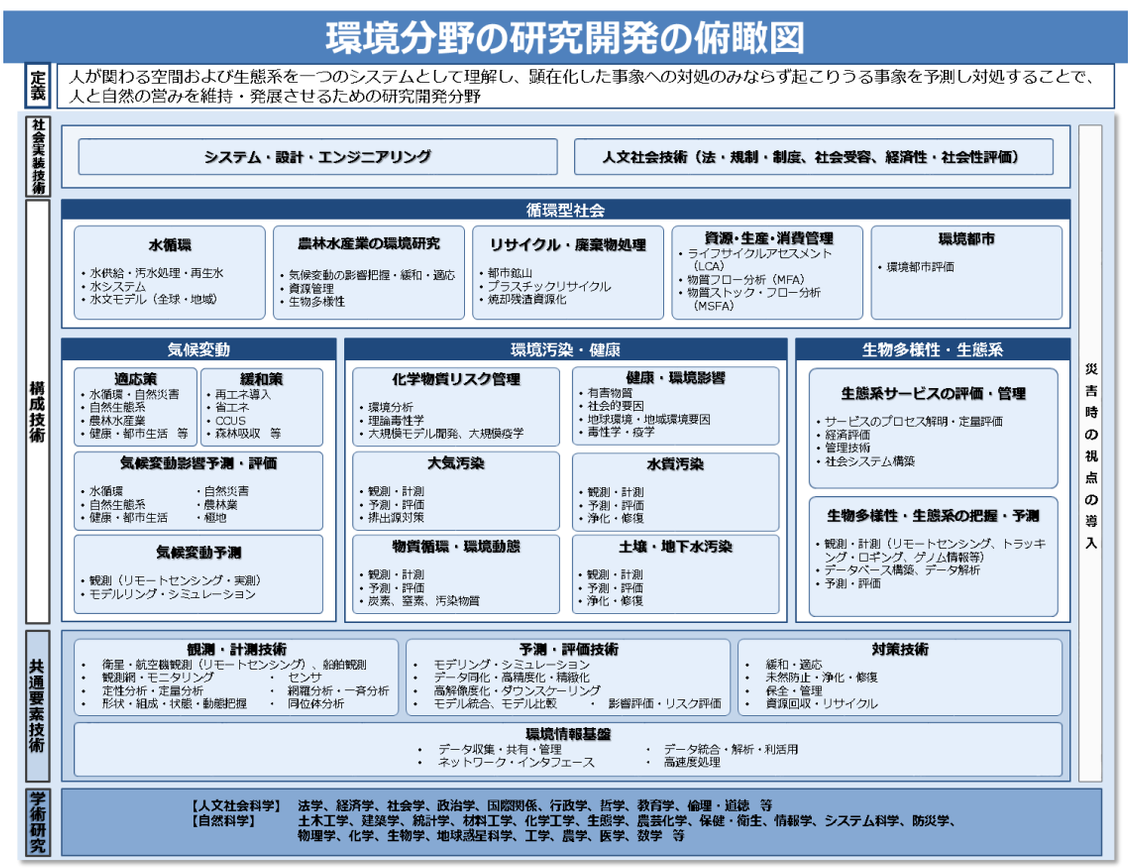
エグゼクティブサマリー

環境分野を「人が関わる空間および生態系を一つのシステムとして理解し、顕在化した事象への対処のみならず起こりうる事象を予測し対処することで、人と自然の営みを維持・発展させるための研究開発分野」と定義し、「気候変動区分」、「環境汚染・健康区分」、「生物多様性・生態系区分」、「循環型社会区分」の 4 区分を設定し俯瞰調査を行った。動向を把握すべき主要な 15 の研究開発領域を抽出し、研究開発の動向やトピックス、研究開発課題、国際ベンチマークをまとめた。



日本、米国、欧州、ドイツ、英国、フランス、中国、韓国の 1地域・7国について、15 の研究開発領域を中心とする研究開発動向（直近 2-3 年程度）と現在の研究開発（科学技術）政策を次ページに示す。

国・地域	概要	
日本	研究開発動向	• 全体的に研究開発レベルは高いが少数精鋭。生物多様性・生態系区分では欧米豪加が優位。 • 気候変動区分では、温室効果ガス（GHG）観測衛星、農林業や健康・都市生活、極地への気候変動による影響研究において強み。 • 環境汚染・健康区分では、土壌汚染に関するコンソーシアムが設立。大気中 GHG 濃度や同位体比測定、ノンターゲット分析、薬物の体内動態予測、出生コホート調査、大規模モデル開発など基礎研究が高水準。 • 循環型社会区分では、農業で多面的機能評価や水循環モデル、水管理等が世界を先導。LCA、MFA（物質フロー分析）、MSFA（物質ストック・フロー分析）ともに基礎研究が進展し応用の基盤が強化。様々な評価手法が都市研究に展開、レジリエンス等を含む包括的な定量化理論開発なども拡大。
	研究開発・科学技術政策	• 第 5 期科学技術基本計画では、エネルギーの安定的確保とエネルギー利用の効率化、資源の安定的な確保と循環的な利用、持続可能な都市及び地域のための社会基盤の実現、食品安全・生活環境・労働衛生等の確保、地球規模の気候変動への対応、生物多様性への対応を提示。地球環境情報プラットフォームの構築を推進。 • 第四次環境基本計画では、震災復興、放射性物質による環境汚染対策も提示。
米国	研究開発動向	• 全ての領域において高い研究開発レベルを維持。 • 気候変動区分は、気候変動予測で基礎・応用ともに世界を先導。気候変動影響では基礎研究が強い。 • 環境汚染・健康区分では、大気汚染や土壌・地下水汚染に強み。物質循環・環境動態では特に衛星観測で世界を先導、モデル研究でも長い歴史。環境・健康影響や化学物質リスク管理も強い。 • 生物多様性・生態系区分では、モニタリングとデータ整備の国際的な発信源であり、衛星観測も世界を先導。InVEST など生態系サービス評価ツールの開発、Eco-DRR など気候変動関連の基礎研究が進展。 • 循環型社会区分では、Food-Energy-Water Nexus の概念のもとパシフィック・ノースウェスト国立研究所（PNNL）などで全球水文モデルを開発。農林水産業の環境研究は基礎・応用ともに強い。LCA や MFA、MSFA など資源・生産・消費管理では議論の中心であり、戦略物質の優先順位評価と意思決定への活用などの応用研究・開発が進展。
	研究開発・科学技術政策	• 2017 年度における科学技術関連予算の編成方針を示す覚書には、9 つの優先分野のうち、気候変動、クリーンエネルギー、地球観測、海洋・北極問題が記載。各省庁で本覚書に基づいた研究開発への予算配分が考慮。 • 環境保護庁（EPA）では、複合的・複雑化している環境の研究や対策技術について、システムアプローチによる研究開発を推進。エネルギー省（DOE）や国立科学財団（NSF）でも食糧・エネルギー・水の複合問題について分野融合の研究を推進。
欧州	研究開発動向	• 全区分で研究開発レベルが高く活発。技術開発だけでなく規格化や政策決定に資する情報構築を進め、ビジネス展開までを視野に入れた戦略を持つ。 • 気候変動区分では様々な EU プロジェクトにて活発な研究開発を推進、基礎・応用ともに強い。 • 環境汚染・健康区分では、越境汚染に敏感で北欧、オランダ、英国を中心に大気汚染モデル研究を推進。水質汚染など問題発掘に積極的に関与。エクスポソームに着目した出生コホート調査を実施中。 • 生物多様性・生態系区分では、基礎から応用まで研究者層が厚い。世界規模のデータベースを維持。生態系サービス評価に関する様々な指標を提案。 • 循環型社会区分では、人間活動を含む複数の全球水文モデルを開発。ウォーターフットプリントなど新概念の提唱と普及には圧倒的な伝統と力がある。リサイクル・廃棄物処理ではプロジェクトが多数発足。特に個別選別技術が世界トップ水準で技術のシステム化にも優れる。資源・生産・消費管理では評価指標を継続的に開発し応用も拡大。気候変動対応のための都市研究や事業化も進む。

	研究開発・科学技術政策	• Horizon2020 の 3 本柱の 1 つ「社会的課題への取り組み」で「気候への対処、資源効率および原材料」を設定（7 年間で 31 億ユーロ）。優先テーマとして、気候変動への挑戦と適応、自然資源・水・生物多様性・生態系の持続可能なマネジメント、非エネルギー系・非農業系の原材料の持続可能な供給、エコ・イノベーションを通じた環境配慮型経済社会への移行、包括的かつ持続的な地球環境観測および情報システムを設定。 • 第 7 次環境行動計画（2013 年）のもと、循環型経済、グリーン経済、競争力のある低炭素経済への転換を推進。
ドイツ	研究開発動向	• 何れの区分も研究開発レベルが高く、注目すべき活動を多数展開。 • 気候変動区分として、気候変動予測、気候変動影響予測・評価の領域で高い研究開発レベルを維持。マックスプランク研究所などが中核となり、気候変動モデル開発の EU プロジェクト CRESCENDO に参画。 • 環境汚染・健康区分では、水質汚染、土壌・地下水汚染などで強み。 • 循環型社会区分では、水循環、農林水産業の環境技術、リサイクル・廃棄物処理、資源・生産・消費管理などの領域で優位。全球水文モデル開発では世界を先導。リサイクル・廃棄物処理では、世界トップの都市鉱山向け粉砕・選別技術を有し、国としてのポテンシャルは極めて高い。
	研究開発・科学技術政策	• 第 6 次連邦政府エネルギー研究プログラム（2011 年）で掲げたビジョン「環境適合性及び信頼性を備えたエネルギー供給構想」に基づき課題や優先事項を設定。低炭素化、エネルギー高効率化、再エネ導入、省エネ、高効率都市、気候保全（炭素管理へのスマートアプローチ）等が該当。その他、放射線防護、気候・気候保護・地球変動、沿岸・海洋・極地・地球科学、環境・持続性の研究、エコロジー・自然保護・持続的利用の分野の研究を推進。 • 気候変動対策の中に、資源効率性の向上、森林管理、草原・湿原保全なども位置付け、気候変動と他の課題を一体的に捉えた対策を実施。
英国	研究開発動向	• 環境分野の研究開発に歴史と蓄積があり、特に気候変動や生物多様性・生態系などの区分で強み。 • 気候変動区分ではハドレーセンター等が早くから地球システムモデル（ESM）開発を手がけ国際的牽引役。 • 環境汚染・健康区分では、大気モデル開発のレベルが高い。土壌・地下水汚染ではサステイナブルレメディエーションの研究開発が加速、ISO 規格提案が進行中。国際窒素管理システム（INMS）を主導。 • 生物多様性・生態系区分では、長期モニタリングと解析から温暖化による生態系変化を明らかにしている。市民によるデータ蓄積、観光統計による生態系サービス情報収集、生態系サービスの貨幣換算評価も推進。
	研究開発・科学技術政策	• 地球温暖化の緩和に向けた低炭素社会の構築を国家としての主要な取り組みとして推進。 • 自然環境研究会議（NERC）の主要テーマとして、気候システム、生物多様性、天然資源の持続可能な使用、地球システム科学、自然災害、環境・公害・健康、（環境関連）技術が該当。 • 都市大気汚染と人体影響との関係、レジリエンス、環境破壊に伴い発生する貧困問題、温暖化に伴う諸影響の評価などについて、先進的かつ時勢を得たテーマ抽出とファンディングを実行。
フランス	研究開発動向	• 特に水循環や農業の領域で存在感を示す。 • 循環型社会区分の水循環では、水メジャーが中東、アジア、アフリカへの展開を意識した応用研究を推進。農業における環境研究では各種予測技術に強み。農業水資源の解析技術では国立科学研究センター（CNRS）や国立環境・農業科学技術研究所（IRSTEA）の活動が代表的。
	研究開発・科学技術政策	• EU の Horizon2020 との整合性を重視した SNR France Europe 2020 では、社会的課題として、資源管理および気候変動への対応、持続可能な輸送と都市システム、横断的テーマとして、地球系: 観測、予測、適応などが記載。 • GHG 削減努力とともに EU も推し進める循環型経済（Circular Economy）への移行も推進。 • 3 大水メジャーのうちの 2 つ（スエズ、ヴェオリア）を創出し世界水フォーラムを間接的に主催するなど各国の水政策に影響力を保持。

中国	研究開発動向	• 全体的に他国・地域と比較して顕著な成果はみられないものの、精力的に研究開発を推進。 • 気候変動区分では観測衛星打ち上げや地球システムモデル（ESM）開発など国家的にテコ入れ。北極では砕氷船整備や小型衛星開発を進め応用研究が進展。 • 環境汚染・健康区分では、中国科学院傘下の研究所や大学で「国家重点実験室」研究が進行中。 • 生物多様性・生態系区分では、近年急速に研究者人口が増加しデータベース整備も組織的に実施。生態系サービスの評価研究も上昇傾向。 • 循環型社会区分では、膜分離活性汚泥法（MBR）などの実証規模研究を実施。政府が関心を持つ希少資源については MFA 研究が活発化。LCA などの手法を用いた都市の評価研究が急速に進展。
	研究開発・科学技術政策	• 「国家イノベーション駆動発展戦略綱要」（2016～2030 年）では戦略的ミッションを設定。「知的･グリーンな製造技術の推進」「グリーン･安全･高効率な現代農業技術の推進」「グリーン･安全･高効率なエネルギー技術の推進」「資源の高効率利用技術と生態保護技術の推進」などが記載。 • グリーン･低炭素という循環型発展モデルの推進が求められているとの認識において、エネルギー開発一辺倒ではなく環境配慮を重視。
韓国	研究開発動向	• 環境都市領域において基盤整備や評価研究、気候変動影響の展開が顕著とされている。それ以外に、世界を先導する研究開発や成果、大きな特徴はみられない。
	研究開発・科学技術政策	• 第 3 次科学技術基本計画（2013-2017 年）における環境関連項目では、①クリーンで便利な生活環境の構築として、気候変動対応力の強化（CCS）、環境保全・復元システムの高度化（汚染物質制御および処理技術）、生活空間の便利さの向上（高効率エネルギー建築物技術、未来先端都市建設技術）、②安全安心な社会の構築として、自然災害予防と被害の最小化（自然災害モニタリング・予測・対応技術）、社会的災害対応システムの確保（原子力安全確保技術、社会的複合災害予測・対応技術）を提示。

以上、世界の研究開発（科学技術）政策および研究開発動向から総合的に判断し、環境分野における世界の研究開発の主な潮流を 6 点抽出した。

1. 統合化
   - 気候変動や汚染、生態系、資源利用なども含めた統合的研究への発展
   - 地球システムモデル（ESM）への関連要素の取り込み
   - Food-Energy-Water Nexus 概念の反映
   - 環境面・社会面・経済面を考慮した持続可能性の概念の反映
2. 大規模化
   - 衛星観測による情報の質・量・種類の飛躍的向上
   - 人間活動データや地球観測データを活用した健康影響の把握
   - 出生コホート調査やエクスポソームの把握
   - 水銀などの有害物質の全球動態モデル
3. 高度化
   - 代謝研究・分析技術の進展による AOP（Adverse Outcome Pathway）への注目
   - 同位体研究の進展による物質循環理解の深化
   - 医薬品および日用品等由来化学物質（PPCPs）やマイクロプラスチックなど新たな汚染物質の認識と対応
   - 選別技術をはじめとするリサイクル技術の高度化
4. 可視化
   - モデル比較、ダウンスケーリング、アンサンブルシミュレーションの実施

- 生態系サービスの定量評価
- リサイクル技術のデータベース構築とデータベース連携、物質フローの可視化
- 環境的側面に加え社会的側面のインパクト評価技術の開発と応用

5. ネットワーク化・共有化
   - 衛星や地上局等の観測ネットワーク構築と得られたデータの共有
6. 研究スタイルの変化
   - 問題設定とデータ収集、シミュレーション設定を共通化し、参加モデルを横断的に分析して論文を執筆する形式に変化

上記及び、社会・経済の動向も踏まえ、日本が現在、国として、大学等を中心に取り組むべき環境分野の研究開発の内容として、以下を提案する。

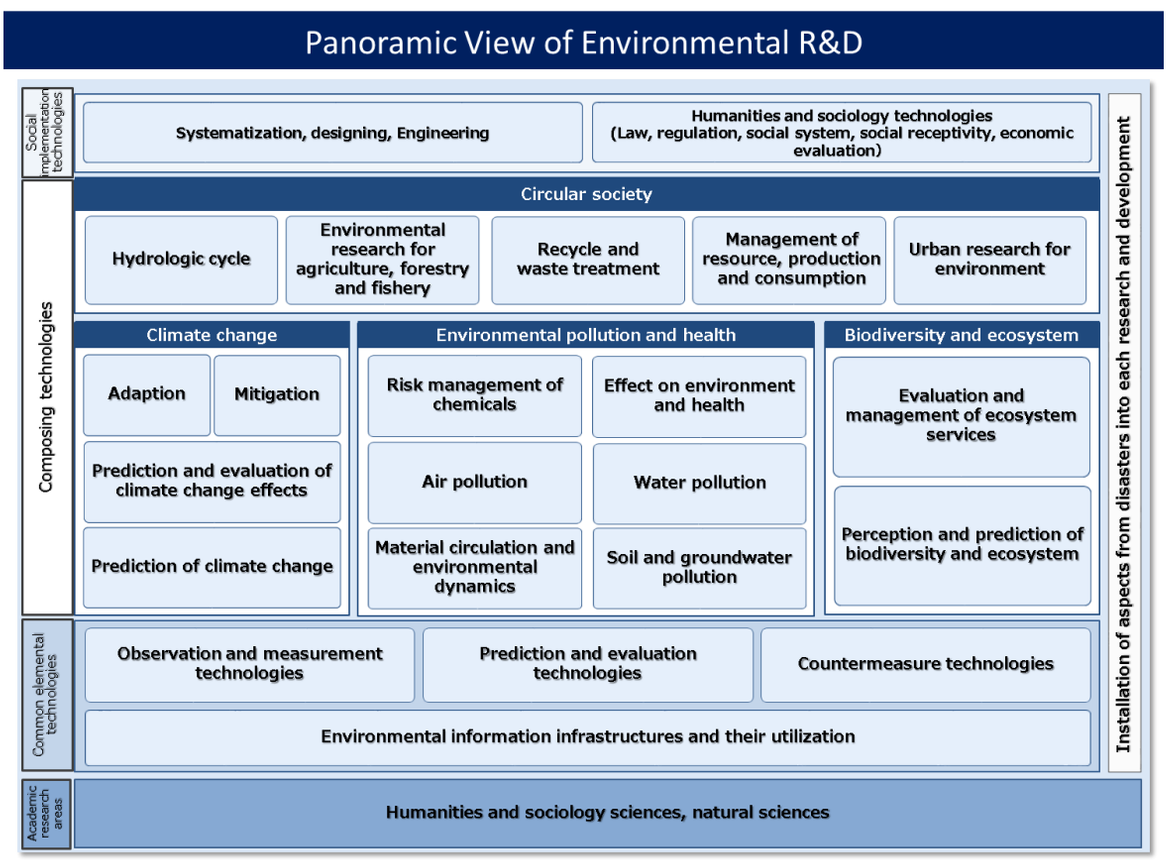
1. 統合的な研究開発の実施
   気候変動や環境汚染、健康影響、生態系管理、資源利用と循環、経済、社会等の関連要素全体を扱う統合的な研究開発への発展
   - 対策間のトレードオフ・シナジー効果の解明
   - 社会的側面も含む多面的な影響や価値の可視化、経済や社会への反映
   - 社会・経済データを含むビッグデータや地球観測データの活用
   - エクスポソーム（化学的、物理的、生物学的、精神的、社会的環境ストレスへの生涯曝露）の把握
   - 持続的な土地、水、生物資源の利用
   - 資源循環研究や技術の高度化・システム化
     （水、希少資源、廃プラ、廃素材や廃機器等）
2. 地球システムモデル（ESM）・気候変動影響予測モデルの開発と応用
   - 予測精度向上（人間活動を含む多様な要素取り込み、ESM では炭素排出に対する気候過渡応答（TCRE）の評価精度向上、高度な海洋生態系モデルの結合等）
   - データ保管・配信・解析やモデル結合作業を支援するシステム開発
   - ダウンスケーリング、アンサンブルシミュレーション
   - 影響予測・評価の強化と対象の拡大
   - その他の環境変動予測・評価
3. 観測や評価の低コスト化・省力化
   - 効率的かつ省メンテナンスで統計学的にも優れた観測手法の開発
   - AOP(Adverse Outcome Pathway)研究の推進（毒性試験の省力化・迅速化）

また、体制面における課題として以下を示す。

- モニタリングやシステム開発の継続性と研究プラットフォーム（衛星や観測船等）維持・強化
  （長期間の継続的な観測によるデータ蓄積が研究開発の深化と発展に不可欠）
- 要素技術だけでなくシステム化の研究開発の推進
- 計算機資源の拡充
- 社会受容性のための技術評価とリスク評価
- 技術資源のデータベース化

Executive Summary

The environment field is defined as the research and development (R&D) field to maintain and develop harmonization for human and nature by understanding the physical space and ecosystems that interact with people as a system, and predicting and coping with not only obvious events but also possible events. The panoramic view survey was conducted based on four categories which are "Climate change", " Environmental pollution and health", "Biodiversity and ecosystem", and "Circular society". And then 15 key R&D areas were extracted to grasp the trend. Trends and topics of R&D, R&D issues, and international benchmarks were organized.



R & D trends mainly in 15 key areas (the most recent 2-3 years) about 7 countries and a region from Japan, USA, Europe, Germany, UK, France, China, South Korea and the current policy of R&D (science and technology) are summarized below.

Japan	R&D Trend	• The overall R & D level is high by a few limited excellent researchers, but Europe, USA, Australia and Canada are dominant in the biodiversity and ecosystem category. • In the climate change category, Greenhouse gas (GHG) observation satellites and the research on the effects of climate change on agriculture, forestry, health, urban life, polar regions are strong.

		• In the environmental pollution and health category, the research consortium of soil contamination was established. Basic research such as atmospheric GHG concentration and isotope ratio measurement, non-target analysis, pharmacokinetic prediction in vivo, birth cohort survey, large scale model development is high level. • In the circular society category, multifaceted functional evaluation, water cycle model, water management etc for agriculture are dominant. Basic research for LCA, Material Flow Analysis (MFA) and Material Stock Flow Analysis (MSFA) has advanced and strengthens the foundation of applied research. Various evaluation methods are developed in urban research and the comprehensive quantification theory development including resilience etc. is expanded.
	Science & Technology Policy	• The Fifth Science and Technology Basic Plan aims to ensure stable energy, energy efficiency, stable resource, and cyclical use of resource, to realize a social infrastructure for sustainable cities and regions, to ensure food safety, living environment, and occupational health etc., to response to global climate change and to biodiversity. And such plan also promotes to construct global environmental information platform. • The Fourth Environmental Basic Plan aims to ensure reconstruction from the Great East Japan Earthquake and environmental pollution control measures by radioactive materials as well.
USA	R&D Trend	• High R & D level is maintained in all areas. • In the climate change category, both basic and applied researches for climate change forecasting are dominant to the world. Basic research for climate change impact is superior. • In the environmental pollution and the health category, the research for air pollution, soil and groundwater pollution is superior. Especially the research for satellite observation in material circulation and environmental dynamics is superior. The model study has a long history as well. The research for environmental and health impacts and risk management of chemical substances are also superior. • In the biodiversity and ecosystem category, the research provides international information on monitoring and data maintenance, and the satellite observation is dominant. The ecosystem service evaluation tools such as InVEST and basic research related to climate change such as Eco - DRR have advanced. • In the circular society category, a global hydrological model was developed at Pacific Northwest National Laboratory (PNNL) under the concept of Food-Energy-Water Nexus. Both the basic and applied researches for environment in agriculture, forestry and fishery industries are superior. The researches for the management of resource, production and consumption such as LCA, MFA and MSFA are central to discussion. The applied research and development have progressed concerning to priority evaluation of strategic substances, and been utilized for decision making.
	Science & Technology Policy	• Climate change, clean energy, earth observation, oceanic and arctic problems are described in the Memorandum which shows the policy of organization of science and technology budget in FY 2017. Each ministry and agency considers the budget allocation to R & D based on this memorandum. • The Environmental Protection Agency (EPA) promotes R & D through a systematic approach on research and countermeasures for complex and complicated environments. The Department of Energy (DOE) and the National Science Foundation (NSF) promote the field integration research on complex issues of food, energy and water.

Europe	R&D Trend	• R & D level is high and active in all categories. Not only technical development but also the construction of information contributing to standardization and policy decisions, have advanced and there is a strategy of R&D with a view to business development. • In the climate change category, active R&D is promoted in various EU projects. Both basic and applied researches are strong. • In the environmental pollution and health category, it is sensitive to transboundary pollution. The air pollution model research is promoted mainly in Northern Europe, the Netherlands and the UK. Active participation in excavation of water pollution problem is seen. A birth cohort survey focused on the exposome is ongoing. • In the biodiversity and ecosystem category, there are many researchers from basic to applied research. Worldwide database is maintained. Various indicators on ecosystem services evaluation are proposed. • In the circular society category, multiple global hydrological models including human activities are being developed. There is overwhelming tradition and power in advocating and disseminating new concepts such as water footprints. Many projects were launched in recycling and waste disposal. Especially individual selection technology is at the world's top level and excellent in systemization of technology. The evaluation indicator for the management of resource, production and consumption are developed continuously and its applied research is also developed. Urban research and commercialization projects for climate change response also proceed.
	Science & Technology Policy	• “Climate action, environment, resource efficiency and raw materials” was set (EUR 3.1 billion in 7 years) in “Research to tackle societal challenges”, as one of the three pillars of Horizon 2020. Priority themes are Challenge and adaptation to climate change, Environment, sustainably managing natural resources, water, biodiversity and ecosystems, Sustainable supply of non-energy and non-agricultural materials, Transition towards a green economy and society through eco-innovation, and Comprehensive and sustained global environmental observation and information systems. • The 7th Environment Action Programme (EAP) aims to turn the EU into circular economy, green economy, and competitive low-carbon economy.
Germany	R&D Trend	• The R & D level is high in all categories, and a number of remarkable activities are developed. • In the climate change category, the R & D for climate change forecast, climate change impact prediction and evaluation are maintained at high level. Max Planck Institute is a core member and participates in the EU project CRESCENDO for climate change model development. • In the environmental pollution and health category, the researches for water pollution, soil and groundwater contamination, etc are superior. • In the circular society category, the researches for water circulation, environmental technology in the agriculture, forestry and fishery industries, recycling and waste disposal, management of resource, production and consumption are superior. The development of global hydrology model is leading the world. There is the world's top crushing and sorting technology for urban mines in the area of recycling and waste disposal. The R&D potential as a country is extremely high.
	Science & Technology Policy	• Issues and priorities are set based on the vision "Energy supply concept with environmental compatibility and reliability" stated in the 6th Federal Government Energy Research Program (2011). The following research fields are promoted; low carbonization, high energy efficiency, introduction of renewable energy, energy conservation, high efficiency city, climate conservation (smart approach to carbon management). The others are radiation protection, climate and climate protection and global change, coastal and ocean and polar and earth science, environment and sustainability, ecology and nature conservation and sustainable use. • The countermeasures that integrate climate change and other issues in climate change measures is implemented including improvement of resource efficiency, forest management, grasslands and wetland conservation, etc.

UK	R&D Trend	• There is a long history and big accumulation in R&D in the environmental field, especially in terms of climate change, biodiversity and ecosystem categories. • In the climate change category, Hadley Center et al. are international drivers since early days on developing the Earth System Model (ESM). • In the environmental pollution and health category, the atmospheric model development is high in level. R&D of sustainable remediation accelerates in soil and groundwater pollution. The proposal of international standardization for such field is ongoing. The researchers lead international nitrogen management system (INMS). • In the biodiversity and ecosystem category, monitoring and analysis for long-term reveal ecosystem change due to global warming. Data accumulation by citizens, collection of ecological service information by tourist statistics, and currency conversion of ecosystem services are promoted.
	Science & Technology Policy	• The establishment of a low-carbon society to mitigate global warming is promoted as a major initiative for a state. • The main themes of the Natural Environment Research Council (NERC) are climate system, biodiversity, sustainable use of natural resources, earth system science, natural disasters, environment and pollution and health and environment related technology. • Advanced and timely theme extraction and funding on the relationship between urban air pollution and human impact, resilience, poverty problems caused by environmental destruction, and various impacts associated with global warming are implemented.
France	R&D Trend	• The areas of water circulation and agriculture are superior. • In the area of hydrologic circulation of the circular society category, water majors promote applied research aimed at deploying to the Middle East, Asia and Africa. The environmental research in agriculture is superior in various prediction technologies. The National Science Research Center (CNRS) and the National Institute of Environmental Studies and Agricultural Science and Technology (IRSTEA) are superior in the analysis technology of agricultural water resources.
	Science & Technology Policy	• SNR France Europe 2020 focuses on consistency with EU's Horizon 2020 and describes resource management and response to climate change, sustainable transport and urban systems as social issues, and describes observation, prediction, adaptation and so on against Earth system as cross-cutting themes. • Not only GHG reduction efforts but also the transition to the Circular Economy are promoted. • Two (Suez and Veolia) of three water majors in the world provide impact in each country's water policy through indirectly hosting the World Water Forum.
China	R&D Trend	• Although there are no notable outcomes in all fields compared to other countries and regions overall, R & D is energetically promoted. • In the climate change category, the government strongly promotes to launch observation satellite and to develop Earth system model (EMS). The applied research has advanced by promoting icebreaker preparation and mini satellite development in the North Pole. • In the environmental pollution and health categories, "National Priority Laboratory" research is in progress at laboratories and universities under the Chinese Academy of Sciences. • In the biodiversity and ecosystem category, the researcher population has rapidly increased in recent years and database is developed systematically. Evaluation research on ecosystem services also has an upward trend. • In the circular society category, the empirical scale research for the Membrane Bio Reactor (MBR) is implemented. MFA research has become active for rare resources that the government is interested in. Evaluation research of urban areas by using LCA has made rapid progress.

China	Science & Technology Policy	• "National Innovation Driven Development Strategy Essentials" (2016 - 2030) presents the following items as a strategic mission; "Promotion of intellectual and green manufacturing technology", "Promotion of green, safety and highly efficient modern agricultural technology", "Promotion of green, safety and highly efficient energy technology", and " Promotion of high efficient utilization technology for resource and ecological protection technology ", etc. • Not only energy development but also environmental consideration is important under the recognition that a recycling-based development model of green and low carbon is required to be promoted.
South Korea	R&D Trend	• Infrastructure development, evaluation research and climate change impacts research are considered remarkable in the urban research for environment. Besides that, no major features are seen.
	Science & Technology Policy	• Environmental related items in the Third Science and Technology Basic Plan (2013 to 2017) presents: (1) strengthening the capability to cope with climate change (CCS), upgrading the environmental preservation and restoration system (Pollutant control and processing technology), improvement of convenience of living space (high-efficiency energy building technology, future advanced city construction technology) for construction of clean and convenient living environment, (2) natural disaster prevention and minimization of damage (natural disaster Monitoring, prediction and countermeasure), securing social disaster response system (Nuclear safety assurance technology, social complex disaster prediction and countermeasure) for construction of safe and secure society.

Comprehensively judging from the international trends and policies for R&D, the main trends of world R&D in the environment field are summarized in the following six points.

1. Integration
    - Development into integrated research including climate change, pollution, ecosystems, resource use, etc.
    - Incorporating related elements to the Earth System Model (ESM)
    - Reflecting the concept of Food-Energy-Water Nexus
    - Reflecting the concept of sustainability considering environmental, social and economic aspects
2. Large and long
    - Dramatic improvement of information quality, quantity, and type by satellite observation
    - Grasping health effects by utilizing human activity data and earth observation data
    - Birth cohort survey and grasping exposome
    - Global dynamics model of harmful substances such as Mercury
3. Advancement
    - Focus on AOP (Adverse Outcome Pathway) due to progress of metabolic research and analytical techniques
    - Deep understanding of material cycling through progress of isotopic research
    - Recognition and countermeasure to new pollutants such as PPCPs(Pharmaceuticals and Personal Care Products) and microplastic
    - Improvement of recycling technologies including sorting technology
4. Visualization

- Conducting model comparison, downscaling, ensemble simulation
- Quantitative evaluation of ecosystem services
- Database construction and database linkage for recycling technology, visualization of material flow
- Development and application of impact assessment techniques on social aspects in addition to environmental aspects

5. Networking and sharing
   - Establishment of observation networks of satellites and ground stations, and data sharing
6. New approach
   - New approach to analyze the results from many models under the fixed one condition

Based on the abovementioned and the social and economic trends as well, the contents of R & D in the environmental field to be tackled by mainly universities in Japan now are addressed hereinafter;

1. Integrated R & D implementation

   Development into integrated R&D dealing with all relevant elements such as climate change, environmental pollution, health effects, ecosystem management, resource use, recycling, economy, and society, etc.
   - Clarification of tradeoff between countermeasures and of synergy effect between them
   - Visualization of multifaceted impact and value including social aspects, reflection on the economy and society
   - Utilizing earth observation data and big data including earth and social data
   - Grasping exposome (lifetime exposure to chemical, physical, biological, mental, and social environmental stress)
   - Sustainable resource utilization of land, water, plant, and marine creatures.
   - Advancement of resource recycling research and element technologies, systematization of such element technologies

     (For water, rare resources, waste plastics, materials and equipment expected to increase)
2. Development of climate system model and climate change impact prediction model
   - Improvement of prediction accuracy (incorporation of diverse elements including human activities for both of EMS and impact prediction models, and improvement of TCRE evaluation accuracy and advanced marine ecosystem model for EMS, etc.)
   - System development to support data storage, distribution, analysis, and model coupling
   - Downscaling and ensemble simulation
   - Strengthen impact prediction and evaluation, and its target expansion
   - Prediction and evaluation of the environmental changes except aforementioned items
3. Cost reduction and labor saving of observation and evaluation
   - Development of observation methods that are efficient, trouble-free and statistically superior
   - Promotion of AOP (Adverse Outcome Pathway) research

Issues in systematic aspects are addressed hereinafter;

- Continuity of monitoring and system development, maintenance and enhancement of research platform (satellites and observation vessels)
  (Data accumulation by continuous observation for long-term is strongly required to deploy R&D deeply.)
- Systematization
- Expansion and enhancement of computational resource
- Technological evaluation and risk assessment for social acceptability
- Database of technological resources