction of sustainable forest management and certified wood sources, as well as ensuring that wood is harvested in a way that does not cause irreversible damage to forest ecosystems. In addition, the amount of waste can be reduced by improving harvesting technologies and increasing the ways of using wood. When processing wood, the use of the best available technologies is necessary to optimize the processing of raw materials and reduce waste.

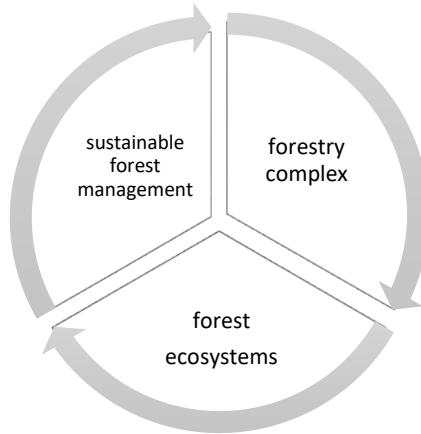


Fig. 3. Circular economy model in the forestry sector.

For example, the use of precision cutting technology and automated production processes leads to a reduction in the amount of wood used, while improving the quality and performance of the product. The principles of "green" design are implemented in environmentally friendly and energy-efficient wood products. For example, designing wood products that are easy to dismantle and repair will not only extend the life of the product, but also facilitate recycling and reuse when the product is disposed of [15, 16].

Assessing the level of development of the circular economy in the forest sector is based on a multidimensional approach and depends on quantitative indicators of recycling efficiency and the environmental impact of resources during the production and consumption of wood. The choice of assessment indicators is crucial for the accuracy of the measurement. Based on the logical framework for measuring the development of the circular economy in the forest sector and based on data availability, a system for assessing the indicators of the development of the circular economy in the forest sector was formulated, including financial, social and environmental aspects, such as resource efficiency, environmental impact, economic efficiency and social well-being (Figure 4).

Economic benefits	<ul style="list-style-type: none"> • Volume of production in a closed-loop economy • Number of jobs created
Social welfare	<ul style="list-style-type: none"> • Share of environmentally friendly products on the market • Population satisfaction with the state of the environment
Resource efficiency	<ul style="list-style-type: none"> • Utilization rate of raw materials and materials • Energy consumption intensity
Environmental Impact	<ul style="list-style-type: none"> • Carbon dioxide emissions • Waste recycling rate

Fig. 4. System of integrated indicators for assessing the circular economy in the forestry sector.

Relevant data should be collected and analyzed to assess the performance of the forest sector in a circular economy. This requires joint efforts by government agencies, industry associations and enterprises to ensure the accuracy and reliability of the data. The system of comprehensive indicators for assessing the circular economy in the forest sector can be used for policy development, corporate strategic planning and market regulation. The corresponding incentive policy is designed to encourage enterprises to improve resource efficiency and reduce environmental pollution. As technology and society develop, the system of comprehensive indicators needs to be constantly updated and improved to meet new challenges and needs.

Based on the results of the study, we will formulate recommendations for the formation of a circular economy model in the forest sector, including the provision of financial incentives to reduce the initial investment costs of enterprises, the use of technological innovations to modernize the industry, and the improvement of laws and regulations to create a favorable policy environment. Through the implementation of these measures, the forest sector will advance in sustainable development, ensuring the efficient use of resources and environmental protection (Table 3).

Table 3. Measures aimed at developing a circular economy model in the forestry sector.

Directions	Improvement measures	Benefits obtained
Obtaining raw materials	Implementation of sustainable forest management, certified timber harvesting	Protect the environment, improve resource sustainability and enhance the image of corporate social responsibility
Technological process	Implementation of highly efficient and energy-saving technologies and equipment for automation	Improve production efficiency, reduce energy consumption, reduce production costs
Product design	Development of removable product designs suitable for recycling	Facilitate product recycling, extend its service life, reduce waste
Production	Use of wood processing waste for the production of secondary products (such as chipboard, cellulose)	Increase revenue from by-products, reduce waste disposal costs and improve resource utilization
Distribution	Creating a closed supply chain and optimizing logistics	Reduce transportation costs, improve supply chain efficiency and reduce carbon footprint
Consumption	Promoting organic products and increasing consumer awareness of environmental protection	Improve product competitiveness in the market to meet demand for environmentally friendly consumption
Recovery	Establishment of a wood product recycling system to promote reuse	Reducing dependence on new resources, creating new jobs and promoting a circular economy
Waste disposal	Use of advanced waste recycling technologies (e.g. biomass energy)	Reducing environmental pollution, developing new energy products and increasing energy diversity

The construction and practice of circular economy modeling are crucial for the sustainable development of the forest sector. Studying successful practices and their in-depth analysis can provide valuable lessons and strategies for the development of a circular economy in the forest sector. These examples usually cover a wide range of business models - from small to large industrial enterprises and entire industrial parks, reflecting the innovativeness and adaptability of different types of enterprises in the practice of a circular economy. In these cases, the key success factors are technological innovation, policy support, market demand and corporate culture. Technological innovation is the main driver of the development of a circular economy, which includes the development of new materials, increased energy efficiency and improved waste recycling technologies. Policy support provides the necessary external conditions for a circular economy, such as financial subsidies, tax incentives, and regulations that can motivate enterprises to implement more environmentally friendly production methods [17]. Market demand is the direct driver of the development of a circular economy. Consumer preferences and demand for environmentally friendly products encourage enterprises to adjust their production strategies. Corporate culture is reflected in the company's commitment to environmental protection and sustainable development, which stimulates innovative activity and a sense of involvement of employees in the implementation of the circular economy. In practice, enterprises may face such problems as lack of financial resources, technical barriers and low market acceptance. The response to this can be, for example, cooperation with financial institutions, the introduction of new technologies, marketing and consumer education. Successful cases serve as an important guide for other enterprises and regions in the implementation of the circular economy model, which will help enterprises avoid the mistakes they may encounter in the practice of the circular economy and increase the level of success of implementation.

4 Conclusion

Circular economy policies and regulations at the national level are the basis for promoting the development of the circular economy and guide businesses and all sectors of society to engage in circular economy practices through legal frameworks and incentives to achieve resource efficiency and environmental sustainability.

Legislative support is the cornerstone of the development of the circular economy. Many countries around the world have either adopted specific circular economy laws or integrated circular economy principles into existing environmental laws. These laws not only set out the goals and principles of the circular economy, but also define specific requirements for their implementation, providing clear guidelines and restrictions for businesses and individuals [18]. For example, laws may provide for resource recovery targets, waste emission limits, and support measures for circular economy-friendly technologies. Through such legislation, the government provides legal guarantees and political support for the development of the circular economy.

Economic incentives are an important means of promoting the development of the circular economy. The use of economic instruments such as tax incentives, financial subsidies and green loans encourages businesses and individuals to adopt circular economy production and consumption patterns. Businesses that adopt cleaner production technologies and recycle resources may be provided with tax incentives or direct financial support. These incentives not only reduce the initial costs of businesses implementing a circular economy, but also increase their competitiveness in the market, thereby facilitating the widespread use and popularization of circular economy technologies.

Research and development in the field of technologies and their promotion are the driving force behind the development of a circular economy. The introduction of innovations and the application of circular economy technologies requires the creation of research centers,

funding for fundamental and applied research and development, and the organization of technology exchange. Exchanges and cooperation in the field of circular economy technologies are encouraged, accelerating the promotion and application of these technologies through the organization of events such as technology exhibitions and seminars.

The creation and implementation of special educational programs help raise awareness of the population and businesses about the circular economy. It is recommended to conduct courses related to the circular economy in schools, colleges and higher education institutions, as well as to organize educational events to increase public awareness of and participation in the circular economy. Popularization of the concept and practice of the circular economy can be achieved through media campaigns and public events aimed at encouraging public participation in the practice of the circular economy.

Setting standards is an important measure to ensure that the market and consumers choose environmentally friendly products and services. These standards provide clear production and design guidelines for enterprises, as well as a basis for consumers to choose environmentally friendly products. The implementation of these standards helps to shape consumer behavior that is favorable to the environment.

Disclosure and transparency are important guarantees for the effective implementation of circular economy policies. The process of implementing circular economy policies should be open and transparent, and by creating a disclosure platform, the public and stakeholders understand the policy development and implementation process and participate in monitoring and evaluation. Such transparency increases the credibility of the policy, promotes its effective implementation, and provides opportunities for the public to participate in the development of the circular economy.

International cooperation is an important trend in the development of the circular economy and is implemented through participation in international agreements, organizing technology exchange events. Through international cooperation, countries can promote best practices in the field of circular economy and work together to solve global environmental problems and achieve sustainable development. Regulation and enforcement are key tools for implementing effective circular economy policies, including supervision of enterprises, fines for violations, and feedback [19]. Through strict supervision, it is possible to ensure the implementation of circular economy policies, promptly identify and resolve problems during their implementation, and thus promote the sustainable development of the circular economy.

Public industrial policies should include incentives such as tax incentives, financial support for research and development, and preferential loans to encourage enterprises to introduce environmentally friendly materials, cleaner production technologies, and recycling of wood processing waste. In addition, it is necessary to stimulate market demand by creating a system of environmental certification and labeling to increase the recognition and demand for environmentally friendly wood products among consumers.

The creation of technology innovation platforms is crucial for the development of the circular economy in the forest sector. These platforms can focus on technological research and development related to the circular economy and promote the development of new materials, processes, and products. It is necessary to encourage technological upgrading and innovation of enterprises by providing incentives such as tax incentives and financial subsidies. At the same time, it should organize technical exchanges and cooperation activities that promote knowledge and technology sharing and accelerate the commercialization and market entry of circular economy technologies. The demonstration effect of public green procurement of circular economy products and services is of great importance. This can promote the green transformation of the supply chain management system. It is necessary to establish a circular economy demonstration zone to focus on advanced technologies, management models and successful practices.

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