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MARUEEB

Teaching Aid Material

SUSTAINABLE OPERATIONS AND SYSTEMS: FROM POLICIES TO NORMS

Editors: Alen Amirkhanian, Norayr Benohanian

Contributors: Alen Amirkhanian, Artak Hambarian, Astghine Pasoyan, Marek Sokáč, Natella Mirzoyan, Gagik Gabrielyan, Daniel Ghevondyan

ԿԱՅՈՒՆ ԳՈՐԾԸՆԹԱՑՆԵՐ ԵՎ ՀԱՄԱԿԱՐԳԵՐ. ՔԱՂԱՔԱԿԱՆՈՒԹՅՈՒՆԻՑ՝ ՆՈՐՄԵՐ
Խմբագիրներ՝ Ալեն Ամիրխանյան, Նորայր Բենոհանյան

УСТОЙЧИВЫЕ ПРОЦЕССЫ И СИСТЕМЫ: ОТ ПОЛИТИКИ К НОРМАМ
Под редакцией Ален Амирханяна, Норайр Беноганяна

MARUEEB
Erasmus+ project

Master Degree in Innovative technologies in Energy Efficient Buildings of Russian and Armenian Universities and Stakeholders

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For additional information on Erasmus+ MARUEEB visit http://ace.aua.am/marueeb.

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Foreword to the series

The present teaching aid material is published in the framework of the “MARUEEB” project promoted by the European Commission in the scheme of the Erasmus+ programme, and it is aimed at establishing a curricular reform at the Masters level on «INNOVATIVE TECHNOLOGIES in ENERGY EFFICIENT BUILDINGS» for Armenian and Russian Universities, according to the last trends of the Bologna Process regarding the student-centred or output-based approach.

The involved Partner Countries’ Universities are

Armenia: National Polytechnic University of Armenia and American University of Armenia;

Russian Federation: Ural Federal University n.a. Boris Eltsin in Yekaterinburg, “Peter the Great” St. Petersburg Polytechnic University, Tambov State Technical University, Voronezh State University of Architecture and Civil Engineering, South Ural State University in Chelyabinsk.

The project, lasting three years, foresees different outcomes having impact on the academic policy of the involved Partner Countries’ Universities, as well as outputs representing tangible results of the improvement jointly achieved by the MARUEEB consortium members.

Amongst these outputs, you have the present evidence of the publication of the MARUEEB teaching aids material: a unique series published having a common series title and distributed, as official Master publications, among the Master programme locations, including Chelyabinsk as affiliated to Yekaterinburg. The series is composed by eight volumes serving as light “text books”, plus a glossary/handbook mostly referring to the Bologna Process implementation.

An editorial board was set-up, comprised of the five editors-in-chief listed in the previous pages (Prof. Vincenzo Bianco from University of Genova, Prof. Ruben Aghgashayan from NPUA, Mr. Alen Amirkhanian from AUA, Prof. Vladimir Alekhin from URFU, Prof. Marina Shitikova from VSUACE and Mr. Angelo Musaio from University of Genova).

For each text, an editor was appointed, with distribution of the tasks among the different Master programmes. The editorial board chose the titles among eight core modules of the different study programmes. Afterwards, the appointed editors collected all the contributions by teachers / staff from the interested consortium members.

In general terms, the majority of the texts' coordination has been appointed to the Partner Countries' party, in order to enhance their awareness on the process of curricula reform. In any case, to be considered as added-value of the active participation to the texts' preparation from each member, the presence of one contribution, for each text, from the two parties (Member States and Partner Countries) was defined.

This major part of the series, being an important moment of joint academic cooperation between Armenian, Russian and European Union scientists, has been certified with the official recognition by the "RAASN" (Russian Academy of Architecture and Constructions Sciences). Therefore, the volumes have been published in order to represent important support to the core modules of the second semester of the implemented Master programmes that have begun from academic year 2017/2018.

The energy efficiency issues are permanent priorities of academic dialogue and joint actions between European Union, Armenian and Russian Federation, and actually the project has elaborated a new multidisciplinary approach to fit in this area, combining energy-saving topics with the energy management training, thus making a complex vision of these important problems.

As far as the national contexts are concerned, Russia has the world's largest share of fossil energy resources. Nevertheless, recognizing that minimizing waste helps preserve Russian resources, the Russian Federation Government passed sweeping new energy-efficiency legislation. However, more remains to be done to identify how energy resources are used and wasted, and where efficiency might be improved. Furthermore, it is clear that energy-saving is closely connected with environmental protection, so saving energy means protecting the environment.

National energy strategy of MARUEEB programme participating countries' aims to reduce country energy dependence by 2030 through boosting the faster growth of the use of the technical potential of energy saving in different sectors of the economy. The strategy also states that « … Energy efficiency is a topical and a cumbersome issue, so addressing every aspect of it is very urgent, as we seem to be falling behind in every respect (…) So, we must improve energy conservation in every area, but I (...) particularly single out the situation in the public utilities sector. All of the governors are well-aware that energy is used in an atrociously inefficient way when it comes to heating and public utilities. (…) Our buildings and our overall housing infrastructure are a kind of "black hole" that sucks in enormous amounts of energy resources. Electric power lines are absolutely outdated, and coupled with outdated illumination devices, they cause immense energy waste». [President in the State Council meeting, July 2009] Therefore, the link between the proposed curricular reform and the labour market is Energy efficiency. Achieving these changes will require effective federal-district-local programs, financing, human resources, and time, both in the Armenian and Russian framework, but will yield significant payoffs.

In light of this, new strategies for a sustainable development are necessary to ensure the compliance with the environment and the available resources. This issue is fundamental for Armenia and Russia, and for their economies in transition towards an innovative phase of improved living standards. Moreover, regarding Armenia, in 2007 the National Program on Energy Saving and Renewable Energy was adopted, which presented the energy saving potential of Armenia and outlined the priority sectors of economy with the highest energy saving potential.

Therefore, the implementation of energy efficiency measures have relevant benefits on Partner Countries' economies, because it helps to maintain competitiveness.

The rapidly growing, power-hungry construction sector is of paramount importance as a source of energy savings. To impose a structural transformation of the building sector, aimed at the implementation of modern standards of energy efficiency, a new class of specialists with advanced and specific competences is necessary.

A new vision of engineering and technological know-how will permit to support this transformation, with specific reference to the design and construction of sustainable buildings, both for Armenia and Russian Federation.

As regards the Armenian framework, as confirmation of attention devoted by national programs to these subjects, recently new thermal insulation standards were prescribed in order to decrease the specific energy consumption in new buildings, but it is not enough, because most of the waste is concentrated in older buildings, therefore a general action of refurbishment is needed.

In the last few years, Armenia has reached consciousness of energy and environmental impact related to buildings, as also reported by IEA - International Energy Agency. Moreover, the rising interest, both of Armenia and Russia, in “20/20/20” European Union policies and NZEB ("nearly zero energy buildings") has resulted in a growing demand for good-quality Engineers having knowledge and skills to analyse, design and develop effective solutions in a broad range of situations. In response to this growing demand, the curricular reform of the Higher Education on energy efficiency in buildings fully complies with the national frameworks.

On the basis of these necessities, the scientific community has to strengthen its capacity building for developing more energy and environment driven study-programmes, with particular reference to Environmental Protection and Energy Efficient Buildings.

The MARUEEB project has tried to give answers to all these issues, by the designing of new Master Courses, including the establishment of up-to-date laboratories and the development of advanced teaching material, for both engineers and scientists seeking for a high qualification in the following main fields: Sustainable Buildings, Energy Efficiency and Sustainable Development. One of the key issues in the development of this ambitious program, the making of updated teaching aid materials, has been considered fundamental for the retraining of local teaching staff and new specialists and for the best definition of the new qualifications.

The material contained in such editorial series has been also prepared taking into due consideration the implementation of the so-called “Bologna Process” in Armenian and Russian Higher Education systems. In such systems, the students are placed at the centre of the educational process, which moves from a “staff to a student-centred” approach. Therefore, the design of new study programmes and teaching material is based on the necessities of the students. This approach will be an additional key element for a qualified teaching offer, able to deal with the latest technological innovations and to ensure an advanced level of education to the specialists in “Green Building”, the key word as link between the improved curricular reform and the labour market. The process of curricula reform, after one year and half of project activities, sometimes has been not so easy and smooth. Anyway, there will be significant payoffs in the medium-to-long term: graduates able to face a more competitive economy, improved level of employment, attention to climate change concerns, better management of natural resources.

All these points have been duly considered and closely connected with the topics of the MARUEEB project: a demand for specialists and new experts in “Green Building” to train specialists for private entrepreneurs and public authorities, to equip students with energy efficiency knowledge, and to provide trainers with managerial competences.

However, the “Green Building” label is not enough to guarantee a sustainable energy saving model, then a sustainable development model. Experienced “Green Masters,” who check whether a possible career will deliver what it promises, can expect highly stimulating tasks that assume high motivations and provide the opportunity to have a part in actively shaping the future.

Once again, we would like to mention the resolution published on the European Commission webpage related to Environmental and Climate Change policies.

Protecting the environment is essential for the quality of life of current and future generations. The challenge is to combine this with continuing economic growth in a way which is sustainable over the long term. European Union environment policy is based on the belief that high environmental standards stimulate innovation and business opportunities. Economic, social and environment policies are closely integrated.

Liliya Mozerova, Angelo Musaio

Նախաբան

Դասավանդմանն օժանդակող սույն նյութը հրատարակվել է Եվրոպական հանձնաժողովի կողմից «Էրասմուս +» ծրագրի շրջանակներում աջակցվող «ՄԱՐՈՒԷԷԲ» ծրագրի համար:

Այն նպատակ ունի հայկական և ռուսական համալսարաններում բարեփոխել «Նորարարական տեխնոլոգիաները էներգաարդյունավետ շենքերում» մագիստրոսական ծրագրի ուսումնական պլանը՝ վերջինս համապատասխանեցնելով Բոլոնիայի գործընթացի ուսանողակենտրոն և արտադրողականության վրա հիմնված մոտեցումներին:

Գործընկեր երկրներից ընդգրկված համալսարաններն են՝

Հայաստանում՝ Հայաստանի ազգային պոլիտեխնիկական համալսարանը և Հայաստանի ամերիկյան համալսարանը

Ռուսաստանի Դաշնությունում՝ Եկատիրինբուրգում Բորիս Ելցինի անվան Ուրալի պետական համալսարանը, Սանկտ Պետերբուգում Պետրոս Մեծի անվան պոլիտեխնիկական համալսարանը, Տամբովի պետական տեխնիկական համալսարանը, Վորոնեժի ճարտարապետական և քաղաքացիական ճարտարագիտության պետական համալսարանը և Չելյաբինսկում Հարավային Ուրալի պետական համալսարանը:

Երեք տարի տևողությամբ ծրագիրը նախատեսում է ունենալ ներգրավված գործընկեր երկրների համալսարանների ակադեմիական քաղաքականության վրա ներազդող տարբեր ձեռքբերումներ ինչպես նաև «ՄԱՐՈՒԷԷԲ» կոնսորցիումի անդամների կողմից համատեղ իրականացվող բարեփոխումների շոշափելի արդյունքներ:

Ձեռքբերումների շարքում է «ՄԱՐՈՒԷԷԲ» դասավանդմանն օժանդակող նյութերի սույն հրատարակությունը: Այն որպես պաշտոնական մագիստրոսական հրատարակություն մագիստրոսական ծրագրերի վայրերում (ներառյալ Եկատիրինբուրգի հետ փոխկապակցված Չելյաբինսկը) բաշխված նույնանուն հրատարակությունների եզակի շարք է: Շարքը բաղկացած է ութ (8) հատորից, որոնք կարելի է համարել համառոտ «դասագրքեր», և բառարանից/ձեռնարկից, որը հիմնականում վերաբերվում է Բոլոնիայի գործընթացի իրականացմանը:

Ստեղծվել է հինգ (5) գլխավոր խմբագիրներից կազմված խմբագրական խորհուրդ, որի անդամները ներկայացված են նախորդ էջերում (պրոֆեսոր Վինչենցո Բիյանկո Ջենովայի համալսարանից, պրոֆեսոր Ռուբեն Աղգաշյան ՀԱՊՀ-ից, Ալեն Ամիրխանյան ՀԱՀ-ից, պրոֆեսոր Վլադիմիր Այյոխին ՈՒՐԴՀ-ից, պրոֆեսոր Մարինա Շիտիկովան ՎՊՃՇՀ-ից և Անժելո Մուսաոն Ջենովայի Համալսարանից):

Յուրաքանչյուր տեքստի համար նշանակվել է խմբագիր՝ տարբեր մագիստրոսական ծրագրերի միջև հանձնարարությունները բաշխելով: Խմբագրական խորհուրդը վերնագրերն ընտրել է տարբեր ուսումնական ծրագրերի ութ հիմնական մոդուլներից: Այնուհետև նշանակված խմբագիրները շահագրգիռ կոնսորցիումի անդամներից հավաքել են ուսուցիչների / աշխատակիցների բոլոր ներդրումները:

Ընդհանուր առմամբ տեքստերի համակարգման մեծամասնությունը նշանակվել է գործընկեր-երկրներին՝ ուսումնական պլանի բարելավման գործընթացի վերաբերյալ նրանց իրազեկվածության բարձրացման համար: Տեքստերի պատրաստման գործում յուրաքանչյուր անդամի ակտիվ մասնակցության համար որոշվել է, որ յուրաքանչյուր տեքստ պետք է երկու կողմից (անդամ երկրներից և գործընկեր երկրներից) ներդրում ունենա:

Կարևորելով Հայաստանի, Ռուսաստանի և Եվրոպական միության գիտնականների ակադեմիական համագործակցությունը, «ՌՃՇԳԱ»-ն (Ռուսական ճարտարապետության և շինարարական գիտությունների ակադեմիա) պաշտոնապես վավերացրել է շարքերի մեծամասնությունը:

Ուստի, հատորները հրատարակվել են, որպեսզի օժանդակեն 2017/2018 ուսումնական տարվանից սկսված մագիստրոսական ծրագրերի երկրորդ կիսամյակի հիմնական մոդուլներին:

Ծրագրի ընդլայնված նպատակն է Հայաստանի և Ռուսաստանի համալսարաններում պրակտիկայի և դասընթացների բարելավումը, որպեսզի մասնագետները «Շենքերի էներգախնայողություն» թեմայի վերաբերյալ առարկաների համար ունենան միջդիսցիպլինար տեխնոլոգիական մոտեցում: Ավելին, հայկական և ռուսական բարձրագույն կրթության համակարգում ուսուցման արդյունքների մոտեցման վրա հիմնված «բակալավր-մագիստրատուրա» երկկողմանի համակարգի կիրառումը կարելի է համարել ստացված:

Էներգաարդյունավետության խնդիրները մշտապես Եվրոպական միության, Հայաստանի և Ռուսաստանի ակադեմիական քննարկումների և համատեղ իրականացվող գործողությունների համար առաջնահերթություն են համարվում: Իրականում ծրագիրը մշակել է ոլորտին համապատասխան նոր, բազմաշերտ մոտեցում, որը էներգիայի խնայողության թեմաները կապում է էներգիայի կառավարան դասընթացի հետ, ինչն էլ նպաստում է նշված խնդիրների վերաբերյալ ընդհանուր տեսլականի ձևավորմանը:

Ինչ վերաբերում է ազգային կոնտեքստին, ապա Ռուսաստանն ունի աշխարհի բրածո էներգիայի աղբյուրների ամենամեծ պաշարները: Այնուամենայնիվ, գիտակցելով, որ թափոնների նվազեցումն օգնում է ռուսական ռեսուրսների պահպանմանը, Ռուսաստանի Դաշնության կառավարությունն էներգախնայողության վերաբերյալ նոր օրենսդրություն է ընդունել: Սակայն դեռ շատ անելիք կա պարզելու համար, թե ինչպես են օգտագործվում էներգիայի ռեսուսները, և որտեղ արդյունավետության բարելավման կարիք կա: Բացի այդ, ինչպես տեսնում ենք, էներգախնայողությունը սերտորեն կապված է շրջակա միջավայրի պահպանության հետ, և էներգախնայողությունն իրենից ենթադրում է շրջակա միջավայրի պահպանություն:

ՄԱՐՌԻԷԷԲ ծրագրի մասնակից երկրների նոր, ազգային էներգետիկ ռազմավարությունները նպատակ ունեն մինչև 2030թ. հնարավորինս նվազեցնել երկրի էներգակախվածությունը՝ խթանելով էներգախնայողության տեխնիկական ներուժի օգտագործման արագ աճը տնտեսության տարբեր ոլորտներում: Ռազմավարությունը նաև նշում է, որ «... Էներգաարդյունավետությունը արդիական և ծանրակշիռ խնդիր է, ուստի դրա յուրաքանչյուր մասին անդրադառնալը հրատապ է, քանի որ կարծես թե ամեն առումով հետ ենք մնում (...): Այսպիսով մենք պետք է յուրաքանչյուր ոլորտում բարելավենք էներգիայի պահպանությունը, բայց ես (...) հատկապես առանձնացնում եմ իրավիճակը կոմունալ ծառայությունների ոլորտում: Բոլոր մարզպետները լավ գիտեն, որ ջեռուցման և կոմունալ ծառայությունների տեսանկյունից էներգիան օգտագործվում է անտանելի անարդյունավետ կերպով:

(...) Մեր շենքերը և ընդհանուր բնակարանային ենթակառուցվածքը կարծես «սև խոռոչ» լինեն, որոնք վատնում են հսկայական քանակությամբ էներգետիկ ռեսուրսներ: Էլեկտրահաղորդման գծերը բացարձակապես մաշված են և հին լուսավորման սարքերի հետ մեկտեղ մեծ քանակությամբ էներգիա են վատնում»,- 2009թ. հունվարին Պետական խորհրդի հետ հանդիպմանն ասել է նախագահը: Հետևաբար, առաջարկվող ուսումնական բարեփոխումների և աշխատաշուկայի միջև կապը էներգետիկ արդյունավետությունն է: Այդ փոփոխություններին հասնելու համար կպահանջվեն արդյունավետ պետական-մարզային-տեղական ծրագրեր, ֆինանսավորում, մարդկային ռեսուրսներ և ժամանակ, ինչպես Հայաստանում, այնպես էլ Ռուսաստանում, սակայն կպահանջվեն նաև զգալի հատուցումներ:

Այս առումով, անհրաժեշտ են կայուն զարգացման նոր ռազմավարություններ՝ շրջակա միջավայրի և առկա ռեսուրսների հետ համապատասխանության ապահովման համար: Այս հարցը հիմնարար է Հայաստանի և Ռուսաստանի, ինչպես նաև իրենց տնտեսությունների համար, որոնք անցում են կատարում կենսամակարդակի բարելավման նորարարական փուլին: Ավելին, ինչ վերաբերվում է Հայաստանն, ապա 2007 թվականին ընդունվել է էներգախնայողության և վերականգնվող էներգիայի վերաբերյալ ազգային ծրագիրը, որը ներկայացրեց Հայաստանի էներգախնայողության ներուժը և նախանշեց էներգախնայողության ամենաբարձր ներուժն ունեցող տնտեսության գերակա ճյուղերը:

Հետևաբար, էներգաարդյունավետությանն ուղղված քայլերի իրականացումը գործընկեր երկրների տնտեսությունների համար ունի համապատասխան օգուտներ, քանի որ այն օգնում է պահպանել մրցունակությունը:

Որպես էներգախնայողության աղբյուր, շատ արագ աճող և էներգիա պահանջող շինարարության ոլորտը կարևոր նշանակություն ունի: Էներգաարդյունավետության ժամանակակից չափանիշների հաստատմանն ուղղված շինարարության ոլորտի կառուցվածքային վերափոխման համար անհրաժեշտ են նոր, առաջադեմ և հատուկ հմտություններով մասնագետներ:

Ինժեներական և տեխնոլոգիական գիտելիքների նոր տեսլականը թույլ կտա աջակցել այս վերափոխմանը՝ հատուկ անդրադարձ կատարելով Հայաստանում և Ռուսաստանում կայուն շենքերի նախագծմանը և կառուցմանը:

Ինչ վերաբերում է Հայաստանին, ապա վերջերս ջերմամեկուսացման նոր ստանդարտներ են սահմանվել՝ նորակառույց շենքերում էներգիայի սպառումը նվազեցնելու համար: Ստանդարտների սահմանումով հաստատվել է ազգային ծրագրերի ուղղվածությունը սույն թեմաներին: Սակայն դա բավարար չէ, քանի որ վատնումը մեծ մասամբ կենտրոնացված է ավելի հին շենքերում: Հետևաբար անհրաժեշտ է վերանորոգման ընդհանուր գործողություն:

Վերջին մի քանի տարիներին Հայաստանում բարձրացել է էներգիայի և շրջակա միջավայրի վրա շենքերի ազդեցության վերաբերյալ գիտակցությունը: Այս մասին հաղորդել է նաև ՄԷԿ-ը՝ Միջազգային էներգետիկ գործակալությունը: Ավելին, «20/20/20» Եվրոպական միության քաղաքականության և «ԳԶԷՇ»-ի («Գրեթե Զրոյական Էներգետիկ Շինություններ») հանդեպ Հայաստանի և Ռուսաստանի աճող հետաքրքրությունը հանգեցրեց որակյալ ինժեներների պահանջարկի աճին, ովքեր ունեն վերլուծության, նախագծման և արդյունավետ լուծումների առաջարկման լայն հմտություններ:

Ի պատասխան այս աճող պահանջարկին, շենքերի էներգաարդյունավետության վերաբերյալ բարձրագույն կրթության համակարգում ուսումնական պլանի բարեփոխումը լիովին համապատասխանում է ազգային համակարգերին:

Հաշվի առնելով այս անհրաժեշտությունները, գիտական համայնքը պետք է խթանի էներգետիկայի և շրջակա միջավայրի վերաբերյալ ուսումնական ծրագրերի մշակման իր կարողությունների զարգացումը՝ հատուկ ուշադրություն դարձնելով շրջակա միջավայրի պահպանությանը և շենքերի էներգաարդյունավետությանը:

«ՄԱՐՈՒԷԷԲ»-ը փորձել է անդրադառնալ այս բոլոր հարցերին նոր մագիստրոսական ծրագրերի նախագծման միջոցով: Սա ներառում է ժամանակակից լաբորատորիաների հիմնումը և առաջադեմ ուսումնական նյութերի պատրաստումը, թե՛ ինժեներների, թե՛ գիտնականների համար, որոնք ձգտում են հետևյալ հիմնական ոլորտներում ստանալ բարձր որակավորում՝ կայուն շենքեր, էներգաարդյունավետություն և կայուն զարգացում: Նորագույն ուսումնական նյութերի պատրաստումը համարվում է այս նպատակային ծրագրերի մշակման առանցքային հարցերից մեկը: Այն կարևոր է տեղական դասախոսական կազմի և նոր մասնագետների վերապատրաստման, ինչպես նաև նոր որակավորումների լավագույն սահմանման համար:

Այսպիսի խմբագրական շարքում պարունակվող նյութը պատրաստվել է հաշվի առնելով Հայաստանի և Ռուսաստանի բարձրագույն կրթության համակարգերում այսպես կոչված «Բոլոնիայի գործընթացի» իրականացումը: Նման համակարգերում ուսանողները կրթական գործընթացի կենտրոնում են, ինչը դասախոսակենտրոն մոտեցումից փոխվում է դեպի ուսանողակենտրոն մոտեցում: Հետևաբար, նոր ուսումնական ծրագրերի և ուսումնական նյութերի պատրաստումը հիմնված է ուսանողների կարիքների վրա: Այս մոտեցումը լրացուցիչ կարևոր տարր կդառնա որակյալ դասավանդման առաջարկի համար: Այն կկարողանա շարժվել վերջին տեխնոլոգիական նորարարություններին զուգընթաց և «Կանաչ շենք» մասնագետների համար ապահովել առաջադեմ մակարդակի կրթություն: «Կանաչ շենք» արտահայտությունը կարևոր կապ է հանդիսանում բարելավված ուսումնական բարեփոխումների և աշխատաշուկայի միջև: Ծրագրի գործունեությունից մեկ տարի անց կարելի է ասել, որ ուսումնական պլանի բարեփոխումների գործընթացը երբեմն այնքան էլ հեշտ և հարթ չի եղել: Այնուամենայնիվ, միջնաժամկետում և երկարաժամկետում նշանակալից դրական արդյունքներ կլինեն՝ շրջանավարտները կկարողանան դիմակայել ավելի մրցունակ տնտեսությանը, կբարձրանա զբաղվածության մակարդակը, կլիմայի փոփոխության մտահոգությունների հանդեպ ուշադրությունը, կբարելավվի բնական ռեսուրսների արդյունավետ կառավարումը:

Այս բոլոր կետերը պատշաճ կերպով դիտարկվել են և սերտորեն կապված են «ՄԱՐՈՒԷԷԲ» ծրագրի թեմաների հետ՝ «Կանաչ շենք»-ի մասնագետների և նոր փորձագետների պահանջարկ՝ մասնավոր ձեռնարկատերերի և պետական մարմինների վերապատրաստման, ուսանողներին էներգաարդյունավետության վերաբերյալ գիտելիքներով ապահովման, վերապատրաստողներին կառավարման հմտություններ տրամադրման համար:

Այնուամենայնիվ, «Կանաչ շենք» պիտակը բավարար չէ, կայուն էներգախնայողության, այնուհետեւ կայուն զարգացման մոդելի ապահովման համար: Փորձառու «Կանաչ վարպետները», ովքեր ստուգում են, թե հնարավոր աշխատանքը ապահովում է նախատեսված արդյունքները, կարող են ակնկալել շատ խրախուսով առաջադրանքներ, որոնք խթանում են ապագայի կերտման մեջ ակտիվ մասնակցությունը:

Ցանկանում ենք կրկին նշել Եվրոպական հանձնաժողովի կայքում հրապարակված Բնապահպանական և կլիմայի փոփոխության քաղաքականության վերաբերյալ բանաձևը՝

Շրջակա միջավայրի պահպանումն անհրաժեշտ է ներկա և ապագա սերունդների կյանքի որակի համար: Մարտահրավեր է հանդիսանում շարունակական տնտեսական աճի հետ սրա միավորումը այնպես, որ երկարաժամկետում կայուն լինի: Եվրոմիության շրջակա միջավայրի քաղաքականությունը հիմնված է այն համոզմունքի վրա, որ բարձր բնապահպանական չափանիշները խթանում են նորարարությունն ու բիզնեսի հնարավորությունները: Տնտեսական, սոցիալական և շրջակա միջավայրի վերաբերյալ քաղաքականությունները սերտորեն փոխկապված են:

Защита окружающей среды необходима для обеспечения качества жизни настоящего и будущих поколений. Основной целью является объединение качества жизни с постоянным экономическим ростом таким образом, чтобы он стал устойчивым на долгое время.

Լիլյա Մոզերովա, Անջելո Մուսայո

REMEMBERING OUR COLLEAGUE

Most of the MARUEEB participants have had the privilege and honour to know and work with Dr. Liliya Anatolevna Mozerova, head of international relations office at Tambov State Technical University, who passed away on 8th October 2016.

The MARUEEB participants once again wish to express the deep sorrow because the premature death of Liliya has not permitted her to enjoy the results to which she deeply and enthusiastically worked.

Who have known her, nowadays can really appreciate the meaning of cooperation and common cultural improvement.

To her we wish to dedicated this whole series, since the realization of MARUEEB and many important joint academic achievements, along several years of cooperation, would not have been possible without her incomparable work.

The MARUEEB participants take commitment to honour her memory by the efforts that will devote to the development of the current cooperation between European Union and Partner Countries institutions, which have had as important promoter Liliya Mozerova.

ՄԵՐ ԳՈՐԾԸՆԿԵՐԻ ՀԻՇԱՏԱԿԻՆ

«ՄԱՐՈՒԷԷԲ»-ի մասնակիցներից շատերը հնարավորություն և պատիվ են ունեցել են ունեցել ճանաչելու և աշխատելու Տամբովի Պետական Տեխնիկական Համալսարանի Միջազգային Հարաբերությունների գրասենյակի ղեկավար դոկտոր Լիլյա Անատոլևնա Մոզերովայի հետ, ով մահացավ 2016 թ. հոկտեմբերի 8-ին:

«ՄԱՐՈՒԷԷԲ»-ի մասնակիցները հերթական անգամ ցանկանում են արտահայտել իրենց խորը վիշտը Լիլյայի վաղաժամ մահվան կապակցությամբ, ինչը նրան չթողեց վայելել այն արդյունքները, որոնց համար նա խորապես և եռանդով աշխատում էր:

Նրան ճանաչողներն այժմ իսկապես կարող են գնահատել համագործակցության և ընդհանուր մշակութային բարելավման նշանակությունը:

Ցանկանում ենք նրան նվիրել այս ամբողջ շարքը, քանի որ առանց նրա անգնահատելի աշխատանքի մի քանի տարիների համագործակցության ընթացքում «ՄԱՐՈՒԷԷԲ»-ի իրագործումը և մի շարք կարևոր համատեղ գիտական ձեռքբերումները հնարավոր չէր լինի:

Հարգելով նրա հիշատակը, «ՄԱՐՈՒԷԷԲ»-ի մասնակիցները ջանք չեն խնայի նվիրվել Եվրոպական միության և Գործընկեր երկրների հաստատությունների ներկայիս համագործակցության զարգացմանը, ինչի կարևոր խթանողներից էր Լիլյա Մոզերովան:

PART 1: FRAMEWORKS AND HOLISTIC POLICIES

CHAPTER 1. OPERATIONS AND SYSTEMS IN THE CONTEXT OF THE UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS

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1.1 - DEFINING SUSTAINABLE OPERATIONS AND PRODUCTION

Operations (e.g., transport of goods or people) and systems (e.g., buildings, factories, or production systems) have impact through their capital outlays and ongoing activities.

A factory or a building comprises materials, the production of which has had an impact on the planet and most likely some communities directly. This impact occurs at each stage of the facility life cycle: its extraction, processing, manufacturing, transport, sales, operations and demolition/disposal.

This chapter introduces the concepts and analytical tools used to think about these operations and systems from a sustainability perspective. The sustainability aspects we'll particularly focus on are environmental and social.

1.1.1 - EARLY DEFINITIONS

One of the earlier definitions of sustainable consumption and production (SCP) was offered in 1994 in the Oslo Symposium on Sustainable Consumption. At the Symposium, SCP was defined as "the use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of further generations."[1]

The Rio+20 Conference, in 2012, highlighted that sustainable consumption and production are critical to sustainable development. The Conference proposed a 10-year framework of programs (10YFP),[2] which offer a global framework to enable international cooperation on sustainable consumption and production in developed and developing countries.

With growing populations and wealth globally, the Rio+20 Conference as well as later the 2030 Agenda (the basis of UN's Sustainable Development Goals or SDGs discussed below) recognized

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[1] https://sustainabledevelopment.un.org/topics/sustainableconsumptionandproduction, accessed June 13, 2018, at 16:53 Yerevan time.

[2] For details on the 10YFP visit http://web.unep.org/10yfp

the urgency to change both consumption patterns as well as how we produce what we consume. The declarations stated that the well-being of humans, the natural environment, and economies, depend on the responsible management of the earth's natural resources. They saw that the most promising strategy involved decoupling economic growth from the increasing rates of natural resource use and negative environmental impacts that occur in both consumption and production stages of our economic life.[3]

1.1.2 - SUSTAINABLE DEVELOPMENT GOALS

Based on the 2030 Agenda, the world community adopted 17 Sustainable Development Goals (SDGs)[4] seeking to integrate sustainability in all aspects of social, economic, and environmental policy making (see Fig. 1.1). These broad and interdependent goals, intended for both developed and developing countries, address challenges in a large number of domains, including industry, urban development, social justice, health, education, environment, conflict resolution and peace.

Each SDG highlights a key goal to be achieved by the year 2030. SDG 1, for instance, sets as a goal the elimination of poverty, especially extreme poverty. SDG 2 sets to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture.

Each SDG in turn has several targets, which guide policy and action. While not all countries are expected to achieve every target by 2030, they are expected to identify national priorities by SDG and their targets.

Provinces, municipalities, and enterprises and businesses can go through a similar exercise and by doing so contribute to the national progress on the SDGs. Many large corporations in fact have gone through such an exercise and have published their corporate policy on meeting the SDGs.

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[3] https://sustainabledevelopment.un.org/topics/sustainableconsumptionandproduction/programme accessed June 13, 2018 at 17:18 Yerevan time.

[4] For details visit https://sustainabledevelopment.un.org. In 2015, the member states of the United Nations adopted a set of 17 Sustainable Development Goals (SDGs), which, over a 15-year period, until 2030, encourage both the developed and developing countries to end poverty, hunger, gender and other social inequalities as well as seek better education, environmental protection, sustainable economic growth and more.

Figure 1.1

Each target has at least 1 indicator, though it often has more. Tracking the indicators will enable the country, cities, or enterprises assess their performance on meeting the targets and the goals.

For the purposes of this chapter, several of the SDG are particularly relevant. Among these are **SDGs 6, 7, 8, 9, and 12**. Engineers have a particularly important role in helping achieve these goals. In Box 1.1, you can find these SDGs and their targets that are most relevant to the topic of this chapter. Along with each target you can also find their related indicators.

The following section—Towards Sustainable Operations and Production—discusses the approaches and tools for operationalizing these SDG targets. In that section, we categorize these approaches and tools into 6 categories, each of which is discussed in sufficient detail to offer a survey and overview of the field.

Box. SDGs most relevant to sustainable operations and production

SDG 6. CLEAN WATER AND SANITATION

TARGET 6.3. By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

INDICATOR 6.3.1. Proportion of wastewater safely treated

INDICATOR 6.3.2. Proportion of bodies of water with good ambient water quality

TARGET 6.4. By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity

INDICATOR 6.4.1. Change in water-use efficiency over time

INDICATOR 6.4.2. Level of water stress: freshwater withdrawal as a proportion of available freshwater resources

SDG 7. AFFORDABLE AND CLEAN ENERGY

TARGET 7.3. By 2030, double the global rate of improvement in energy efficiency

INDICATOR 7.3.1. Energy intensity measured in terms of primary energy and GDP

SDG 8. DECENT WORK AND ECONOMIC GROWTH

TARGET 8.4. Improve progressively, through 2030, global resource efficiency in consumption and production and endeavor to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programs on sustainable consumption and production, with developed countries taking the lead

INDICATOR 8.4.1. Material footprint, material footprint per capita, and material footprint per GDP

INDICATOR 8.4.2. Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP

TARGET 8.8 Protect labor rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment

INDICATOR 8.8.1. Frequency rates of fatal and non-fatal occupational injuries, by sex and migrant status

INDICATOR 8.8.2. Increase in national compliance of labor rights (freedom of association and collective bargaining) based on International Labour Organization (ILO) textual sources and national legislation, by sex and migrant status

SDG 9. INDUSTRY, INNOVATION, AND INFRASTRUCTURE

TARGET 9.4. By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities

INDICATOR 9.4.1. CO2 emission per unit of value added

SDG 12. RESPONSIBLE CONSUMPTION AND PRODUCTION

TARGET 12.4. By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment

INDICATOR 12.4.1. Number of parties to international multilateral environmental agreements on hazardous waste, and other chemicals that meet their commitments and obligations in transmitting information as required by each relevant agreement

INDICATOR 12.4.2. Hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment

TARGET 12.5. By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse

INDICATOR 12.5.1. National recycling rate, tons of material recycled

TARGET 12.6. Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle

INDICATOR 12.6.1. Number of companies publishing sustainability reports

Source: https://sustainabledevelopment.un.org

Box 1.1

1.2 - TOWARDS SUSTAINABLE OPERATIONS AND PRODUCTION

To discuss sustainable and responsible production, we will look at a wide range of activities. Some of these will be manufacturing, some construction, and some services. The solutions we discuss could be cross-cutting and useful for many of these economic sectors or they may be more specific to one or two.

- Light manufacturing (textiles, food processing and packaging, electronics)
- Heavy manufacturing (smelters, chemical plants, metal stamping)
- Construction (roads, bridges, buildings, industrial facilities)
- Mining (metals, stone, aggregate)
- Tourism
- Fashion and apparel
- Food services
- Retailers
- And more

Regardless of the industry, key decisions are made at each stage of operation as well as the final product or service about the amount and type of energy and material to be used. Each stage also generates waste in various forms (gas, liquid, or solid) that have to be managed to protect people and the environment.

The schematic in Figure 1.2 presents the material and energy flows of the production-to-consumption continuum for a product, such as a tea kettle or a computer. Services, such as tour packages, will have different schematics but also involve a series of material and energy flows that could have important environmental and social implications. They therefore have to be planned and managed effectively.

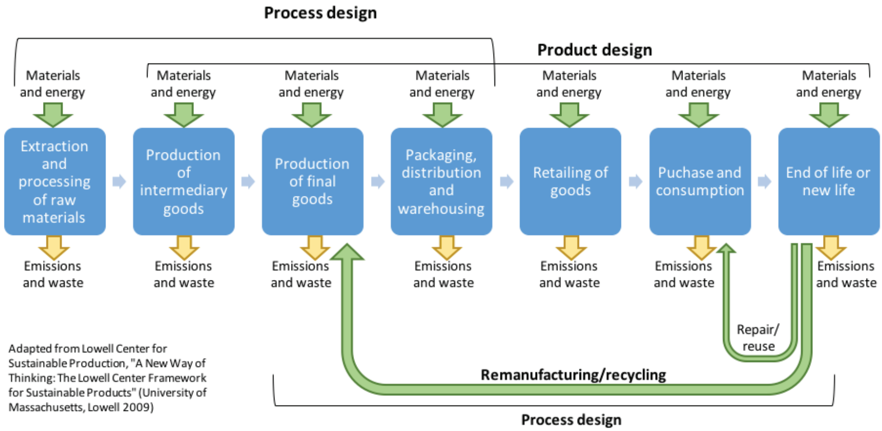

Figure 1.2

To pursue sustainable production and consumption goals, the material and energy inputs would have to be minimized, emissions reduced and captured, waste radically reduced if not eliminated, products at their end of life either repaired or reused and, if reuse is not possible, remanufactured or recycled. In addition, we would need to ensure worker, community and consumer safety.

For a service-sector business, such as a tourism company, the business value chain and process would be different than the one presented in the scheme. Nonetheless, even in tourism, products are used to deliver the service. Guidebooks are published, buses are used, hotels are booked, etc. All of these involve products that have production processes not very different from the scheme presented. In deciding on the sustainability of a service operation, in part, the emphasis will be on whether the goods selected to be offered to the tourist meet the sustainability expectations.

Countries, industries, and communities can use the following six broad approaches and tools to make advances on their sustainable production goals:

1. RESOURCE EFFICIENCY – Aiming to decouple economic growth and resource use, with true gains in efficiency.

2. CLEANER AND NO-HARM PRODUCTION – Taking steps toward operations and production that pollute less and cause no harm to ecosystems.
3. ECO DESIGN AND LIFE CYCLE ASSESSMENT – In designing or planning products and operations, using design principles that are aligned with environmental and social sustainability. Part of this requires that we understand the product from a life cycle perspective, which accounts for cumulative embedded resources (water, energy, minerals) of a product as well as its impact after it has lived its useful life.
4. ENVIRONMENTAL MANAGEMENT SYSTEMS – Companies adopt a voluntary Environmental Management System (EMS) that helps them set goals, monitor, and assess their environmental performance and operational efficiency. There are several EMS options companies can choose.
5. OCCUPATIONAL HEALTH AND SAFETY – Adopting and adhering to occupational health and safety standards, reducing work-related injuries and illnesses.
6. COMMUNITY HEALTH AND SAFETY – Developing and adhering to community health and safety norms, including dealing with industrial accidents and disasters.

1.2.1 - DECOUPLING AS A POLICY GUIDE

In the last two decades or so, there has been growing policy discourse on resource efficiency and impact. This discourse has been motivated by several factors.

On the one hand, policymakers globally have recognized the need to reduce environmental impact of economic activity (e.g., reduction of greenhouse gas emissions based on climate change concerns).

On the other, there is recognition that we need economic growth for years to come, so that billions of human beings left behind and the new ones being born can benefit from an adequate standard of living. The challenge here is to do this without causing an environmental collapse.

The Organization for Economic Cooperation and Development (OECD) was one of the first international organizations that offered some policy guidance on this dilemma by suggesting that some countries have—and more should pursue—policies that "decouple" production of economic goods from negative impacts on the environment.

Since then, the United Nations Environment Programme (UNEP)'s International Resource Panel (IRP) has published several useful reports on decoupling. In this chapter we will heavily rely on them, at times directly using their texts.

As shall become evident, the concept of decoupling, defined below, is clearly connected to the concept of productivity gain. However, decoupling places the emphasis on the resource used and the harmful impacts, which are of interest when we want to pursue environmental and social sustainability.

Defining decoupling[5]

In the context of this chapter, "decoupling" refers to disassociation of increased economic production from resource and environmental stress. There are <u>two types of decoupling</u>: A) resource decoupling and B) impact decoupling.

A. **Resource decoupling** means using less resources used per unit of economic output. Resources could include energy, water, minerals, biomass, land, and the like. Economic output could mean GDP or per capita GDP.

B. **Impact decoupling** means reducing environmental impact of any economic activity per unit of economic output. Environmental impact could include pollution, greenhouse gas emissions, deforestation, loss of biodiversity, and more. Economic output, again, could mean GDP or per capita GDP.

In addition to the two types of decoupling, for each type of decoupling there are <u>two levels of decoupling</u>: 1) relative decoupling and 2) absolute decoupling.

1. **Relative decoupling** refers to when economic growth rate is higher than resource use or impact rate.

2. **Absolute decoupling** refers to when economic growth takes place but resource use or impact decreases in absolute terms.

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[5] UNEP (2011) Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel. Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E.U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Romero Lankao, P., Siriban Manalang, A., Sewerin, S.

These four aspects of decoupling are summarized in a matrix (see Figure 1.3). There are many factors that need to be considered to make a decision on which of the four paths to pursue and how to prioritize them.

Ideally you would pursue both resource and impact decoupling. In fact, when you pursue one, you may naturally get the other as a consequence. So if you reduce your fossil-fuel-based energy, you will also reduce your impact in terms of carbon dioxide emissions, etc.

With respect to level of decoupling, from an environmental perspective, it would clearly be preferable to decouple absolutely, that is, reduce overall use and impact and not only relative to economic growth. That is, the ideal solutions from an environmental viewpoint would be the bottom two boxes of the matrix, namely A2 and B2.

	A ***Resource Decoupling***	**B** ***Impact Decoupling***
Relative Decoupling **1**	**Over time, use of inputs such as water and energy has grown but at a slower rate than economic output**	**Over time, negative environmental impact of economic activity, e.g., air pollution, has grown but at a slower rate than economic output**
Absolute Decoupling **2**	**Over time, use of inputs such as water and energy has decreased in absolute terms while economic output has increased**	**Over time, negative environmental impacts, such as air pollution, has decreased in absolute terms while economic output has increased**

Figure 1.3

As this section is on resource efficiency, for the remainder of this section we will focus on "resource decoupling." The next section focuses on cleaner and no-harm production. "Impact decoupling" solutions will be discussed in that section.

1.2.2 - RESOURCE EFFICIENCY (RESOURCE DECOUPLING)

Resources often considered in industrial policy include materials that extracted from nature and modified to create economic value. They can be measured both in physical units (e.g., tons, kWh's or cubic meters), and in monetary terms expressing their financial value. These include energy, industrial minerals and ores (such as metals), construction minerals (gypsum, stone, etc.), water, biomass, land, among others. These are the resources we will focus on.

There are other non-material or hard-to-measure intangible assets that can have real economic value, such as beauty of nature, which may be important in economic growth and policy when, say, we want to develop a tourism industry, but from the viewpoint of resource efficiency, they are not directly relevant. As discussed below, some of the growth of service sector and use of non-material economic assets appears to be at the base of "dematerialization" of the economies.

1.2.2.1 - Mineral, fossil fuel, and biomass use

Looking at a 105-year history (1900-2005) of global material consumption and GDP, there is evidence that overall material consumption has grown in the four major material classes: biomass, fossil energy carriers, ores and industrial minerals, and construction minerals (Fig. 1.4). Total material extraction increased over that period by 8.5 times, from 7 million tons in 1900 to 60 million tons in 2005. By 2009, this number had increased to 68 million tons.[6] Material consumption continues to grow and had accelerated in the 2000s with China, India, and Brazil showing rapid rates of material-intensive development.

Economic growth data, however, shows that even though global material resource use has increased, it has done so at a slower pace than the world economy, which grew by a factor of 23 from 1900 to 2005. Thus some resource decoupling has taken place to some extent 'spontaneously,' suggesting some "dematerialization" of economies. This is particularly true for industrialized countries.

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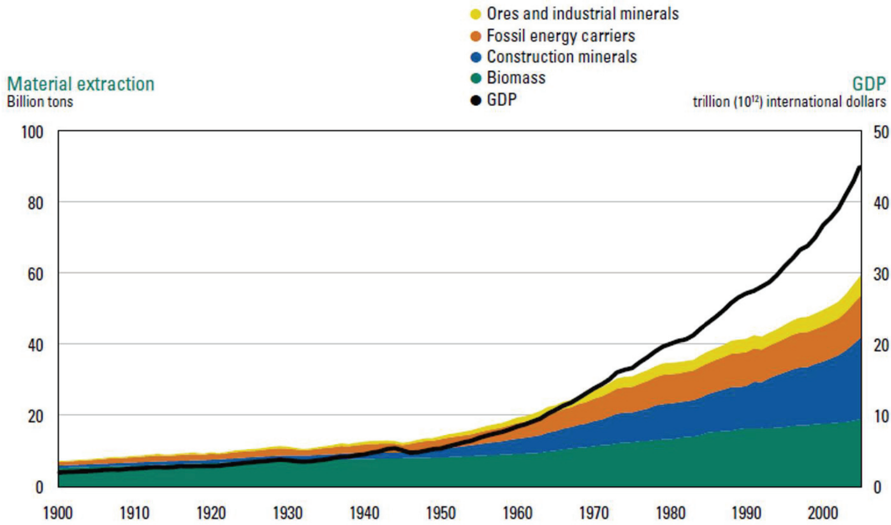
[6] Krausmann *et al.,* based on SEC Database " Growth in global materials use, GDP and population during the 20th century" (update 2011), Version 1.2 (August 2011), including data 1900-2009: http://uni-klu.ac.at/socec/inhalt/3133.htm

More research is needed on this but part of the difference in growth factors may be accounted for changes in economies with greater significance of financial and services sectors. Also advances in material and product design have probably impact the material-intensity of final products such as housing, electronics, packaging, etc.



Source: p. 11, Decoupling natural resource use and environmental impacts of economic growth. UNEP International Resource Panel, 2011

Figure 1.4

For each type of material, the extraction growth rates in the 20th and early part of 21st centuries differ:

- Construction minerals grew by a factor of 34
- Ores and industrial minerals grew by a factor of 27
- Fossil energy carriers grew by a factor of 12
- Biomass extraction increased by a factor of 3.6. This low growth is result of replacing biomass with fossil fuels to meet our energy needs.

A key question regarding sustainable production and consumption is if the planet will be able to support such rates of material extraction/use with growing populations and wealth, even if there is relative material resource decoupling. Also, how can we ensure that we remain within the limits of the ecologically possible? The UNEP 2011 report on decoupling suggest 3 scenarios of material use to the year 2050 (see Fig. 1.5):

<u>SCENARIO 1: Business-as-usual scenario (BAU).</u> In this scenario, the per capita annual metabolic rate (tons of materials per capita per year) of developing countries catch up (converges) with that of industrialized countries, while industrialized countries freeze their metabolism rate at 2000 levels.

The BAU scenario would result in a worldwide metabolic volume of 140 billion tons annually by 2050. This would mean an average material use rate of 16 tons per person per year. In relation to the year 2000, this would be a three-fold increase in the yearly resource extraction worldwide, and establish global metabolic rates that are similar to today's European average.

This scenario assumes no major system innovation towards sustainability, such as a radical move away from fossil fuels.

<u>SCENARIO 2: Moderate contraction (by a factor of 2) and developing countries catching up.</u> In this scenario, developed countries reduce their material use by factor of 2 (i.e. from an average of 16 tons per capita to 8 tons per capita), while developing countries increase their material use rates and by 2050 catch up with developed countries, achieving parity.

For the developed countries, reaching a factor 2 reduction of material use would imply resource productivity gains of 1–2% annually—within the range of recent historical productivity gains. It would, however, require substantial economic structural change and large investments in innovations enabling resource decoupling.

This scenario would yield a global material use of 70 billion tons by 2050—about 40% more resource extraction than in the year 2000.

SCENARIO 3: Radical contraction (freeze total material extraction to 2000 level) and converge metabolism rates for industrialized and developing countries. This scenario stipulates a global material use of 50 billion tons per year by 2050 (the same as in the year 2000). The average global metabolic rate would be 6 tons per person per year.

This scenario requires radical resource-use reductions in developed countries, by a factor of 3 to 5. In this scenario, some countries classified as 'developing' in the year 2000 would have to achieve 10–20% reductions in their average material use while simultaneously eradicating poverty. Such an outcome can be expected only if we have radical system and technological change that are sustainability-oriented.

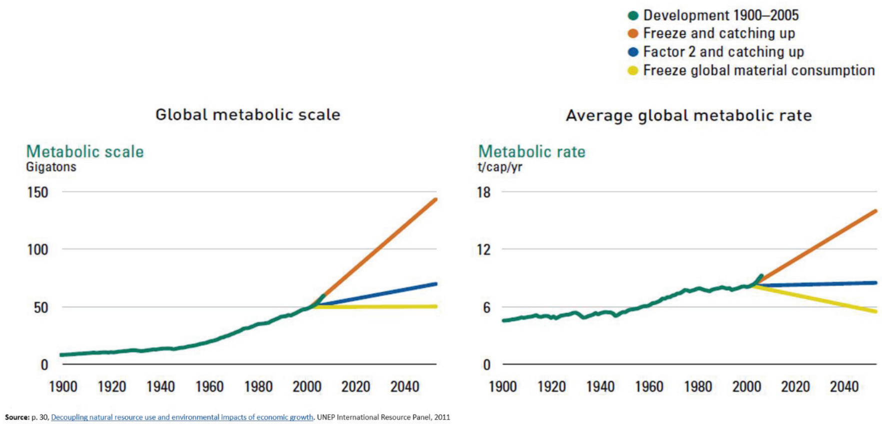


Figure 1.5

The technological potential for decoupling is large, with substantial economic benefits. Some of this can be achieved in the short/medium term and some in the longer term.[7] But if we are to achieve significant results, we would have to turn on our innovation engines full throttle. With this,

[7] UNEP (2016). Global Material Flows and Resource Productivity. An Assessment Study of the UNEP International Resource Panel. H. Schandl, M. Fischer-Kowalski, J. West, S. Giljum, M. Dittrich, N. Eisenmenger, A. Geschke, M. Lieber, H. P. Wieland, A. Schaffartzik, F. Krausmann, S. Gierlinger, K. Hosking, M. Lenzen, H. Tanikawa, A. Miatto, and T. Fishman. Paris, United Nations Environment Programme.

we will turn to a discussion of the policy and technological directions that will help with decoupling material use from economic growth.

The European Union, Japan and China, among others, have high-level policy frameworks and laws that support resource efficiency and guide investments into green sectors of the economy. Increasingly, developing countries are mainstreaming sustainable consumption and production and green economy policies into their national development plans, recognizing the need to decouple their development efforts from increasing natural resource use, emissions and waste.[8]

In Japan, for instance, recycling laws for specific product groups have been enacted for 1) packaging and containers, 2) home appliances, 3) end-of-life vehicles, 4) food, 5) construction and demolition, and most recently, 6) small electronics. Whereas Japan's Home Appliance Recycling Law covered bulky electrical equipment, diverting them from landfill to recycling, the country's more recent recycling act for small electronics aims to recover critical materials.[9]

The EU's 2015 circular economy policy package identified five priority areas; 1) plastics, 2) food waste, 3) critical raw materials, 4) construction and demolition, and 5) biomass and bio-based products. In addition, the EU already has legislated Directives for packaging, WEEE (waste electrical and electronic equipment), ELV (end-of-life vehicles) and batteries.[10]

In the remainder of this section, we'll focus on how material can be reduced through more resource-efficient processes, though without incurring a reduction in the services provided. This latter point is particularly critical when dealing with material use in products, structures, etc. that can have human health consequences. Material reduction should never take place at the expense of human health and safety.

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[8] Ibid.

[9] UNEP (2017). *Resource Efficiency: Potential and Economic Implications. A report of the International Resource Panel*. Ekins, P., Hughes, N., et al.

[10] Ibid.

But the potential to reduce remains big while maintaining the expected material services. A manufacturer of hair shampoo, for instance, has been able to redesign its shampoo bottles so that they are thinner, reducing material use by 30%, while meeting the strength specifications.[11]

Broadly speaking the material extraction reductions can occur through reduction of materials use, reuse of the materials and products, and their recovery and recycling from waste streams.

In the remainder of this section, we'll mostly discuss approaches to reduce material use in economic activity. These would include intensifying material use, reducing excess materials through design or material substitution, innovative technologies and more.

Intensifying material use, or advancing the sharing economy

Many products, such as privately-owned vehicles or tools at home, sit unused for the vast majority of their lives. In theory, this leaves significant potential for much-reduced production of materials if people were prepared to share vehicles, tools, or other products.

Car sharing clubs, for instance, work by users paying membership fees and then picking up cars they can drive, paying by hourly or daily rates for the use of the car. The cars are picked up at one of the many street locations and can be dropped off at any of the predetermined street locations in the city. Typically there are many locations in a city so that it would be convenient for club members to pick up and drop off cars.

Car sharing clubs are a growing phenomenon in cities with dense populations and good public transport. In 2017, the largest car-sharing company globally was car2go, with 2.5 million members serving 25 cities worldwide.[12] The second largest car club, Zip Car is in the United States, and has expanded its service beyond private individuals to businesses.

[11] https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/manufacturing-resource-productivity

[12] https://en.wikipedia.org/wiki/Carsharing, visited June 17, 2018, 14:00 Yerevan time.

While there is some social or cultural resistance to sharing vehicles or household tools, in many urban areas such solutions are becoming accepted. Some estimates suggest that 1 car sharing club automobile, replaces 15 privately owned cars.[13]

Shared bicycle systems, such as the Velib in Paris, are a common feature in many urban areas. This business model, often referred to as "the sharing economy," is also getting traction in relation to other industries such as retail, consumer goods, hospitality, entertainment, media and communication.

Reducing excess material use through lightweight design[14]

Components of cars and buildings could be made more lightweight while maintaining desired product performance. For example, material could be saved by producing beams that are thicker and therefore stronger at the points at which they will bear the largest loads, and thinner at less loadbearing points (Fig 1.6). A UNEP report published in 2014 reports that typically building mass is 15-30% greater due to over-specification. While increased material optimization requires greater design costs, with increasing adoption of mass customization of fabrication, some of these solutions may become more feasible, enabling even more material savings.

Figure 1.6

[13] "Seeing the back of the car". *The Economist*. 22 September 2012. Accessed June 17, 2018, 13:50 Yerevan time.

[14] UNEP (2017). *Resource Efficiency: Potential and Economic Implications. A report of the International Resource Panel*. Ekins, P., Hughes, N., et al.

Lightweight design can also be achieved through innovations in the materials themselves. For example, higher-strength steel allows less material to be used without reducing its structural qualities. Steel company ArcelorMittal estimates that higher-strength steel can achieve a 32 percent reduction in the weight of steel columns, and a 19 percent reduction in the weight of steel beams.

Moreover, there is considerable scope for gains if this kind of material innovation becomes more widespread, as many countries currently use comparatively low-strength steel. For example, China, which currently consumes 60 percent of global steel reinforcement bar (rebar) output, typically uses lower-strength steel of around 335 Mega Pascale (MPa) for rebars, while Europe uses 400–500 MPa steel in rebars.

However, in China the codification of a Design Specification of High Strength Steel Structures is under way, which aims to provide guidance for and promote the use of higher-strength steels, from 460 MPa to 690 MPa (Shi et al., 2016). McKinsey calculates that "if all developed countries moved to a 500 MPa rebar strength and if 50 percent of the use of rebars in developing countries moved to 450 MPa, this would save around 45 million tonnes of steel in 2030." To the extent that steel could be strengthened even further, this could further increase material savings.

Reducing excess material use through reducing scrap and wastage in production[15]

Reducing demand would be the first approach in developing material management strategies. Clearly, reduced material demand/use reduces the energy use and environmental impacts of extracting and processing materials. In addition, experience in Germany suggests that, with guidance, improved material efficiency yields quick benefits for businesses. The German Government's material efficiency agency, demea[16], offered quantified material flow analysis to help small and medium-sized enterprises (SMEs) identify material savings potentials. On average, companies saved 2.3 percent of annual company turnover, with smaller companies saving a greater

[15] Ibid.

[16] https://www.innovation-beratung-foerderung.de/INNO/Navigation/DE/Demea/demea.html

proportion. Investments generally paid off within 13 months. While demea has discontinued this program, it now has a network of more than 50 consulting firms across Germany that can advise companies on material savings.

The mass production of manufactured components from intermediate products, such as sheets or bars of metal, generates large amounts of scrap material, left over after the desired product has been cut, punched or forged from the material. For example, blanking and stamping metal to produce a car door results in half of the original liquid metal being left behind as waste (Fig. l.7). This causes a doubling in the embodied energy of the part. Again, this kind of resource-inefficient process is driven by the fact that the cost savings in simplified processes and economies of scale outweigh the costs, to the manufacturer, of the lost materials.

Figure 1.7

However, such material and energy wastage can be avoided through better design of the arrangement of blanks to fit more closely on a fixed-width sheet. Such techniques, common in the textile industry, are being introduced in the metals fabrication industry.

Reduction or avoidance of packaging is another way of reducing material use. In one example, Electrodomésticos Taurus designed a blender whose packaging formed useful parts of the product itself, thereby eliminating cardboard packaging.

Reducing materials through material substitution

Bamboo has been proposed as a potential substitute for less sustainable resources, in a range of applications including "co-firing in power plants, producing bio-oil, for food, paper, clothing, furniture, wind turbine blades, sporting equipment, [and] scaffolding and construction."[17]

Bamboo has a tensile strength reaching 370 MPa, which is comparable to the figure for lower-strength steel quoted by McKinsey (2011); however, its light weight means its ratio of tensile strength to specific weight is six times greater than that of steel. This means that in well-designed buildings, it can be substituted for steel and produce structures that are wind- and earthquake-resistant.

However, it will also be important to consider that there could be potentially negative impacts of replacing non-renewable with renewable resources, for example through increased demand for land and related impacts on ecosystems and biodiversity.

Research on alternative materials is taking place worldwide. Researchers at the Cambridge University in England are working on carbon nanotube wire that could replace copper as a conductor of electricity. Once commercialized, such technologies could fundamentally change the material composition of electronics, cars, aircrafts, and more.[18] Figures 1.8 and 1.9 show examples of how alternative materials can be used for paneling and structural elements.

Figure 1.8

17 UNEP (2014). Decoupling 2: technologies, opportunities and policy options. A Report of the Working Group on Decoupling to the International Resource Panel. von Weizsäcker, E.U., de Larderel, J, Hargroves, K., Hudson, C., Smith, M., Rodrigues, M.

18 http://www.mining.com/researchers-make-carbon-wire-that-could-replace-copper-54552/ visited on June 17, 2018, 15:25 Yerevan time.

Figure 1.9

Reducing materials through innovative technologies

Substantial material reductions is possible through innovative design approaches. The advent of 3D printing is an important development for this. 3D printing allows for highly customized components to be produced to specification in a manner that significantly reduces material wastage. General Electric, the multinational power systems and engine manufacturer, is now producing nozzles for jet engines in this manner, with significant material savings—reducing the weight of the component by 25 percent. It is estimated that with 3D printing and its materials savings potential, empty mass of aircrafts can be reduced by 4–7%.

1.2.2.2 - Energy use

Over the period ranging from 1990 to 2015, globally there has been a relative decoupling between energy use and economic growth. Between 1990 and 2015, the energy supply (TPES measured in tons of oil equivalent) grew by a factor of 1.6 whereas the global GDP (measured with PPP in 2010 dollars) grew by a factor of 2.3.[19] As can be seen in the comparative Table 1.1, there is relative

[19] https://www.iea.org/statistics, visited June 17, 2018, 17:28 Yerevan time. The search was set for "World" and "Indicators."

decoupling also for OECD countries.[20] EU 28 shows absolute decoupling, led by Germany and the UK, which also show absolute decoupling in energy use and economic growth.

Table 1.1

Comparative Economic Performance and Energy Use

		1990	2015	FACTOR CHANGE
World	Economic Output*	45,735	105,035	2.3
	Energy Use**	8,774	13,647	1.6
OECD	Economic Output	28,088	47,731	1.7
	Energy Use	4,535	5,259	1.2
EU 28	Economic Output	11,703	17,701	1.5
	Energy Use	1,647	1,586	0.96
Germany	Economic Output	2,414	3,473	1.4
	Energy Use	351	308	0.88
UK	Economic Output	1,513	2,477	1.6
	Energy Use	206	181	0.88
France	Economic Output	1,688	2,456	1.5
	Energy Use	224	247	1.1
U.S.	Economic Output	9,064	16,597	1.8
	Energy Use	1,915	2,188	1.1
China	Economic Output	1,831	18,432	10.1
	Energy Use	879	2,987	3.4

Notes: (*) GDP PPP (billion 2010 USD)
(**) Total Primary Energy Supply or TPES (Million tons oil equivalent, Mtoe)
Source: International Energy Agency

Let's focus on EU 28 to better understand energy use and economic growth, which shows an impressive absolute decoupling (Fig. 1.10). A simple way to express the decoupling is through concept of energy intensity, namely, how many units of energy is needed to produce 1 unit of economic output. If energy intensity goes down, it means less energy is used per economic output and vice versa.

This can happen for several reasons. For one, it could in part be due to the growth of the service sector and reduction of the energy-intensive industrial sector. Some of this may have taken place, with some of the industrial activities moving to Asia. But it could also mean that there are

[20] OECD, Organization for Economic and Cooperation and Development, has thirty-four (34) industrialized member countries. For list of member countries visit http://www.oecd.org/about/membersandpartners/list-oecd-member-countries.htm.

improvements in efficiency, more energy efficient buildings, lighting, heating, passenger and freight transportation, industrial equipment and facilities.

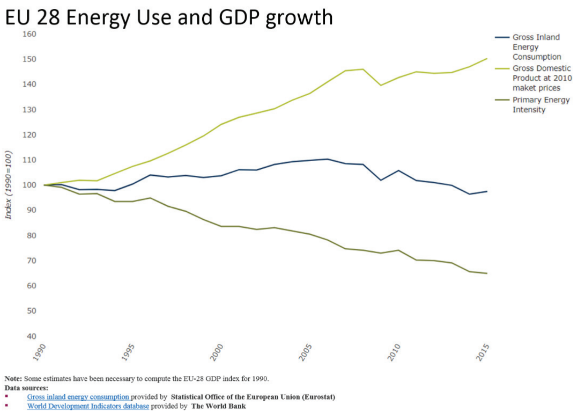


Figure 1.10

The EU has had very active policy with a great many tools to enable this to happen. It developed an EU-wide Energy Efficiency Directive, which among other provisions set a 20% energy savings target by 2020 (when compared to the projected use of energy in 2020). This was roughly equivalent to turning off 400 power stations. In 2016, the EU updated including a new 30% energy efficiency target for 2030 and measures to update the Directive to make sure the new target is met.[21]

The EU’s energy efficiency measures included:

- An annual reduction of 1.5% in national energy sales
- Implementing energy efficient renovations to at least 3% of buildings owned/ occupied by central governments for each year
- Mandatory energy efficiency certificates (building energy passports) to be available upon sales and rental of buildings

[21] https://ec.europa.eu/energy/en/topics/energy-efficiency, visited June 19, 2018, 21:50 Yerevan time.

- Minimum energy efficiency standards and labelling for a variety of products such as boilers, household appliances, lighting and televisions
- Preparation of National Energy Efficiency Action Plans every three years
- Planned rollout of close to 200 million smart meters for electricity and 45 million for gas by 2020
- Large companies conducting energy audits at least every four years
- Protecting the rights of consumers to receive easy and free access to data on real-time and historical energy consumption
- Making information available on the Commission's published guidelines on good practice in energy efficiency

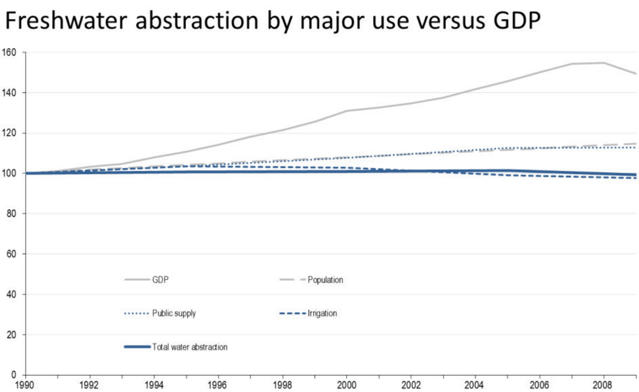
1.2.2.3 - Water use

Freshwater resources are important both for people and for a good part of nature. The distribution of freshwater varies greatly among different parts of the world. The pressures on freshwater resources come from both overuse and from degradation of their quality, which mainly stems from agricultural, industrial, and domestic use. Weather and climactic conditions also impact the quantity and quality of water available. In this section we focus on water use (and overuse). Later in the chapter, we'll discuss water pollution.

Freshwater resources need to be managed sustainably so that an adequate supply is available for human use (including economic activities) and to support ecosystems. Consequences for over-abstraction can include low river flows, water shortages, reduced food production, human health problems, loss of wetlands, desertification, and salinization of freshwater bodies in coastal areas.

Renewable vs. Non-renewable water: It is also important to make a distinction between "renewable" and "non-renewable" water resources. Although the water cycle is a closed loop, where water transforms from one state to another and moves from one compartment to another, the timescale of replenishment of water in different compartments is vastly different from each other. They can range from days for some ponds to tens of thousands of years for some groundwater reserves. As the UNEP report states, "The use of non-renewable water resources presents a more serious pressure and unsustainable use-pattern than the use of renewable water resources and hence makes a stronger case for decoupling."[22]

Globally there is progress toward decoupling water use and economic growth. This can be seen particularly in developed countries. Statistics for OECD countries show that between 1990 and 2009, OECD country economies grew 1.5 times but total water abstraction decreased by 1%. This happened at the same time that population grew and public supply of water increased. Water use for irrigation, however, also decreased. This has been possible by improving the efficiency of water distribution (reducing the leaks and losses) as well as using more efficient irrigation systems for agriculture (Fig. 1.11).



***Graph**. Freshwater abstraction by major use versus GDP, OECD, 1990-2009 (1990=100)*
***Data excludes** Chile, Estonia, Israel, and Slovenia*
***Source**: OECD Environmental Data*

Figure 1.11

There are country-specific examples of progress on water use decoupling. The two cases highlighted here are Australia and Singapore.

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[22] UNEP (2015) Options for decoupling economic growth from water use and water pollution. Report of the International Resource Panel Working Group on Sustainable Water Management.

Australia[23]

From 2001 to 2009, Australia has reduced water consumption by around 40%, while GDP has grown by more than 30 per cent, as Figure 6.1 shows. Usage in agriculture decreased from 12,200 to 7,000 Gigalitres (GL) from 2004-05 to 2008-09. Brisbane has achieved a 50 per cent per capita reduction in potable water usage from 2005-10. This came at negligible cost as most of the reduction was achieved through highly cost-effective investments in water efficiency and demand management.

This has allowed the use of scarce water in higher value sectors, like industry and manufacturing, resulting in significant improvements in water productivity – an increase of economic return from AU$50 million to AU$95 million per GL of water. There is still significant potential to improve water productivity through greater uptake of drip irrigation and irrigation- scheduling techniques as well as higher use of treated recycled water.

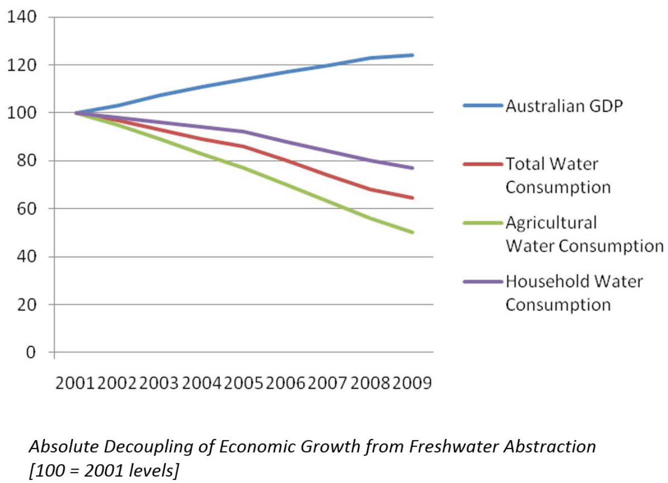


Figure 1.12

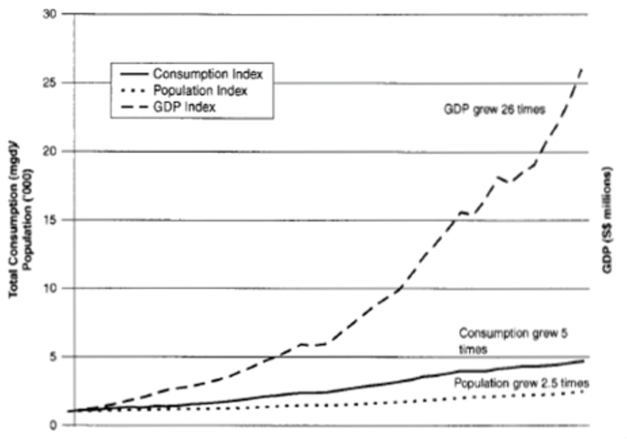
[23] The text of the case used here is directly from: UNEP (2014) Decoupling 2: technologies, opportunities and policy options. A Report of the Working Group on Decoupling to the International Resource Panel. von Weizsäcker, E.U., de Larderel, J, Hargroves, K., Hudson, C., Smith, M., Rodrigues, M.

Singapore[24]

Singapore has achieved economic growth rates in excess of 10 per cent over the last 40 years with the economy growing 25-fold in one of the fastest transitions from "developing" to a "leading first world" country in history. Its population has grown by a factor of 2.5 in that period to 4.4 million people. Yet water use has only increased five-fold, or a two-fold per capita increase. This represents a factor five decoupling (Figure 6.2). The average Singapore home now uses four times less water than a US home of comparable income. Singapore's water utility focused on reducing the demand for water by improving efficiency, cutting waste and expanding alternative sources of freshwater supply. Wasted water has been reduced (Khoo, 2005) to 5 per cent by 2002 compared to 40 per cent and 60 per cent for other Asian urban centers. This has allowed Singapore to cut its imports of water from Malaysia by 60 per cent and to commit to ending those imports entirely by 2060 through additional demand management and alternative water supply management options (PUB, 2009).

Singapore is one of the most striking successes, though other cities have also demonstrated the economic benefits of a focus on absolutely decoupling economic growth from freshwater extraction. Jerusalem, Los Angeles, San Diego, Austin, Melbourne, and Sydney have all achieved significant reductions in water demand over the last two decades (Postel, 1997).

[24] The text of the case used here is directly from: https://www.unenvironment.org/news-and-stories/press-release/singapores-remarkable-water-decoupling, accessed June 19, 2018, 22:18 Yerevan time.



Singapore GDP, population and total water consumption growth (1965-2007) [1965 =1] (Source: Khoo, T, C., 2008)

Figure 1.13

Water-use issues in Armenia

- Almost half of water is used for irrigation, making it the largest user. The water use is highly inefficient with flood irrigation and poor time management.
- This was followed by fisheries, which used about 25% for all water. This sector is using precious underground water resources. The use of closed-loop water recycling is missing.
- Mining was in the third place.
- Rapid growth of small hydropower generation stations, without adequate legislation and oversight, has resulted in impact to some of the river ecosystems as well as rural communities having access to water for irrigation.
- The most critical body of freshwater in the country is Lake Sevan. Its elevation has been rising since the low it reached in 2002. Demands on it, however, remain big for hydropower generation and irrigation in the Ararat Valley. There is also increased use of fisheries in the lake, which has water quality risk. Mining and mineral processing waste may also impact the lake.
- The municipal water distribution system in Armenia has a high level of losses. The non-revenue water (NRW)—defined as the difference between volume of water entering the

distributing system and the volume of water billed for—is one of the highest in the world.[25] Estimates suggest this number reaches an average of 75-85%, a part due to “commercial losses” (including theft, illegal connections or inaccurate billing) and another part “technical losses (including leakage due to the poor condition of the existing infrastructure networks). Veolia, the current utility provider, is expected to reduce these losses.

Types of solutions to water-use efficiency

The solutions to improving water-use efficiency fall into several categories:

- Reducing losses by fixing leakages
- Using more efficient technologies, such as drip irrigation or more efficient plumbing fixtures
- Water management, irrigating at the right time of the day (say 5 AM and not 12 NOON, where a significant amount of the water would be lost to evaporation due to the heat from the sun)
- Water recycling (wastewater treatment)
- Water harvesting (rainwater harvesting, …)
- Proper water pricing policy, with due consideration to social aspects, such as the water-bill affordability for low-income residents

1.2.3 - CLEANER AND NO-HARM PRODUCTION (IMPACT DECOUPLING)

Production activity uses materials and energy and, in the process, emits pollutants and generates waste. The emissions and the waste can be generated from industrial processes, such as mining, smelting, energy generation, transporting goods, cutting, molding, and assembling parts and more.

These pollutants and waste can harm the air, water, land, and ecosystems. They can also damage human health. To ensure sustainable production and consumption, we need to reduce or eliminate such harmful emissions and waste.

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[25] See p. 10, http://siteresources.worldbank.org/ARMENIAEXTN/Resources/110711_watersector_eng.pdf, accessed June 21, 2018, 12:12 Yerevan time.

In the language of decoupling, we need to achieve impact decoupling. That is, we need to increase economic output while reducing the harmful emissions and waste, with their harmful impact.

The only pollutant for which there is longitudinal and systematic analysis of emissions and economic growth is carbon dioxide and equivalent emissions.[26] The greenhouse gas emissions are particularly relevant for late 19th, 20th and 21st century economies as there's been increasing reliance on fossil fuels as a source of energy. Burning of fossil fuels emits carbon dioxide and other greenhouse gases. The large quantities of fossil fuels used by humans have increased the atmospheric concentrations of CO2 and other greenhouse gases. This is bringing about massive climate and habitat disruptions, which are expected to only intensify.

Historical evidence shows that from 1900 to 2000, there has been relative decoupling of economic growth from greenhouse gas emissions. The global economy grew 22-fold whereas fossil fuel use grew by 14 times and greenhouse gas emissions grew by 13 times.[27]

The environmental imperative, however, is to create absolute decoupling. To reduce the CO2 or equivalent emissions, solutions have to come from use of renewable energy, energy efficiency, agriculture, sustainable cities, and better management of forests.

1.2.3.1 - Atmospheric pollution

Air pollution occurs when harmful or excessive quantities of substances including gases, particulates, and biological molecules (pollens, viruses, etc.) are introduced into the Earth's atmosphere. It may cause diseases, allergies and even human death. It may also cause harm to other living organisms such as animals and food crops as well as damage to the natural or built

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26 p. 20, UNEP (2011) Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel. Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E.U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Romero Lankao, P., Siriban Manalang, A., Sewerin, S.

27 Ibid.

environment. Human activity (industry, transport, agriculture) and natural processes (volcano eruptions, wildfire smoke, radon) can both generate air pollution.[28]

In this section, however, we'll briefly review the key anthropogenic air pollutants. The main anthropogenic sources of outdoor air pollution (hereafter, air pollution) are:

- Transport
- Power and heat generation (especially fossil-fuel based though others may also generate harmful emissions)
- Industry (including mining)
- Agriculture
- Waste management
- Construction

As WHO reports, air pollution is a major environmental risk to health. It further states that by reducing air pollution levels, countries can reduce the burden of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma.

Various international organizations and countries identify different emissions as pollutants. The World Health Organization's 2005 "WHO Air Quality Guidelines"[29] offer global guidance on thresholds and limits for key air pollutants, which include:

- Particulate matter (PM) 2.5 (particles in air that 2.5 micrometers or smaller in diameter and can cause lung and cardiovascular diseases)
- PM 10 (particles in air that are 10 micrometers or smaller in diameter and can cause lung and cardiovascular diseases)
- Ground-level Ozone (O_3) (or tropospheric Ozone)
- Nitrogen Dioxide (NO_2)
- Sulfur dioxide (SO_2)

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[28] https://en.wikipedia.org/wiki/Air_pollution

[29] http://www.who.int/airpollution/publications/aqg2005/en/. This guidebook is available in several languages including Russian.

Other pollutants typically included are:

- Carbon monoxide
- Heavy metals (lead, cadmium, chromium, arsenic, etc.)
- Volatile organic compounds (VOCs)
- Ozone-depleting compounds (CFC's, etc.)
- Greenhouse gases (CO_2, methane, etc.)
- Dust

While most of these are directly hazardous to human health, some, such as carbon dioxide, pose climate change risks, which eventually harm humans and other organisms.

A key point to keep in mind about this emissions is that there are ways to:

a) Reduce or eliminate them

b) Manage them

c) Protect ourselves from them in case they cannot be reduced or eliminated

In the in-depth section of this chapter, we will discuss particulate matter (PM), heavy metals, and sulfur dioxide and nitrogen oxides, as they are important for Armenia with respect to transport in Yerevan, mining and smelting in the regions, and cement factories in Ararat and Hrazdan.

There are many examples of successful policies across various fields and economic sectors:[30]

- **Industry (including mining and smelting):** clean technologies that reduce industrial smokestack emissions (using filters and scrubbers); prevention of fugitive tailings of dust and particulate matter
- **Energy:** ensuring access to affordable clean household energy solutions for cooking, heating and lighting
- **Construction:** control and management of dust

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[30] Based on http://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health, visited June 21, 2018, 11:30 Yerevan time

- **Transport:** shifting to clean modes of power generation; prioritizing rapid urban transit, walking and cycling networks in cities as well as rail interurban freight and passenger travel; shifting to cleaner heavy-duty diesel vehicles and low-emissions vehicles and fuels, including fuels with reduced sulfur content
- **Urban planning:** improving the energy efficiency of buildings and making cities more green and compact, and thus energy efficient
- **Power generation:** increased use of low-emissions fuels and renewable combustion-free power sources (like solar, wind or hydropower); co-generation of heat and power; and distributed energy generation (e.g. mini-grids and rooftop solar power generation)
- **Municipal and agricultural waste management:** strategies for waste reduction, waste separation, recycling and reuse or waste reprocessing as well as improved methods of biological waste management such as anaerobic waste digestion to produce biogas, are feasible, low cost alternatives to the open incineration of solid waste. Where incineration is unavoidable, then combustion technologies with strict emission controls are critical

1.2.3.2 - Water pollution

Water pollution is the contamination of water bodies, surface or underground. Our focus will be on contamination caused by human activities. Examples include releasing insufficiently treated municipal, industrial, or agricultural wastewater into natural water bodies. This can lead to public health problems as well as damage to ecosystems. Water-pollution types can be placed in 6 categories:

1. **Pathogenic microorganisms** – These are pollutants that result from water that contains human or animal fecal matter, which can wash into bodies of water through untreated sewerage water and surface water runoff. Human exposure to these microorganisms can lead to health problems such as digestive problems, jaundice, and even neurological damage. Worldwide, waterborne diseases are linked to significant disease burden. Waterborne diarrheal diseases, for example, are responsible for 2 million deaths each year, with the majority occurring in children under 5.[31]

Solutions: Ensuring drinking water source is clearly separated from potential contamination from sewer or animal waste. It is also necessary to treat wastewater before releasing into the natural

[31] http://www.who.int/sustainable-development/housing/health-risks/waterborne-disease/en/ accessed June 21, 2018, 13:13 Yerevan time

environment. In many small communities this can be done with low-capital intensive, and low-maintenance natural treatment systems.

2. **Excess nutrient** – Top soil, fertilizers, animal waste, untreated sewer, all have high concentrations of nitrogen and phosphorous, which plants use in order to grow. When soil erosion, surface runoff, and disposal of untreated fecal matter enter water bodies, they create a condition of excess nutrient. In some bodies of water—such as lakes, estuaries, and slow-moving water—this results in the process of eutrophication, where eventually the body of water becomes hypoxic and dead water.

Solutions: Ensuring drinking water source is clearly separated from potential contamination from sewer or animal waste. It is also necessary to treat wastewater before releasing into the natural environment. In many small communities this can be done with low-capital-intensive natural treatment systems.

3. **Metals, salts, acids** – Metals and salts occur naturally in the environment, including water. The acidity of water bodies also differ from place to place. However, human activity—such as mining, construction, and agriculture—can increase the concentration of metals (including harmful heavy metals like lead), salts and acidity of water. In this category, for instance, the key forms of pollution from mining include heavy-metal pollution and acid rock drainage. These can have severe impacts on aquatic and terrestrial ecosystems, including humans.

Solutions: The solution to these types of pollution are varied. The most obvious one is to avoid producing the pollution. In the case of acid rock drainage, most of the solutions focus on trying to neutralize the acid, prevent exposure of mine materials to oxygen and flowing/percolating water, or otherwise prevent bacteria from catalyzing the necessary reactions.[32]

4. **Chemicals and pharmaceuticals** – A good amount of the chemicals we use in agriculture, industry, and our homes (such as our cleaning agents or medicines) enter into water bodies. These can have significant impact on aquatic ecosystems. Many studies have shown the impact of these chemicals and pharmaceuticals on fish populations, including their hormonal systems, reproductive capacity, and more.

[32] https://www.americangeosciences.org/critical-issues/faq/what-can-be-done-prevent-or-clean-acid-mine-drainage

Solutions: The solution to these types of pollution are varied. The most obvious one is to avoid using chemicals that can persist in nature and harm it. Easy personal decisions could be to stop buying antibacterial soaps, which can be harmful to the environmental and possibly human health. Instead one could simply buy regular ones. This same can be true for many of the household cleaning agents we use.[33] The pharmaceuticals would need to be controlled both with disposals and at the production site. The consumer-generated pharmaceutical pollution of water needs to be managed at the level of municipal wastewater treatment plants. Households can also prevent flushing leftover or expired medicines into toilets.

5. **Heat** – Human environments, such as cities, and activities, such as industry, are also a source of heat for bodies of water. When bodies of water become warmer, they can retain less dissolved oxygen. As a consequence the aquatic ecosystem can be radically disrupted.

Solutions: For industrial water, the use of cooling ponds before release or the use of heat exchangers to transfer the heat from the outgoing water into the incoming water (very much like an air-to-air heat exchanger). These will result in cooled-down water entering into the natural bodies of water. In urban areas, bio-retention landscapes are becoming more prevalent. Through these landscapes urban runoff water, instead of going into the storm drainage system, goes into landscape areas where it percolates into the soil. In the process it cools down, is filtered, and some of the water recharges the underground water reserves.

6. **Radioactive materials** – Radiation can enter waterways through eroding or dissolving underground deposits of radioactive metals such as uranium, from the air due to accidental or intentional release, in seepage from improper disposal sites, in mining runoff or dumped mine tailings, or from industrial activities. It can become a health concern when radioactive materials become concentrated in waterways. The primary environmental and human health risks from radiation involve cancer, but the degree of risk varies with how much radiation is involved over how long a time period.[34]

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[33] https://www.epa.gov/saferchoice

[34] https://www.epa.gov/sites/production/files/2016-02/documents/160112parent_plain_english_descriptions_finalattainsnames.pdf

Solutions: The main approaches here should be information and awareness, proper disposal of waste, and prevention of accidents. Depending on the specifics of the situation, there may also be medical responses to help deal with exposure.[35]

1.2.3.3 - Land pollution

Potentially contaminated sites (PCS) are sites where historical, recent, or current activities could emit contaminating elements into soil or water. These activities could include:

- Waste disposal sites
- Industrial objects
- Warehouses of waste and chemicals
- Military objects
- Electric transformer stations
- Mine tailing ponds
- Fuel and petroleum stations
- Bus, train, and truck parks
- Dry cleaners

Frequently encountered soil contaminants can be heavy metals, hydrocarbons, pesticides (including persistent organic pollutants, POPs). This results from mining, smelting, industrial and energy production, agriculture, and transportation. Some of it enters soil through deposition from air, some from water, and some from solid waste disposed on land.

There are several ways of dealing with these contaminants, including:

- Removal and containment of the contaminated soil (often a costly solution and may be entirely infeasible when quantities are very large)
- Bioremediation, which allows microbes to digest the organic compounds

[35] https://emergency.cdc.gov/radiation/countermeasures.asp

- Phytoremediation, which plants trees and other plants that withdraw the heavy metals from soil and accumulate them in their organism. Phytoremediation can also stabilize the heavy metals in soil so they don't disperse
- Capping and containing the soil
- And a few other solutions

1.2.4 - ECO DESIGN AND LIFE-CYCLE ASSESSMENT

Eco-design[36] focuses on designing and planning products, systems and services with the aim of offering solutions that reduce energy consumption as well as environmental, health, and social impacts throughout the life cycle of the product, system, or service. With adequate eco-design (including design of chemicals), some of the negative impacts of products can be reduced or eliminated.

1.2.4.1 - Cradle-to-Grave Design

The notion of "cradle to grave" in relation to environmental and industrial thinking has been around for several decades. What cradle-to-grave thinking suggests is that, when we consider designing, making, or using products, we should not only consider the impact of the product at the stage of production. From an environmental perspective, we should consider the entire lifecycle of the project/product, including use and disposal.

If we want to consider the environmental impact of say, buying and driving an automobile, it is not enough to consider the period of our use, e.g. by only looking at its fuel efficiency. Undoubtedly, fuel efficiency is important; however, the impact of an automobile goes far beyond its use of fuel. What needs to be considered is the car's lifecycle: mineral extraction, transport and processing;

[36] The term eco-design in this chapter is used very broadly to include all design approach that consider the environment. In the EU Ecodesign Directive, however, the concept is used in the context of developing consistent EU-wide rules for improving the environmental performance (mostly energy performance) of products, such as household appliances, information and communication technologies or engineering. The Directive sets out minimum mandatory requirements for the energy efficiency of these products.

design of the automobile; manufacturing and molding of metals, plastic, and fabrics, and their assembly; transportation of the final product to retailers; marketing and sale of the product; use and repair; disposal of the car and its parts.

Such a cradle-to-grave perspective could be adopted for all services and industrial products. The analytical tool used in cradle-to-grave design is lifecycle assessment (LCA). LCA is a technique that avoids a narrow outlook on a product, allowing for the analysis of the impact of a product's entire life. It allows for:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential impacts associated with identified inputs and releases;
- Interpreting the results to help make a more informed decision.

Such an assessment is very data- intensive and requires the use of computer programs. There is a wide variety of software programs available in the market, all of which require some level of training to use. Some of the recognizable names in the LCA software market are GaBi (by PE International), SimaPro, and OpenLCA. The field, however, is changing rapidly, with many more entrants into the market in the recent past.

1.2.4.2 - Cradle-to-Cradle Design

Arguments for cradle-to-cradle design were put forward with great force and eloquence by architect William McDonough and chemist Michael Braungart in their seminal 2002 book called *Cradle-to-Cradle: Remaking the Way We Make Things*.

In this book, they put forward the bold premise that what we see in terms of environmental deterioration is not a necessary result of human activity, population growth or economic progress. Instead, it is a failure of design. They even go as far as to state that we know all we need to know about how not to cause harm. We have simply failed to use this knowledge effectively in our design of processes, products, and resources.

A fundamental step we need to take is to look at the circular nature of biological systems and the environment. Nothing goes to waste in nature. There are no landfills. Every material or organism becomes part of another material, organism, or element - there is no waste in nature. We have to redesign our products and practices with this in mind, eliminating the concept of waste.

They posit that human societies have two types of metabolism: a) biological metabolism and b) technical metabolism. "With the right design all of the products and materials manufactured by industry will feed into one of these two metabolisms…." Products or buildings can be designed to have a limited life; however, this means designing products/materials that can be taken apart and used and reused without downcycling.

The authors used the publishing of their book as an opportunity to demonstrate how one could fundamentally redesign an all-too-common product, a book. Their book is not made of paper. Instead, it is made of plastics, polymers that are infinitely recyclable. Neither were trees cut down, nor was any chlorine used to turn the paper white. The inks are non-toxic and can be washed by safe simple chemical processes in boiled water. These inks can then be recovered from the water and reused. The glues used are also recoverable and reusable without toxic effects.

Over the past decade, McDonough and Braungart have put their design principles into practice. Through their consulting firm, MBDC, they have worked with dozens of companies including Steelcase, Proctor & Gamble, Pepsico, Energizer, Nike, etc. They also offer cradle-to-cradle certification (C-2-C certification) for products and processes. Herman Miller has more than 20 products with C-2-C certification.

Cradle-to-cradle thinking can be used in spheres other than product design and manufacturing. For example, in the management of purchasing and contracting there have also been innovations. The multinational company Armstrong, a building materials manufacturer, now takes back its fiber ceiling tiles and uses recovered material to produce new ceiling tiles. There are increasing examples of purchasers of building materials, such as carpets, furniture, and drywall, making contractual conditions that the seller take back and fully utilize recovered material to produce the same material.

1.2.4.3 - Design for Sustainability (D4S)[37]

In 2009, the United Nations Environment Programme (UNEP) in partnership with the Technical University of Delft in the Netherlands developed and published a guideline for product development called Design for Sustainability (D4S).

The method—which is available online free of charge in the form of a manual, a series of modules, and a few worksheets—offers entrepreneurs and companies tools to improve or create new products that have the needed quality, are relevant to market needs, and have good environmental performance and social benefits.

Concepts such as clean technology, cleaner production, and eco-efficiency were followed by thinking about product impacts for its entire life cycle. Concepts like Ecodesign (as used in the EU Directive on Ecodesign) and Design for the Environment (DfE) were developed and put into practice to address the environmental concerns associated with production and consumption processes.

D4S is the latest evolution of product design and takes into account the overarching goals of sustainability, which include environmental, social and economic concerns.

- Environmental impacts can be divided into three main categories: ecological damage, human health damage and resource depletion.
- Societal impacts can include on-the-job injuries, consumer and employee health effects to chemical exposure, exploitation of labor, child labor, and resource conflict (diminishing water and food supplies).

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[37] All the materials related to DS4 are available at http://www.d4s-sbs.org/. They are also available from UNEP's Document Repository. The manual, for instance, can be downloaded here: https://wedocs.unep.org/handle/20.500.11822/8742.

- Economic value to be created through the product or service is adequately informed by the market with respect to demand, competition, pricing, and the like.

As noted, this methodology is available in the English language online. Companies and organizations can use it to review their existing products or develop new ones. Universities can also consider integrating some of the content in their teaching materials.

1.2.4.4 - Green Chemistry[38]

Most chemicals are also designed with many decisions made by scientists and engineers about the elements used and processes employed. Chemists working with the principles of green chemistry seek to reduce or eliminate toxicity, conserve energy, reduce water use, reduce waste, and take into account life cycle considerations such as the use of more sustainable or renewable feedstocks and designing for end of life or the final disposition of the product.

The field has advanced quickly. The Nobel Prize in Chemistry was won for research in areas of chemistry that were largely seen as being green chemistry in both 2001 (Knowles, Noyori, Sharpless) and 2005 (Chauvin, Grubbs, Schrock). These Nobel Prizes helped solidify the importance of research and work in green chemistry. The field has also bloomed rapidly. Green chemistry groups, journals, and conferences are launched all over the world.

There are many developments and examples in the field of green chemistry. The following are a few as presented by the American Chemical Society.

Computer Chips: To manufacture computer chips, many chemicals, large amounts of water, and energy are required. In a study conducted in 2003, the industrial estimate of chemicals and fossil fuels required to make a computer chip was a 630:1 ratio! That means it takes 630 times the weight of the chip in source materials just to make one chip! Compare that to the 2:1 ratio for the manufacture of an automobile.

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38 This section directly uses the text from the American Chemical Society, a leading scientific society globally, and their examples of green chemistry. The same and more information is available at https://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry.html. Other sources of information on green chemistry include: https://www.epa.gov/greenchemistry and http://www.euchems.eu/divisions/green-and-sustainable-chemistry-2/.

- Scientists at the Los Alamos National Laboratory have developed a process that uses supercritical carbon dioxide in one of the steps of chip preparation, and it significantly reduces the quantities of chemicals, energy, and water needed to produce chips.
- Richard Wool, former director of the Affordable Composites from Renewable Sources (ACRES) program at the University of Delaware, found a way to use chicken feathers to make computer chips! The protein, keratin, in the feathers was used to make a fiber form that is both light and tough enough to withstand mechanical and thermal stresses. The result is feather-based printed circuit board that actually works at twice the speed of traditional circuit boards. Although this technology is still in the works for commercial purposes, the research has led to other uses of feathers as source material, including for biofuel.

Medicine: The pharmaceutical industry is continually seeking ways to develop medicines with less harmful side-effects and using processes that produce less toxic waste.

- Merck and Codexis developed a second-generation green synthesis of sitagliptin, the active ingredient in Januvia™, a treatment for type 2 diabetes. This collaboration led to an enzymatic process that reduces waste, improves yield and safety, and eliminates the need for a metal catalyst. Early research suggests that the new biocatalysts will be useful in manufacturing other drugs as well.
- Originally sold under the brand name Zocor®, the drug, Simvastatin, is a leading prescription for treating high cholesterol. The traditional multistep method to make this medication used large amounts of hazardous reagents and produced a large amount of toxic waste in the process. Professor Yi Tang, of the University of California, created a synthesis using an engineered enzyme and a low-cost feedstock. Codexis, a biocatalysis company, optimized both the enzyme and the chemical process. The result greatly reduces hazard and waste, is cost-effective, and meets the needs of customers.

Biodegradable Plastics: Several companies have been working to develop plastics that are made from renewable, biodegradable sources.

- NatureWorks of Minnetonka, Minnesota, makes food containers from a polymer called polylactic acid branded as Ingeo. The scientists at NatureWorks discovered a method where microorganisms convert cornstarch into a resin that is just as strong as the rigid petroleum-based plastic currently used for containers such as water bottles and yogurt pots. The company is working toward sourcing the raw material from agricultural waste.

- BASF developed a compostable polyester film that called "Ecoflex®." They are making and marketing fully biodegradable bags, "Ecovio®,"made of this film along with cassava starch and calcium carbonate. Certified by the Biodegradable Products Institute, the bags completely disintegrate into water, CO_2, and biomass in industrial composting systems. The bags are tear-resistant, puncture-resistant, waterproof, printable and elastic. Using these bags in the place of conventional plastic bags, kitchen and yard waste will quickly degrade in municipal composting systems.

1.2.5 - ENVIRONMENTAL MANAGEMENT SYSTEMS

An Environmental Management System (EMS) is a set of internal rules, policies, practices, and records that an organization (such as a company or government agency) may develop to track, monitor, and improve its environmental performance.

An EMS is developed by an organization based on its specific products, services, and operations. A beverage bottling company would have a different set of environmental goals than a mining company or a hotel operation.

The International Standards Organization (ISO) provides guidelines to organizations on developing an EMS. The ISO 14001 is the standard that offers this guideline. Another set of guidelines, available developed by the European Union is called Eco-Management and Audit Scheme (EMAS). It is considered a more structured and rigorous process.[39]

At the very basic level, an EMS helps an organization address the demands on it through regulation. Much like voluntary accounting audits, it offers a proactive, systematic and cost-effective way to identify problems, reduce the risk of non-compliance, and improve health and safety practices for employees and the public.

Additionally, an EMS can help address non-regulated issues, such as energy and water conservation or waste reduction. It can promote stronger operational control and employee stewardship.

[39] http://ec.europa.eu/environment/emas/pdf/factsheets/EMASiso14001_high.pdf

Basic elements of an EMS include the following:[40]

- Reviewing the organization's environmental goals
- Analyzing its environmental impacts and legal requirements
- Setting environmental objectives and targets to reduce environmental impacts and comply with legal requirements
- Establishing programs to meet these objectives and targets
- Monitoring and measuring progress in achieving the objectives
- Ensuring employees' environmental awareness and competence
- Reviewing progress of the EMS and making improvements

The EMS systems are based on the simple principle of Plan-Do-Check-Act. Figure 1.14 shows the process for the EU's EMAS. Organizations within EU will contact the competent bodies in their own country. Organizations not in the EU can join EMAS through EMAS Global.

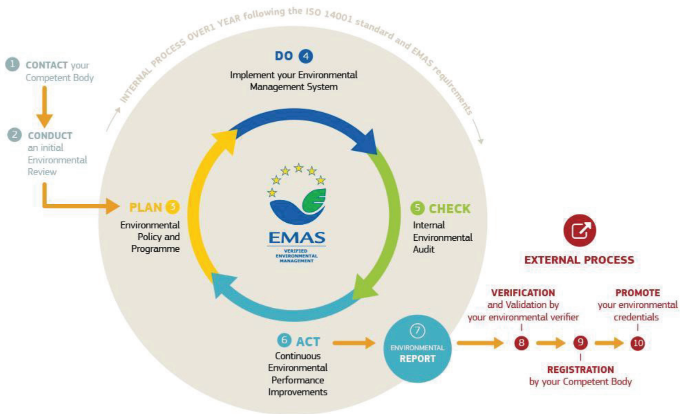

Figure 1.14

In 2009, the European Commission completed the "Study on the Costs and Benefits of EMAS to Registered Organizations." The study identified the benefits and costs of EMAS registration as well

[40] https://www.epa.gov/ems/learn-about-environmental-management-systems#what-is-an-EMS accessed June 22, 2018, 18:51 Yerevan time

as the incentives and barriers facing new registrants. Around 460 EMAS registered sites (approximately 11 percent of EMAS registered sites in Europe) participated in the survey.[41] The three benefits most commonly identified in the study are:

- Increased efficiency savings: The primary benefit of EMAS registration is cost savings through increased resource efficiency. EMAS helps registered organizations identify opportunities to better manage their resources.
- Reduced negative incidents: EMAS provides organizations with a better overview of their processes and greater control, which allows organizations to reduce the number of negative incidents.
- Improved stakeholder relationships: Improved relations with regulators, non-governmental organizations (NGOs) and the local community increases trust and understanding between parties, thereby reducing the number of complaints received from stakeholders.

A 2016 literature review[42] of EMAS concludes that the assessments conducted show that environmental performance improvements depend on the extent to which the EMS is integrated into the structure of the organization. The more embedded, the more improvements in performance. The authors note that improvements in the relationships with stakeholders arise as one of the most important intangible outcomes of EMS adoption.

1.2.6 - OCCUPATIONAL HEALTH AND SAFETY

Production and operations cannot be considered sustainable if workers are injured and killed. Very few of us would use products if we knew people were made sick or killed in the process of producing those products. Humanity is striving to eliminate slavery and abusive human relationships. Lack of safety and health at work creates a situation which can be characterized as abusive.

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41 http://ec.europa.eu/environment/emas/pdf/factsheets/EMASBenefits_high.pdf

42 Tourais, P. and Nuno Videira. "Why, How and What Do Organizations Achieve with the Implementation of Environmental Management Systems?—Lessons from a Comprehensive Review on the Eco-Management and Audit Scheme." *Sustainability* 2016, *8*(3), 283; https://doi.org/10.3390/su8030283

Every year, approximately 270 million people in the world suffer from occupational injuries, fatal and non-fatal. A recent report by the International Labour Organization (ILO) estimates that about 2 million occupational fatalities occur every year globally.[43]

The costs to employers, individuals, families, and society arising from these injuries are considerable. These costs become even harder to bear as all are preventable and can be eliminated by taking measures and methods that we know.

Many developed countries have extensive and comprehensive occupational safety and health (OSH) management systems. The results from these countries are that they consistently show low and reduced accident rates. In fact, an increasing proportion of occupational injuries in the world is occurring in developing countries.

A factory worker in Pakistan, for example, is eight times more likely to be killed at work than a factory worker in France. The injury rates can also vary by industry. For instance, agriculture, forestry, mining and construction, and generally, small enterprises have a worse safety record than large ones.

Workers, employers and governments must ensure that a safe and healthy work environment is established and maintained. All three have responsibilities to ensure that this takes place. The following are some of the key principles at the national level offered by ILO, though they have been grouped together of this chapter:

POLICIES AND LEGISLATION

- Occupational safety and health policies must be established. Such policies must be implemented at both the national (governmental) and enterprise levels. They must be effectively communicated to all parties concerned.
- A national system for occupational safety and health must be established. Such a system must include all the mechanisms and elements necessary to build and maintain a preventive

[43] This section directly uses text from Alli, B. O. (2008) Fundamental Principals of Occupational Health and Safety. International Labour Organization.

safety and health culture. The national system must be maintained, progressively developed and periodically reviewed.

IMPLEMENTATION

- A national program on occupational safety and health must be formulated. Once formulated, it must be implemented, monitored, evaluated and periodically reviewed.
- Social partners (that is, employers and workers) and other stakeholders must be consulted. This should be done during formulation, implementation and review of all policies, systems and programs.
- Occupational safety and health programs and policies must aim at both prevention and protection. Efforts must be focused above all on primary prevention at the workplace level. Workplaces and working environments should be planned and designed to be safe and healthy.
- Occupational health services covering all workers should be established. Ideally, all workers in all categories of economic activity should have access to such services, which aim to protect and promote workers' health and improve working conditions.
- Compensation, rehabilitation and curative services must be made available to workers who suffer occupational injuries, accidents and work-related diseases. Action must be taken to minimize the consequences of occupational hazards.
- Workers, employers and competent authorities have certain responsibilities, duties and obligations. For example, workers must follow established safety procedures; employers must provide safe workplaces and ensure access to first aid; and the competent authorities must devise, communicate and periodically review and update occupational safety and health policies.
- Policies must be enforced. A system of inspection must be in place to secure compliance with occupational safety and health measures and other labor legislation.

CONTINUOUS IMPROVEMENT

- Continuous improvement of occupational safety and health must be promoted. This is necessary to ensure that national laws, regulations and technical standards to prevent occupational injuries, diseases and deaths are adapted periodically to social, technical and scientific progress and other changes in the world of work. It is best done by the development and implementation of a national policy, national system and national program.

- Information is vital for the development and implementation of effective programs and policies. The collection and dissemination of accurate information on hazards and hazardous materials, surveillance of workplaces, monitoring of compliance with policies and good practice, and other related activities are central to the establishment and enforcement of effective policies.

EDUCATION AND AWARENESS

- Health promotion is a central element of occupational health practice. Efforts must be made to enhance workers' physical, mental and social well-being.
- Education and training are vital components of safe, healthy working environments. Workers and employers must be made aware of the importance of establishing safe working procedures and of how to do so. Trainers must be trained in areas of special relevance to particular industries, so that they can address the specific occupational safety and health concerns.

The ILO reports the following about Armenia's participation in labor-related conventions:[44]

- Fundamental Conventions: **8 conventions out of 8 ratified and in force**
- Governance Conventions (Priority): **3 out of 4 ratified and in force**
- Technical Conventions: **18 of 177 in force**
- Out of **29** Conventions ratified by Armenia, of which **29** are in force and **no** Convention has been denounced.

Sampling of labor conventions ratified by Armenia

Occupational safety and health

Convention	Date	Status
C174 - Prevention of Major Industrial Accidents Convention, 1993 (No. 174)	03 Jan 1996	In Force
C176 - Safety and Health in Mines Convention, 1995 (No. 176)	27 Apr 1999	In Force

Social security

Convention	Date	Status
C017 - Workmen's Compensation (Accidents) Convention, 1925 (No. 17)	17 Dec 2004	In Force
C018 - Workmen's Compensation (Occupational Diseases) Convention, 1925 (No. 18)	18 May 2005	In Force

1.2.7 - COMMUNITY HEALTH AND SAFETY

Other than the health and safety of workers, sustainable production activities also need be concerned about the health and safety of the community in which they operate. One of the latest

44 Data available from ILO's NORMLEX, information system on international labor standards. http://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:11200:0::NO::P11200_INSTRUMENT_SORT,P11200_COUNTRY_ID:2,102540#Occupational_safety_and_health.. For a profile of Armenia's occupational safety at ILO visit: http://www.ilo.org/safework/countries/europe/armenia/lang--en/index.htm

guidelines on the topic has been developed by the World Bank as part of its Environmental and Social Standards (EES).[45] The launch date of these new Standards was October 1, 2018.

While these standards are intended to enable the World Bank and its borrowers to better manage environmental and social risks of projects and to improve development outcomes, they can also be used by countries, communities, and businesses to generally guide their policy and program development.

The EES #4 specifically focuses on Community Health and Safety. It identifies the following areas, which require attention. We will use the areas as general thematic focus areas for Community Health and Safety and suggest broad directions that would be consistent with principles of sustainable production.[46]

1. **Infrastructure and equipment design and safety** – Ensuring structures and facilities meet national standards of design and safety. In cases where national standards may be lagging in international best practice, there is a need to review and upgrade standards and legislation. The World Bank (2016) report, for instance, pointed out that mining dams in Armenia are built with an "upstream" approach that is no longer best practice for seismic zones. The recommended approach is "downstream" approach. This means that Armenian legislation on the technical safety of such facilities has to be reviewed and, if needed, updated. In parallel, training and capacity building needs to take place to make sure the technical reviewers are aware of any new standards.
2. **Safety of services** – Community water resources, for instance, must be protected from pollution. They should also be ensured that services such as water, power, gas are provided uninterrupted. A project or a company cannot overuse water resources, leaving the community in need of water, for instance. This should be reviewed at the Environmental Impact Assessment phase of a project and thereafter monitored regularly.
3. **Traffic and road safety** – Industrial, construction, mining, warehousing, and the like have operations that use roads intensively. They also typically utilize roads with big vehicles with

[45] http://www.worldbank.org/en/projects-operations/environmental-and-social-framework

[46] World Bank's ESS does not always offer specific guideline. It also frequently refers to national legislation. In cases where national legislation is defective or missing, the guidelines can bring attention to these defects or gaps but their weakness lies in that they do not necessarily mandate an improvement in legislation. As such we will broadly use the framework and offer policy objectives for each areas. We will also identify some of the governance tools through which these can be implemented.

heavy loads. Management of the traffic and road safety issues is typically addressed at the Environmental Impact Assessment phase and the operational plan of the company. Some of the issues to address would be hours where these large vehicles can utilize the roads. In planning, attention needs to be paid to vehicle mix, volume, speed, weight, height, length, as well as lane widths, slopes, speed management, roadside uses, pedestrian usage and facilities. All risks must be addressed.

4. **Ecosystem services** – A production activity may impact the ecosystem services (e.g., water for agriculture, forest economy, fishery, etc.) that a community depends on. The enterprise must understand and avoid harming these. In situations where harm is unavoidable, in some countries legislation mandates compensation to the community. A working Environmental Impact Assessment process should capture all risks and address them. This also requires continuous inspection and monitoring to ensure compliance with the conditions of approval.

5. **Community exposure to health issues** – The emissions and waste from production activity can expose community members to health hazards. A smelting operation, for instance, emits heavy metals like lead that could enter children's bodies and cause harm to their neurological and intellectual growth potential. An operation could also dispose toxic materials directly into the water body, which many communities downstream may depend on for agriculture or drinking. The Environmental Impact Assessment should address these issues and eliminate the risks. In the case of mining in Armenia, for instance, in addition to EIAs the mining operators are expected to produce Mine Waste Management Plans. Through such plans, the issue of health impacts can also be addressed. Aside from plans, it is critical that the environmental conditions are monitored to ensure compliance with the approval conditions of the operation, including the health of community members for a range of health hazards known to be related to the types of production taking place. If legislation or norms are defective in this regard, national policymakers should address the gaps. It will be an advisable practice to regularly review such legislation and standards to ensure consistency with international best practice. It should be pointed out that the EMS tool discussed in the previous section can also be used by companies to monitor their own performance with regard to emissions, waste, and the like.

6. **Management and safety of hazardous materials** -- Hazardous materials and wastes are defined as materials that present a risk to human health, property and the environment due to their physical or chemical characteristics. These can include: explosives; compressed gases, including toxic or flammable gases; flammable liquids; flammable solids; oxidizing

substances; toxic materials; radioactive material; corrosive substances; chemical fertilizers; soil amendments; chemicals, oils and other hydrocarbons; paints; pesticides; herbicides; fungicides; asbestos; metal waste; hospital waste; used batteries; radioactive medical waste; fluorescent light bulbs and ballasts; byproducts of plastic incineration at low temperatures; and PCBs in electrical equipment.[47] The risks and impacts on community health from hazardous materials that may be used in an operation are considered as part of the Environmental and Social Impact Assessment. It is important to note that risks to the community may occur during the transport of hazardous materials to and from production sites, as well as from exposure during production activities. Where the risks and impacts of community exposure to hazardous materials and wastes are potentially significant, it may be appropriate to develop a Hazardous Waste Management Plan or a Hazardous Materials Management Plan for implementation of mitigation measures throughout the project life-cycle. In addition, it is best practice for a country to have a hazardous material transportation governance scheme as well as to develop a disaster management plan in case of an accident.

7. **Emergency Preparedness and response** – Production activities involve big structures that may fail (buildings, dams, bridges, etc.). Mine dams could break. Earthquakes may collapse bridges. Also, they may use materials that are toxic. Explosions, leakages, breakages can release these materials into the community placing property, health, and even life of residents in danger. A Risk Hazard Assessment is a mechanism for identifying potential risks to community health and safety that are caused by man-made or natural emergency events. Where such emergency events could have a significant impact on the communities—for example, fire, explosions, leaks or spills—this assessment can be conducted either as part of the Environmental and Social Impact Assessment or as a stand-alone activity. When there are risks that hazardous material or substances may be released by a project, the potential for emergency events needs to be assessed. The Risk Hazard Assessment can help determine if such emergency events call for the preparation of an Emergency Response Plan, which describes the measures to be put into place to address the emergency and protect those at risk. In preparing this response plan, it is important that the views of all segments of the local community, including the elderly, children and any vulnerable groups that may be present, along with those of the emergency services/local response teams and relevant government agencies, be taken into consideration. In Armenia, it would be critical for mining companies as well as all heavy industry (such as, smelters

[47] http://www.worldbank.org/en/projects-operations/environmental-and-social-framework/brief/environmental-and-social-standards#ess4

and chemical producers) to develop community disaster management plans. These would be plans that not only protect company employees and assets but also protect the community. Armenia has an increasingly developing emergency responder network under the direction of the Ministry of Emergency Situations. The planning, prevention, and response capacities at the national, local, and company level must be enhanced. For some of the in-country initiatives on disaster risk preparedness and prevention related to industry, review UNDP's Disaster Risk Reduction activities as well as the activities of the National Platform for Disaster Risk Reduction (ARNAP).

PART 2: SUSTAINABLE GENERATION AND USE OF ENERGY

CHAPTER 2. ENERGY EFFICIENCY IN ENTERPRISE OPERATIONS AND SYSTEMS: FACILITIES

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There is no doubt that in addition to the main activity (e.g. manufacturing, storage, service, etc.), lighting and HVAC comprise the most, if not all energy consumption of any enterprise.

2.1 - LIGHTING

Artificial lighting provides necessary levels of illumination at the particular workplane independently from time of the day, as well as independently from the fact if a particular workplane dedicated to particular types of operational tasks is lit by daylight from a window.

Human eye, luminosity function

Figure 2.1 shows a cross-section of the human eye. The *lens*, in conjunction with the *cornea* and *iris*, provides projection of the object image to the *retina*. Information from the retina is transferred to the brain through the optic nerve.

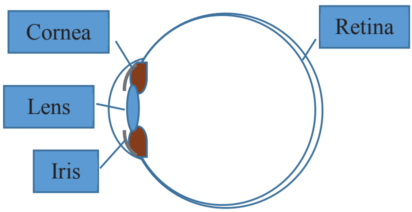

Figure 2.1 The human eye cross-section.

Note the *rods* (in grey) and *cones* (colored red, green and blue) inside the retina that are similar to the color photo sites on the image sensor of a camera. There are three types of cones, for red, green and blue (RGB) colors. Cone output signals are continuously interpreted by the brain to form pictures.

This interpretation takes place in a way that provides the full color, binocular (3D) richness of the

Each type of cone of the retina has its own sensitivity spectrum (see e.g. https://www.quora.com/Why-are-only-seven-colors-visible-to-the-naked-human-eye, https://en.wikipedia.org/wiki/Color_vision#/media/File:Eyesensitivity.svg). The rods sense black and white in low light conditions – for detecting of brightness levels only at poor lighting conditions, which is often called *scotopic luminosity*, and the vision is called *scotopic*.

At high brightness, when cones are actuated, the vision is called *photopic*, and in intermediate levels – *mesopic*. Photopic vision starts at luminance levels as low as three candela per square meter (see below for candela definition) and higher. Scotopic vision occurs at very dark illumination, below $2x10^{-5}$ cd/m^2.

While humans sense the light in the range of 380nm – 720 nm of the light wavelengths, the peaks of sensitivity for each type of cone usually are in the 560-580, 530-540 and 420-440 nm – in red, green and blue range respectively.

These sensitivity spectra are defining integral human light perception, called luminous spectral sensitivity or standard luminosity function (SLF, Figure 2.2) - a model of the spectral sensitivity of the human eye to different wavelengths. This function is also called *average frequency response* of a human eye. It is worth remembering that the word “luminous” always means the radiant intensity or EMR that is related to the light as perceived by humans in the context of the visible spectrum sensitivity. As the graph shows, for the wavelength corresponding to the peak intensity, λ=555 nm, the radiant and luminous intensity values match, having the same perceptual effect. However, e.g. for a λ=490 nm blue light, one needs to have approximately five times more radiant intensity from the source to have the same perceptual luminosity effect as for the green 555 nm light, if at a moment the color information is disregarded and overall brightness or illumination is taken into consideration.

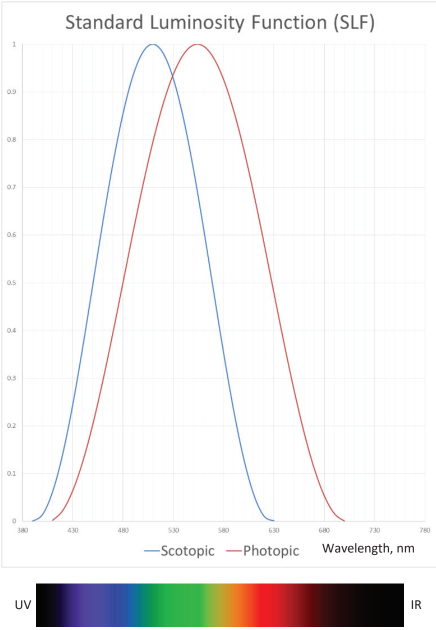

Figure 2.2 Overall spectrum of human perception of light intensity, or in other words standard luminosity function, schematically, the horizontal axis is in nm-s. Note the Scotopic (blue) and Photopic (red) cases. The peak of the Photopic, i.e. bright conditions, sensitivity is at 555 nm.

Naturally, if a light source generates radiation beyond the range of the sensitivity spectrum, humans will not be able to see it, and this energy is wasted. Thus, to be effective, the light sources should generate as much as possible within this spectrum. Unfortunately most of the light sources generate in a wider or much wider spectrum, contributing more in the heat generation and lesser in light generation.

Also human comfort needs illumination that allows reliable color perception. This means:

a. we are always interested in photopic sensitivity

b. we need to make sure that the colors are reproduced with high fidelity. Here the benchmark is the daylight – humans have been sensing daylight for ages.

It is necessary to mention that along these sensitivity spectra, there are also a number of other biophysical and psychological factors and criteria that influence human vision, not discussed in this text. All of the virtually infinite colors that people perceive can possibly be obtained through excitation of red, green, and blue cones, i.e. through a certain superposition of signals coming from the cones.

It is necessary to mention that human comfort also depends on diurnal color preferences, with cooler illumination, containing more blue components, preferred at daytime, and warmer illumination, containing more red light components, preferred at evenings and at night. Later we will discuss more on this topic.

2.1.1 - MAIN PARAMETERS OF LIGHTING

Luminous intensity: *Candela*, the name coming historically and meaning candle in Latin, is the unit characterizing the visible brightness of a source. As the word "luminous" hints (discussed in the previous section), the luminous intensity is the radiant power or radiant flux, but of course, weighted by the *luminosity function*, so that it always takes into account humans' spectral perception of light (luminosity).

General Physical Definition: Candela is the light intensity emitted in a normal direction from 1/600000 m^2 surface area of a black body radiator at the temperature of platinum solidification T = 2045 K and pressure of 101325 pascals.

Definition: candela is the luminous intensity of a source, that emits monochromatic radiation of frequency 540×10^{12} *hertz, which corresponds to 555 nm wavelength green light and that has a radiant intensity in that direction of 1 ⁄ (683.002) watt per steradian (W/sr).* Or for 555 nm 1 cd = *1 ⁄ (683.002)* W/sr. In other words, if a source of 555 nm has power generation of 1 ⁄ (683.002) W/sr, whatever brightness people *statistically* feel, is called 1 candela. Thus a 683.002 candela source of 555 nm provides 1 W/sr in all directions of radiant flux (or radiant intensity).

Luminous flux: ***Lumen*****.** While candela characterizes a source of light, in photometry we also need to characterize a *flux of visible light*, similar to the radiant intensity (radiant flux) in radiometry. It is natural to derive this unit through *candela*. The unit is called *lumen* (*lm*):

Equation 2-1

$$1 \text{ lm} = 1 \text{ cd}\cdot\text{sr}$$

If a light source equivalent to 1 candela radiates in all directions uniformly, then within each unit steradian of solid angle, in any direction, the luminous flux will be equal to 1 lumen. Thus, as has been mentioned in the previous section, lumen and candela can be used interchangeably, depending on the context of the measurement. The same source of 1 candela in all directions, i.e. within the total solid angle $\Omega = 4\pi$ sr, will have total luminous flux of $1 \text{ cd} \cdot 4\pi \text{ sr} = 4\pi \text{ cd}\cdot\text{sr} \approx 12.57$ lumens. Again, for the 555 nm wavelength monochromatic source, where the (λ=555 nm) = 1, and for $I_R(\lambda)$ = 1 W/sr, radiant intensity will transfer to 683.002 cd, and as the radiation is uniform in all directions, that will represent total of ≈8583 lumens.

Illumination: ***Lux*****.** Illumination is, in fact, the target variable that is regulated by the standards. The unit used for illumination is the *lux, lx*.

The lux is defined as the ratio of the unit luminous flux to the unit area, normal to the surface, that it illuminates:

1 lux = 1 lumen / 1 square meter.

$1\text{lx} = 1\text{lm/m}^2 = 1 \text{ cd}\cdot\text{sr/m}^2$.

Luminance: ***cd/m²***. Also target variable that is regulated by the standards, the *luminance* levels are measured in candelas per square meter, cd/m^2, aka *nit (nt)* and for an ideal diffuse (or Lambertian, Figure 2.3) reflector, is defined as:

Equation 2-2

$$L_v = E_v R/\pi,$$

Where L_v is the luminance level in cd/m^2, E_v is the illumination level in lux, R is the reflectivity (same as albedo), $\pi = 3.14159...$. For example, if a pavement has 30% reflectivity, assuming it is totally diffuse, means it is a Lambertian diffuser - does not have any specular, i.e. mirror type reflective component, and the illumination level is 300 lumen, then $L_v = 300 \times 0.3 / 3.14159 \approx 28.65$ cd/m^2.

Here is another description of luminance: if a square meter of pavement has 1 cd/m^2 luminance, if looking at this square from a very large distance, and assuming no loss of energy in the air mass, that square meter is generating the same luminous flow as just a source that has 1 candela brightness. Also look at Figure 2.3.

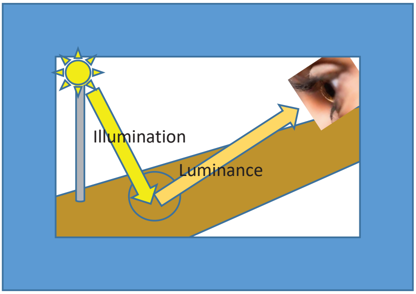

Figure 2.3 Explanation of the candela per square meter. (see also http://www.aeny.com.tw/products/lamp/technology_support/Lighting_Terms.htm, http://rsagencies.co.za/lumens-for-the-laymen/)

Correlated color temperature (CCT). The *intensity* and the *peak* of the so called black body radiation (BBR) spectrum – the dependency of the intensity of radiation of a body from the wavelength of the light at certain temperature are uniquely defined by the temperature of the body. Naturally, the peak of its SPD is stipulating a certain hue or coloration that allows tying the temperature and color for black body radiators that are also known as Planckian radiators, see e.g.: https://www.downlights.co.uk/faq-which-colour-temperature-.html, http://www.photographymad.com/pages/view/what-is-colour-temperature,

http://www.luxtg.com/tag/color-temperature/.

Depending on the source temperature, the light is perceived “white” but these colors have different perceptual impact (http://agi32.com/blog/category/sports-lighting/).

It needs to be stressed that the CCT is defined for light sources that are overall perceived as “white” light sources that however may have some kind of coloration. Due to the phenomenon of *metamerism*, there might be huge number of light sources that deliver overall white perception, but certainly, they will have different color rendition abilities. In the cases if the source is not a Planckian radiator, we speak about Matching or Relative Color Temperature, that is the closest to the spectrum of a BBR at certain temperature.

Color Rendering Index and Color Quality Scale. The ultimate criteria for describing the color comfort is defined via a so-called Color Rendering Index (CRI) and Color Quality Scale. CRI is a measure of a light source's ability to show object colors "realistically" or "naturally" compared to a familiar reference source, either incandescent light or daylight.

Color rendering index, CRI is 100 for the ideal light sources, i.e. the ones that have a very smooth and mostly uniform or slightly increasing or decreasing pattern, and decreases for the ones that are inferior, which can even get negative values.

Here is the widely accepted definition of color rendering:

Effect of an illuminant on the color appearance of objects by conscious or subconscious comparison with their color appearance under a reference illuminant (here illuminant is synonym of “light source”), such as daylight or BBR.

Roughly speaking, the number itself is calculated as 100 minus a sum of mean-square distance of the light source SPD from an ideal SPD (such as SPD of a BBR source), naturally both in the visible range. For instance, as the incandescent lightbulb is virtually a *Planckian radiator*, its SPD has 0 mean-square distance from the BBR curve at respective temperature, yielding CRI=100. The real calculation is a longer and more complex procedure, with involvement of 8 color matching cards. However, it is known to be imperfect, e.g. it yields negative values for monochromatic sources. That is why the more modern Color Quality Scale (CQS) with 15 color cards and more advanced color space implementation is in the process of development and has obvious advantages over CRI [http://colorqualityscale.com]

Although usually as a reference light source a Planckian blackbody radiator of 5000K is chosen, other BBR sources such as incandescent lamps that always have CRI = 100 but with other temperatures also can be chosen. This is because the human eye and the brain interpretation psychophysically adapt to the color temperature and map the colors to resemble as much as possible the daylight illumination condition. However this is smoothly possible for light sources that have close to CRI = 100. Otherwise, brain exerts extra efforts for interpretation, which is perceived as discomfort.

Table 2.1. CCT and CRI for a number of various light sources. Note the CRI = -44 for low pressure sodium lamp. See also https://en.wikipedia.org/wiki/Color_rendering_index

Light source	CCT (K)	CRI
Low-pressure sodium (LPS/SOX)	1800	-44
Clear mercury-vapor	6410	17
High-pressure sodium (HPS/SON)	2100	24
Coated mercury-vapor	3600	49
Halophosphate warm-white fluorescent	2940	51
Halophosphate cool-white fluorescent	4230	64
Tri-phosphor warm-white fluorescent	2940	73
Halophosphate cool-daylight fluorescent	6430	76
"White" SON	2700	82
Quartz metal halide	4200	85
Tri-phosphor cool-white fluorescent	4080	89
Ceramic discharge metal-halide lamp	5400	96
Incandescent/halogen bulb	3200	100

Table 2.1 shows the CCT and CRI for a number of various light sources.

Note the SPD of the low pressure sodium lamp, making it the worse color rendering source. In many cases the low-pressure sodium CRI is marked as 5, but different variations of the same lamp go to negative values, as indicated in Table 2.1. See also http://www.paullights.com/what-is-the-meaning-of-cri-or-colour-rendering-index/,

http://www.eia.gov/todayinenergy/detail.cfm?id=18671.

Luminous efficacy: lumen per watt, lm/W. Luminous efficacy, K, defines the efficiency of light sources. This is the ratio of visible luminous flux to radiant flux emitted by a source. In other words, luminous efficacy shows the lumens generated I_L versus the total radiation of power I_R.

Equation 2-3

$$K = I_L / I_R = 683.002 \left[\int_{\lambda=390nm}^{720nm} V(\lambda) I_R(\lambda) d\lambda \Big/ \int_{\lambda=0}^{\infty} I_R(\lambda) d\lambda \right],$$

where $I_R(\lambda)$ is the spectral power distribution (SPD) of the source radiation in all directions, i.e. the relationship of the radiation intensity from the wavelength of radiation, $V(\lambda)$ denoting unitless standard photopic luminosity function (Figure 2.2). If $I_R = I_L$, then we have $K = K_m$, where the maximum luminous efficacy is defined as K_m=683.002 lm/W – only possible for ideal 555 nm light generation source. In real life this parameter characterizes any advancement in light source technology, and in fact it currently varies in between 10 ÷ ≈300 lm/W.

Lighting Power Density (LPD), *W/(m² lx 100)*. This parameter denotes how much power is consumed per square meter to provide certain level of illumination, e.g. 100 lx. It allows comparing energy efficiency of various lighting solutions.

1.1.2 - LABORATORY TESTING

Spectrometers are devices that allow measuring the intensity or power of radiation depending on the frequency or equivalent wavelength. The simplest spectrometer is composed of a source holder, a prism and a measurement detector under various angles (http://labs.physics.dur.ac.uk/level1/projects/spectrometer.php). Due to the dispersion in the prism, the light from the source is decomposed to its components, intensities of which are continuously measured by a detector. This measurement in fact yields the spectrum power distribution (SPD).

Spectra of incandescent and fluorescent lightbulbs are, respectively, continuous nature for the first and linear spiky for the second. Note SPD-s of various light sources. Also note that all SPD-s are in the visible range of approximately 350 ÷ 750 nm.

To achieve higher accuracy and to eliminate the influence of the prism material itself, the grating spectrometers are developed. Here the decomposition of the input beam is taking place due to the diffraction, rather than the dispersion used in a glass (quartz) prism spectrometer. Action of a diffraction grating is analogous to a prism.

Any SPD measured through a spectrometer can be converted in *spectrophotometric* measurement, if the received SPD is normalized by the standard luminosity function (SLF), which can be done numerically in the digital device or in post measurement through the computer. Another interesting piece of equipment is the *spectrocolorimeter*, which can provide the source colorimetric values in CIE 1931 and 1976 color spaces, as well as allowing measurement of the relative color temperature.

A luxmeter is a light intensity meter that is sensitive to the visible radiation range and is normalized according to the photopic standard luminosity function, Figure 2.2.

Since it is normalized per SLF, it automatically counts for human vision and delivers the readings not in energy values but in *lux*. Usually it has a silicon photovoltaic conversion sensor, which covers virtually all visual range. The measurement ranges from 0.1 ÷ 1 000 000 lux with 0.1 lux step, which is more than enough e.g. for indoor photopic measurement.

The luxmeter is easy to use; it also usually has a number of convenient functions, such as reading memory, etc. The detector area usually is small enough to easily understand the distribution of the illumination. They may cost from a few tens of US dollars to thousands, depending on accuracy, sensitivity and functionality. Some luxmeters also measure luminance in cd/m^2.

It is interesting to mention that any iOS or Android device has the capability of installing a lux meter app that uses the device's camera sensor and provides measurement. While it may not pretend to have very high accuracy, in many applications, especially those that are straightforward and use relative values, it can be rather helpful.

Integrating Sphere. In order to measure the total flux of energy or light provided by a light source, integrating spheres are used. As the name hints, the function of this sphere is to integrate spatially all rays coming out of a light source, so that measurement becomes universal for all light sources and provides repeatable, consistent results. While any light source may have certain directionality, which varies from one source to the other, the integrating sphere allows smoothing through diffusion all the directional non-uniformity of the rays emitted from the light source (http://www.intechopen.com/books/international_journal_of_advanced_robotic_systems/design-and-analysis-of-an-underwater-white-led-fish-attracting-lamp-and-its-light-propagation, http://es.slideshare.net/juanquispe/1-luminotecnia-12002847).

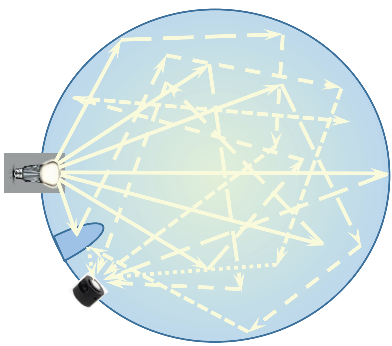

Figure 2.4. The integrating photometric sphere. Note the baffle (deflector) blocking direct illumination of the detector.

Figure 2.4 schematically shows the photometric integrating sphere. Light source and detectors through ports in the sphere are inserted inside. Due to highly diffusive material of the sphere, such as magnesium oxide or barium sulphate, up to 25 diffusive reflections take place before the light is fully absorbed. The diffusely-reflected light rays reach every small unit area on the internal surface with high uniformity – including the detector. The baffle (deflector) is inbetween the source and the detector to prevent illumination by direct primary rays that generally are non-uniform.

The integrating sphere's internal surface usually has uniform and well-known frequency response in the range of near IR to near UV, which makes it perfect for luminance-related measurements. However, for a BBR source, total energy measurement may require several integrating spheres to cover this inherently wide range (e.g. gold-plated integrating spheres are also used for infrared range). Another requirement for any component inside the sphere is that it not generate photoluminescence. The latter causes extra radiation beyond reflection and diffusion, usually out of the light source emission range. Naturally, there is a requirement towards the area of the ports, which should not exceed 5% from the total internal area of the integrating sphere. If a port is not used, a cover coated with the same material as the internal surface caps it. Naturally, integrating spheres can also be used for accurate transmission and reflectance measurements. To plot the directional diagrams, black, non-reflective, non-diffusive internal coatings are used with a *goniometric* setup, i.e. the detector can be moved to angled positions.

The sizes of laboratory photometric integrating spheres may vary between few tens of mm to several meters. Naturally the larger devices are heavy and relatively expensive.

2.1.3 - ENERGY EFFICIENT LIGHTING AND STANDARDS

The lighting aspect of health is related to psychology and avoiding depression, especially for seniors; also, for teenagers it is important to set the circadian clock, i.e. biological diurnal rhythm, in a proper manner, which, properly set, affects the rest of one's life.

The parameters are: lighting hours and seasonality; lighting spectrum and spectrum changes during the 24 hours; lighting intensity and its distribution.

Many aspects of these parameters are reflected in the standards and norms that are discussed in this chapter.

One interesting aspect is based on psychophysical data collected by Dutch physicist **Arie Andries Kruithof**. It appears to be that certain combinations of correlated color temperature and the illuminance level—or in other words, color and intensity—provide pleasing and comfortable illumination. For example, an illumination of 6000K and 10000 lux is a pleasant one. The same 6000K and 100 lux is a not a pleasant one – it is perceived as bluish. At 100 lux, the pleasant illumination should be within 2500K – 3000K. And vice versa - an illumination of 3000K and 10000 lux is not a pleasant one, but for 10000 lux 4000K and higher color temperature is pleasant. This mechanism of the human vision is telling about the adaptation ability that humans have gained through evolution; usually at night time prehistoric humans were using fire to illuminate their caves and dwellings, which forced them to develop a mechanism that adjusts the colors for lower levels of illuminance. That is why the home illuminance is usually very pleasant if realised in warm tones. Naturally this logic is true for Planckian black body radiators, since they have the highest color rendering index – since the fire and the sun are also Planckian. That is one of the reasons that the highest CRI-s are related to sources with smooth, spikeless spectrum power distribution in the visible range. Thus, as it has been described in the citations above, the circadian rhythms require whiter illumination during the daytime and warmer, lower-correlated color temperature (CCT) at the evening.

Our preferences for CCT versus illuminance may be intimately associated with the state of our circadian rhythms.

Indoor lighting

2.1.3.1 - Day lighting – windows, light pipes, their benefits;

In short, daylighting equals benefiting from the daylight inside various buildings and constructions, usually meant beyond the regular window technology. Note that the use of daylighting very successfully addresses two main important issues:

1. Health related issues – intensity, spectrum, light distribution;

2. Energy efficiency.

Clerestory Windows

An example of a window that goes beyond the main mode of window technology is the so-called ***Clerestory Window***, well known in architecture, - when the window is well above of the eye level, high on the wall (http://www.houzz.com/ideabooks/391008/list/bathe-in-the-light-of-clerestory-windows, beeyoutifullife.com, www.nrel.gov).

The clerestory windows in general provide very comfortable lighting, because they do not blind via direct bright outdoor light or direct sun rays; thus they do not contribute to ***glare***.

Skylights

The next important solution is the skylight; at

https://acuitybrands.wordpress.com/2012/07/12/acuity-brands-opens-new-state-of-the-art-daylighting-training-center-as-part-of-newly-renovated-sunoptics-facility/ ,

https://acuitybrands.wordpress.com/2012/12/04/sunoptics-launches-prismatic-daylighting-solution-for-suspended-ceiling-applications-offers-wide-variety-of-choices-in-lens-and-size-options/

one can find illustrations of the concept.

Note that there are two realizations of the skylight:

- Via light pipe concept. The latter is especially important for constructions that has internal rooms without any windows;
- Architectural solution – using designed light passes.

Very often light pipes have matte diffusers that provide *lambert* diffusion of the light, which is especially attractive since it provides smooth, even illumination. Any surface is emitting according to lambert diffusion, if the brightness of the surface, in this case visible brightness, is the same regardless of the angle of the vision line to the surface that carries lambertian diffusion. This property is very much valued by artists, architects and photographers. The lighting setup may be very close to a surface with lambertian diffusion of the matte semi-transparent diffusers. This effect is achieved also by using diffusers on the entrance of the light pipe.

It is always important to remember that daylighting solutions work best with other solutions that energy efficient building science prescribes; in addition, it is no less important to use the experience of ergonomics, concepts of comfort and productivity.

Translucent walls, floors

Transparent or translucent walls, floors and roofing is another modern means to optimize indoor lighting (https://www.reddit.com/r/pics/comments/3g09ev/room_with_mirrors_on_the_floor_ceiling_and_walls/, http://barnabygunning.com/_project.php?ID=3, brucine.blogspot.com, http://weburbanist.com/2013/10/07/house-of-hemp-and-blood-16-futuristic-building-materials/).

2.1.3.2 – Energy-efficient indoor lighting technologies and solutions;

One can define the energy-efficient indoor lighting technologies and solutions as a combination of:

- Means to use the daylighting efficiently both from windows of external facades, and skylines for internal spaces. There is no doubt that the most effective use of daylighting comes when it is planned starting from the design and architecture stage of any construction. Naturally, the latter should involve geographic, climatic, environmental and other local data.
- Importantly the requirements from the users of the buildings driven by their age and type of activities should be carefully examined and taken into account.
- Modern light sources should be vastly implemented, variating a number of their characteristics to satisfy the energy efficiency goals and goals related to comfort and performance.

- It is necessary to remember that lighting characteristics involve the following parameters:

  - lighting source efficacy in Lm/W, showing amount of light that can be obtained from 1 watt of power consumed – energy efficiency;

  - Color rendering index, unitless, showing the ability of the illumination to render the colors correctly;

  - Correlated color temperature in degrees of Kelvin that has substantial psycho-emotional effect on humans, including considerations of the circadian stimuli requirements, i.e. changing the color temperature during the time of the day;

  - The level of illumination of the surfaces in the building spaces in Lux, as well as luminance, with consideration of the albedo of the surfaces;

  - Directionality or diffusivity of the illumination, and comfort in terms of avoiding glare - the direct light from point sources reaching eyes of users;

  - Avoiding unwanted blue hazard and ultraviolet (UV) sources

  - Using automated control systems addressing the level of illumination depending on the demand;

  - Flexibility of the control system in terms of level of illumination, directionality/diffusivity, spectrum and grouping to conform to the comfort, performance and type of the activity.
- In all cases, the environmental impact of any solution should be estimated in quantitative manner, e.g when replacing with more efficient light sources, estimate CO2 and other gas emission savings.

2.1.3.3 - Control systems and their application for energy-efficient solutions;

A control system should address the following requirements:

1. the level of needed illuminance;
2. automatic switch-off lighting if there is no demand – e.g. the room is not occupied;
3. automatic switch to daylighting;
4. control of the daylighting via blinds, ownings, or electrochromic windows (https://www.yellowpages.com.au/qld/lutwyche/queensland-blinds-and-awnings-15442851-listing.html, http://home.howstuffworks.com/home-improvement/construction/green/smart-window3.htm)
5. Possibility of separate control of each luminary and its brightness and spectrum (color temperature);
6. Control directionality/diffusivity ratio either via optical means or via balancing between the levels of brightness of luminaria of e.g. a spotlight, floodlight and diffuse sources;

7. Perform programmed lighting via individual or grouped luminaria to conform to the comfort, performance and type of the activity.

No doubt that this kind of control should be a part of smart home or smart space concept.

Similar approaches can be implemented for architectural lighting.

2.1.3.4 - Approaches for energy-efficient upgrade of lighting systems

When the upgrade is due in an existing construction, in contrast to starting with the architectural design, the energy-efficient lighting will have to conform to already-existing walls, windows and other elements.

Daylighting

In this case the daylighting can be performed through upgrade of existing windows with consideration of electrochromic ones, adding of certain type of reflection and shading devices, or implementation of heliostats if possible.

Heliostats are whether influence ready mirrors that have a mechanism to direct the solar rays at desired direction, e.g. entrance of a skyline or a window (http://wikoda.com/product/sunflower/).

In fact here the heliostat helps the operation of a skyline or a light pipe. A more straightforward approach is to use a heliostat just to illuminate a window (Lumena.ch, http://www.tectonica-online.com/topics/lighting/daylighting-norbert-lechner/26/)

The goals of upgrading an electric lighting system

The goals for the lighting system upgrade are:

- Replacing older, power consuming light sources with newer, energy efficient ones
- Improving the illuminance level, bringing it to a level prescribed by standards and norms
- Improving the color characteristics, i.e. the correlated color temperature and color rendering index
- Performing automation, to avoid losses in non-occupied room, and for advanced systems to conform the light level and spectrum to circadian rhythms, to perform more comfort and safety.

For detailed steps and calculation of the upgrade, please see sections starting from "Assessment of performance (audit) of lighting systems".

2.1.3.5 - Standards and norms for indoor lighting, measurement methodology

The standards are driven a lot by psychic-emotional and psychic-biological effects. A number of parameters are defining the quality illumination, as shown in the Figure 2.5.

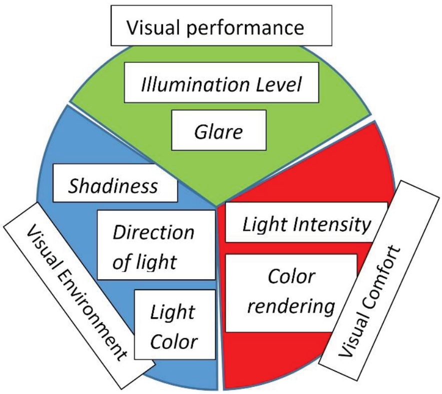

Figure 2.5. Best practices of lighting design: parameters of illumination. See also http://www.lightingdeluxe.com/workplace-lighting-ergonomics.html

The following is a citation from an excellent article for architects https://www.archtoolbox.com/materials-systems/electrical/recommended-lighting-levels-in-buildings.html.

Recommended Lighting Levels in Buildings

Lighting in our living and workplaces is critically important for our ability to accomplish tasks efficiently and safely. In addition, proper light levels prevent eyestrain, which allows us to work comfortably for longer periods of time. This article covers proper lighting levels and will include various lighting concepts during the conversation. If you need to brush up on the basics of lighting, check out our Properties of Light article.

There are two main concepts that architects need to understand as they plan lighting in their buildings: Light Levels and Lighting Power Density.

Light Levels in Buildings

Since we are concerned mainly with accomplishing tasks in our buildings, we need to understand the Illuminance, or the amount of light that is hitting a surface. In an office, we might want to understand the amount of light that is hitting our desk; however, in a gymnasium or corridor we may be more interested in the amount of light hitting the floor.

Illuminance is measured in foot candles (FC) or lux. 1 FC is the amount of light that hits a 1 square foot surface when 1 lumen is shined from 1 foot away – this equates to 1 lumen per square foot. 1 lux is the amount of light that hits a 1 square meter surface when 1 lumen is shined from 1 meter away – this equates to 1 lumen per square meter. 10 lux is roughly 1 FC.

We need to provide enough light to allow people to accomplish their tasks, but not so much light that it is hard to see the tasks – over-lighting is just as bad as under-lighting. Detailed tasks like drafting require more light, while general tasks like walking can be accomplished with less light.

The most cited reference for lighting levels is the IESNA Lighting Handbook, which is published by the Illuminating Engineering Society. The lighting levels listed below come from the Handbook as well as various other lighting references.

Lighting Power Density (LPD)

Lighting power density is the amount of power used by lighting per unit of building area. In the United States, LPD is measured in watts per square foot. Included in the watt measurement is all power consumed by light fixtures, ballasts, controls, transformers, etc. – essentially, if the component or device is involved in lighting, it must be included in the calculation.

Lighting power density is established by local and international codes. The values listed below for LPD come from the 2015 version of the International Energy Conservation Code (IECC 2015).

Please keep in mind that certain cities or states may have codes that require LPDs to be a certain percentage BELOW the IECC. Always make sure to check your local codes before establishing LPD criteria for your project.

There are two ways to calculate the lighting power density. The first way is to use an LPD that applies to the full building based on the type of building (school, museum, office, etc.) – this method is very basic and is called the Building Area Method. The second way is to calculate the LPD based on each specific room and is called the Space-by-Space method – this method is much more accurate and may result in a lower LPD number, which is helpful when applying for utility incentives.

Many utility incentive programs require the design team to improve upon the lighting power density baseline required by local codes. For instance, a utility incentive program may require a 15% (or more) improvement over the baseline LPD in order to receive a lower electricity rate.

Recommended Light Levels by Space

The table below provides recommended light levels from the IESNA Lighting Handbook and LPD levels from the IECC 2015. Check your local jurisdiction for other or more stringent requirements. The US General Services Administration provides lighting levels and LPDs for US Government buildings, which can be used as a guide for other types of buildings.

The required light levels are indicated in a range because different tasks, even in the same space, require different amounts of light. In general, low contrast and detailed tasks require more light while high contrast and less detailed tasks require less light.

Please keep in mind that this chart is not comprehensive. The IESNA Lighting Handbook has pages and pages of various categories. If you have a very specific need, we recommend further research.

ROOM TYPE	LIGHT LEVEL (FOOT CANDLES)	LIGHT LEVEL (LUX)	IECC 2015 LIGHTING POWER DENSITY (WATTS PER SF)
Bedroom - Dormitory	20-30 FC	200-300 lux	0.38
Cafeteria - Eating	20-30 FC	200-300 lux	0.65
Classroom - General	30-50 FC	300-500 lux	1.24
Conference Room	30-50 FC	300-500 lux	1.23
Corridor	5-10 FC	50-100 lux	0.66
Exhibit Space	30-50 FC	300-500 lux	1.45
Gymnasium - Exercise / Workout	20-30 FC	200-300 lux	0.72
Gymnasium - Sports / Games	30-50 FC	300-500 lux	1.20
Kitchen / Food Prep	30-75 FC	300-750 lux	1.21
Laboratory (Classroom)	50-75 FC	500-750 lux	1.43
Laboratory (Professional)	75-120 FC	750-1200 lux	1.81
Library - Stacks	20-50 FC	200-500 lux	1.71
Library - Reading / Studying	30-50 FC	300-500 lux	1.06
Loading Dock	10-30 FC	100-300 lux	0.47
Lobby - Office/General	20-30 FC	200-300 lux	0.90
Locker Room	10-30 FC	100-300 lux	0.75
Lounge / Breakroom	10-30 FC	100-300 lux	0.73
Mechanical / Electrical Room	20-50 FC	200-500 lux	0.95
Office - Open	30-50 FC	300-500 lux	0.98
Office - Private / Closed	30-50 FC	300-500 lux	1.11
Parking - Interior	5-10 FC	50-100 lux	0.19
Restroom / Toilet	10-30 FC	100-300 lux	0.98
Retail Sales	20-50 FC	200-500 lux	1.59
Stairway	5-10 FC	50-100 lux	0.69
Storage Room - General	5-20 FC	50-200 lux	0.63
Workshop	30-75 FC	300-750 lux	1.59

The overall general requirements for the illuminance norms are shown in the Figure 2.6, as a function of tasks performed. The general logic here is related to the accuracy of the tasks to be performed – the smaller the elements that are involved in the task, the higher is the responsibility; the lesser the contrast, the higher the illumination level should be.

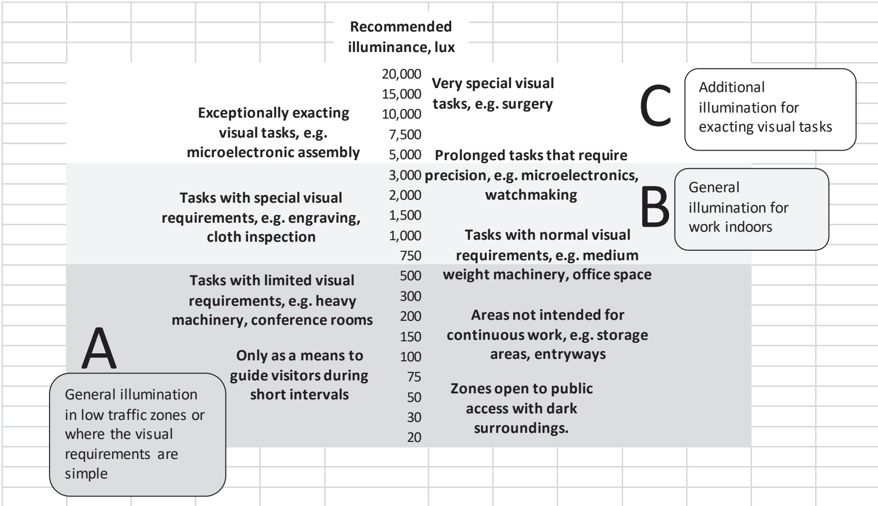

Figure 2.6. Levels of illumination as a function of tasks performed, see also http://www.iloencyclopaedia.org/contents/part-vi-16255/lighting

A citation from the International Energy Agency Annex 45 (IEAAnnex45): http://www.lightinglab.fi/IEAAnnex45/guidebook/4_lighting%20and%20energy%20standards%20and%20codes.pdf

4.1.5 Recommended illuminance levels

Details of the recommended illuminance values for office lighting found in different national recommendations worldwide are tabulated in *Appendix A*. Basically, the differences in recommended illuminances are not high since they tend to be related to the CIE recommendations. However, there are countries which recommend lower values of minimum illuminance.

The ISO standard ISO 8995-1:2002 (CIE 2001/ISO 2002) states that in the areas where continuous work is carried out the maintained work plane illuminance should not be less than 200 lx. In all the reviewed recommendations, the minimum work plane illuminances in offices were higher. ISO 8995-1:2002 standard does not give any recommendation for uniformity of illuminance on the work plane, but suggests that the illuminance in the vicinity of the task should not be too low in comparison to the illuminance on task area. For example, the illuminance in the vicinity[48] of task is 300 lx for a task with illuminance of 500 lx, 200 lx for a task with illuminance of 300 lx. However, the illuminance in the vicinity of task should be equal to the illuminance in the task area if the value for task illuminance is below 200 lx. In most countries which were reviewed, the minimum maintained illuminance on desks for regular office work is 500 lx, but lower values are recommended in India (300 lx), Denmark (300 lx), USA (depending on type of task) and Australia (320 lx). Minimum illuminance values for lounges, lobbies and corridors are specified within a range from 50 to 100 lx depending on country.

[48] The terms used in softwares for lighting calculations, to which Chapter 5 is dedicated - are: **Task area**, **Surrounding area** and **Background area**. For each case the uniformity and values for this areas are specified by CIE

Basic measurement methodology

The measurement of the illumination is being performed mostly by the lux meters, which have a response spectrum very close to that of human eye photopic vision.

The measurement is performed on the particular surface of interest – table, floor, wall, etc. Certain types of measurements require taking into consideration the reflections from the walls, etc., but the lux meter by its nature of measurement cannot take this into consideration. However, the reflectance from the wall is yet another parameter that plays an important role in the lighting design.

Outdoor Lighting

Outdoor Lighting: Special Needs of Street Traffic, Pedestrians, Parks, Landscaping and Nature

Harmony between the human, the environment – urban, rural and wilderness – during the dark hours of the day is the task of the outdoor lighting.

Outdoor lighting allows more efficiently prolonging outdoor activities beyond the sunlit daytime, which is especially important e.g. for countries that are close to polar circle. One needs to differentiate the *functional* and *aesthetical* applications.

The functional applications, first of all the street and road lighting is to support safety of pedestrians and means of transportation, while the aesthetical applications are first of all related to architecture, landscaping and other artistic expressions, such as monuments, parks, etc..

Here is the list of parameters addressing consideration of outdoor lighting:

1. Energy Efficiency
2. Lighting levels per norms and standards
3. Aesthetics and integration to architectural environment
4. Weather protection or encapsulation, other mechanical factors – vibration, vandalism, etc.
5. Integration into electric, transport and other infrastructure
6. Photoluminescence – street markings
7. Safety
8. Automation, reliability, including monitoring

9. Environmental aspects, light pollution

2.1.3.6 - Street lighting: specificities, infrastructure, energy efficient solutions - the functional or traffic illumination

Street illumination provides substantial increase in safety of transportation, which is the primary goal in this case. The key parameter for the street lighting is the *brightness or luminance of the pavement.* The brightness here is composed of the combination of the *level of illumination* and the *reflectivity characteristics* of the pavement.

Reflectivity of the pavement

Apparently the same level of illumination of e.g. a concrete pavement which has higher albedo, i.e. reflectivity of around 0.5, and a new-laid fresh asphalt pavement, which has albedo of 0.04, i.e. it is black dark, yields very different luminance levels – i.e. the pavements and objects that have higher reflectivity seem brighter.

Light distribution curve

Evidently, the real pavements are not lambertian diffusers, especially if they are wet, or covered by ice or snow – in that case, lots of glare is observed. Here one needs to take into consideration the angular distribution of light (ADL) aka light distribution curve (LDC) of the luminaries (http://www.digikey.tw/en/articles/techzone/2012/may/decoding-luminous-intensity-distribution-data-for-led-modules, http://www.slideshare.net/MikePitcher/luminaires-module-3).

The next important characteristic of the street lighting that is regulated by norms and standards is the uniformity of the luminance distribution (http://www.ecoworldusa.com/products_street.html, https://www.pinterest.com/drewboyd/attribute-dependency-technique/), that also very much depends on the LDC of luminaires, as well as the frequency of the light posts. Naturally, to increase the distance between the light poles as much as possible, special types of luminaries with wide LDCs are used.

There are several types of LDCs of luminaires that indicate the particular pattern of the directionality of the light spread to the pavements. Usually on the posts with an arm, luminaires have the following functions:

1. Providing lighting levels per norms and standards
2. Safeguarding weather protection or encapsulation to provide stability of electric and physical parameters
3. Sustaining mechanical influences – vibration, as well as resisting vandalism, etc.
4. Being friendly in integration into electric, transport and other infrastructure
5. Providing aesthetics and integration to architectural environment
6. Providing cost efficiency of installation and operation

To provide energy efficiency, lighting levels and the uniformity of illumination, the luminaries have certain optical elements, such as reflectors, diffusers or their combination in one, that allow achieving certain LDCs, i.e. help to direct the light in the needed directions for uniform illumination.

In fact, some modern light sources themselves, such as light emission diodes (LED), may already have the optical elements that provide the required LDC, or can easily fitted with such optical element. In this case, the luminaries have the function of weather protection and providing stability of electric and physical parameters of lighting devices.

LDCs are categorized in several ways in several lighting systems of standards. E.g., the US system of standards defines the light distribution patterns (LDP), Type I to Type V showing various needs on various types of the roads or crossroads

(http://onlinemanuals.txdot.gov/txdotmanuals/hwi/luminaires.htm#i1002398).

In the Russian standard the LDCs are categorized as Concentrated (концентрированная - К), Deep (глубокая - Г), Cosine or Diffuse (косинусная или диффузная - Д), semi-wide (полуширокая - Л), wide (широкая - Ш), sine (синусная С) and uniform (равномерная – М).

Note that American categorization is for roads and the Russian - for all cases of LDCs.

Often, instead of LDCs the luminaires are characterised via so-called *3d LDC*, however, in many cases, due to symmetry two orthogonal planes are enough to describe a luminaire (www.artemide.com, https://sourceforge.net/projects/qlumedit2/).

Luminaire efficiency

One needs to take into consideration that any luminaire, as an optical device, has its efficiency, as defined in the Equation 2-4.

Equation 2-4

$$K = F_{luminaire}/F_{source}.$$

In other words, the luminaire efficiency is the percentage of luminous flow produced by the lamps that is emitted by the luminaire.

This efficiency may vary depending on a number of characteristics of the luminaire, in the range of 50% - 93%, or even up to 100% - for the aforementioned LED luminaire – since it does not need any additional optical element to form the required LDC (http://spie.org/newsroom/3490-energy-saving-led-light-sources). Naturally, the luminous efficacy in this case must be multiplied by the luminaire efficiency K to obtain the final output luminous efficacy of the source/luminaire combination.

The current trend in the world is to install luminaires with LEDs. In addition to the higher efficacy, LEDs also provide much better color rendering index (CRI) and give flexibility to decide on correlated color temperature (CCT). In fact, while lot of research shows that the visibility and related safety on the roads increase with LEDs providing higher CRI and CCT, one needs to remember the circadian rhythm driven requirements to the color temperature – at evening and night the CCT should be lower and should not completely represent daylight. But during driving at evening or nighttime, the driver must be in wakeful state; thus, exactly following the circadian rhythm will make driver sleepy, increasing the probability of accident. Moreover, even using luminaries with higher color temperatures will be more effective, as the peak of human eye perception of light intensity at nighttime shifts towards the blue side of the spectrum (with maximum sensitivity of 1700 lm/W for scotopic vision, which occurs at 510nm).

Control, Monitoring and Automation

Control and automation plays an important role to provide energy-efficient, comfortable and reliable lighting. It actually can perform a number of functions, such as:

1. Perform switching lighting on and off to follow diurnal lighting patterns
2. Switch off or substantially dim lighting when no need – this is more essential for roads in rural areas, which do not have very high traffic
3. Perform monitoring of all electrical and physical operational data and environment
4. Perform monitoring communication with the lighting authority or business, to indicate and report e.g. light source end of lifetime failure, or vandalism, as well as damage due to force majeure elements or weather conditions.
5. Such monitoring communication may provide invaluable statistics on
   - light source longevity;
   - reasons of failure;
   - time to repair;
   - road conditions that effect resulting pavement reflectance (luminance);
   - statistics correlating e.g. light source failure with traffic accidents;
   - other data correlated to power supply… etc.

Communication is usually performed via wireless data networks, GPRS, 3G, with Internet connection (http://www.monitormymeter.com/lighting-automation.html). Here is a citation from Maven Systems web site (http://www.monitormymeter.com/lighting-automation.html):

> Maven's street lighting solution gives you the capability to remote monitor, and control street lights, in a fail-proof way. The solution has Internet connectivity in order to upload data to cloud application, to enable remote monitoring. The data can be accessed from smart phones as well. The solution allows you to schedule the different operations of light, according to time of day. This helps in minimizing human interference with daily operations. The solution maintains historical data in order to help you make informed business decisions based on consumption patterns.
>
> **Key benefits**
>
> - Control street lights at feeder level or individual level.
> - Reduce your electricity bill by up to 30%.
> - No additional cost of wiring.
> - Find faulty lights.

- Schedule feature for ON / OFF / DIM.
- Measure the electricity consumption and associated theft / faults.
- ON / OFF control for
  - Single lighting panels
  - Multiple fixture panels
- Centralized monitoring and control of lights.
- Integration with existing SAP / ERP[49] system.
- Customized solutions are available as per requirement from design to delivery for OEMs.

Features

- Automated ON / OFF control of individual lights.
- Single data concentrator shall support up to 300 lighting poles.
- Supports mesh network and hopping of data for large coverage of 100s of KMs.
- Electricity saving modes,
  - Time based scheduling and ON / OFF control with day light harvesting
  - Pre-defined templates for one in two, one in three or customized ON / OFF
  - Override support to ON / OFF individual lights as required
  - Light sensors input based control (optional)
- Easy to install, plug-n-play retrofit solution.
- Secure cloud based graphical user interface for collecting real time data with an ability to export data in CSV format for further analysis.
- Support for smart phone for monitor and control and alerts.
- Fault detection alarms and events using email / SMS.
- Daily / monthly / weekly reports:
  - Electricity consumption.
  - ON / OFF audit reports.
  - Fault and error notification.
  - User activity report.

Infrastructure

Naturally, the functional, street lighting infrastructure tightly relates with the road and traffic infrastructure. Thus it is everywhere where there are streets and various constructions. It requires

[49] Enterprise resource planning software developed by the German company SAP.

connection to the electric grid, with a related set of distribution and voltage transformer requirements.

Here is a citation from the EU STEER project for street lighting optimization, http://transportlearning.net/competence/docs/Competence_reference%20material_urbandesign_en.pdf:

> *Street lighting costs, i.e. electricity and maintenance, can be a significant expense for municipalities, so it is important to take advantage of opportunities for efficiency improvements. Manufacturers are continually developing products that are more energy efficient and cost-effective. New options are being developed for all applications, but matters are complex. Moreover, increasing traffic, demand of residents for safety, many regulations and an ever tightening budget make the decision of how to improve on energy and cost efficiency even more complicated.*
>
> ***Measures***
>
> *There is a vast array of measures. The reality will be a mixture of these measures, these include:*
>
> - *Reducing operating hours*
> - *Reducing power and/or number of lamps operating*
> - *Replacing inefficient light sources by efficient ones*
> - *Replacing lighting fixture/luminaire*
> - *Improving control system*
> - *Improving maintenance practices"*

An interesting trend that is developing worldwide is not only related to the replacement by the LEDs, but also using solar and wind energy to power the street lighting. This is especially important for remote site cases, and depending on the remoteness can be economically more effective. Possibly in the future most of the lighting may be independent from the electrical grid.

This is a winning combination, also because the LEDs consume little, but solar power has intermittence and the smaller the storage battery, the less the cost. Naturally the storage battery's size will depend on the light source power consumption.

Note that combined solar and wind power has an advantage compared to only solar or only wind. The advantage is related to the fact that combined solar+wind is less intermittent than only solar or only wind. However installing two technologies at the same pole is more expensive, but somewhat compensated with the smaller size of the battery.

Anyway, the decision to install either technology or their combination should be made based on the local wind and solar monitoring data. E.g. if at a geographic location site, sun prevails – then no need for a wind turbine, and vice versa. The combination may work well with about equal availability of the sun and wind.

2.1.3.7 - Architectural lighting – aesthetics, light and heavy colors, composition, etc

In modern life, architectural lighting design is rather visible, in the sense that the interesting solutions usually are being noted and appreciated. Since it relates to the aesthetic perception of people, all the artistic rules work here.

One can divide the architectural lighting into two main directions:

- lighting of existing architectural constructions, in many cases historic architectural monuments, sculptures and other artefacts;
- including the lighting as part of a new modern architectural design project.

Another important issue here is related to the fact that there are no strict rules, regulations, norms and standards for aesthetical lighting – the lighting design, just like the architecture, is subject to the artistic expression, with only some, vital functional needs taken into consideration.

A few general rules here are:

- Darker colors seem heavier;
- Smoother transitions give the feeling of lightness and need to be at the upper part of the architectural expression, and vice versa – high-contrast transitions prefer to be at the bottom;
- Pure strong colors seem heavier – good for the bottom, and colors that are diluted by white seem lighter and are good for the top.

A citation from the http://www.colourlovers.com:

To paraphrase a classic riddle, which weighs more: a pound of yellow feathers or a pound of red lead? Color may be a weighty subject, but the spectrum can't be gaged in terms of tonnage. The Swiss painter Paul Klee observed that colour can be "neither weighed nor measured. Neither with scales nor with ruler can any difference be detected between two surfaces, one a pure yellow and the other a pure red, of similar area and similar brilliance. And yet, an essential difference remains, which we, in words, label yellow and red" (*On Modern Art*, 1948). Klee was right—even though colors don't technically have weight, they can appear quite heavy and substantial or extraordinarily light and vaporous.

Visibility and artistic expression

One of the important tasks of architectural lighting is putting stress on the building via lighting, to provide its higher visibility. In the parks the norms do not strictly regulate the LDC for the luminaires, as illustrated in the. Ground luminaria should have extra protection corresponding to the international protection code of IP67 – level 6 for dust and dirt particles and level 7 for water ingress. Low poles are very common in the parks. For architectural expression unlimited variety of luminaria can be used. If retro style is used, or 19th century lighting poles are operated, however, they possess modern lighting technology, in many cases sodium lamps or LEDs.

Fountain illumination

This type of illumination is one of the most prominent examples of how an architectural lighting solution could be appreciated (Figure 2.7). Naturally a more enhanced, IP68 protection level is required here.

Figure 2.7. Fountain illumination

Building screens – Sydney opera

One of the most modern type of the illumination in the digital era is the use of powerful projection equipment for artistic expression.

Vandalism protection

In general, if vandalism is an issue, IP65 category of protection is needed in addition to enforced encasement of luminaria.

2.1.3.8 - Standards and norms for outdoor lighting, measurement methodology

Documents

In Armenia the norms of the outdoor lighting are defined by the" – Republic of Armenia Construction norms: Artificial and Natural Lighting (**ՀՀ ՇՆ II 8.03-2016**). In Russia this is regulated by the "СНиП 23-05-95" and number of GOSTs such as *СП 52.13330.2011 «ЕСТЕСТВЕННОЕ И ИСКУССТВЕННОЕ ОСВЕЩЕНИЕ», Актуализированная редакция СНиП 23-05-95*, Издание официальное*", in the USA by the Roadway Lighting Standards, defined in a number of acts (e.g. Energy Policy Act 2005; Energy Independence and Security Act 2007; American Recovery and Reinvestment Act 2009, etc.). The Armenian code is developed based on the existing Russian norms, that in turn are based on EU norms, such as ISO standard ISO 93.080.

The International Commission on Illumination (usually abbreviated CIE for its French name, Commission internationale de l'éclairage) is the most important world authority in lighting science and engineering (http://cie.co.at/).

Norms

The most important quantity that is being standardised is the *brightness or the luminance* of the pavement, see Figure 2.3 of this chapter. As it has been mentioned there, the luminance depends not only on the illumination, but also on reflective characteristics of the pavement, the type of the pavement, its reflective properties, the angle of illumination incidence, and the condition – e.g. being wet, covered by snow or ice, etc.

The total uniformity of the luminance is also standardised usually as > 0.4, i.e. the brightness of the darkest part of the pavement should not be less than 40% (0.4) of the brightness in the brightest area for the cases with average brightness of larger than 0.6 cd/m^2. However, for the cases with average brightness of lesser than 0.6 cd/m^2 the non-uniformity should not be less than 35% (0.35) of the brightness in the brightest area. The Table 2.2 shows the norms in Armenia for city roadways of various categories and Table 2.3 for rural lighting – which are much simpler compared with city norms.

Table 2.2. The Armenian norms for the city roadway lighting

The road category[50]	**Average brightness of the road, cd/m^2**	**Total uniformity of the pavement brightness, at least**	**Lane uniformity of the pavement brightness, at least**	**Average illumination of the road, at least, lx**	**Total uniformity of the drive illumination, at least**	**Maximum relative density of power consumption W/(m^2 lx 100), not more than**
A1	2,0	0,4	0,7	30	0,35	6,0
A2	1,6			20		5,0
A3	1,4			20		4,8
A4	1,2			20		4,5
B1	1,2	0,4	0,6	20	0,35	4,5
B2	1,0			15		5,3
G1	0,8	0,4	0,5	15	0,25	5,0
G2	0,6	0,4	0,5	10		5,0
G3	0,4	0,35	0,4	6		5,0

Table 2.3. The Armenian norms for the rural lighting

Category	***Average illumination, at least, lx***	***Non-uniformity, at least***
Main streets, public and shopping center squares	10,0	0,25
Urban streets: - *Main* - *Secondary*	6,0 4,0	
Horticultural and cottage association areas village streets and drives	2,0	0,10

[50] A1 being highest category highway and G3 – lowest category roadway.

The norms regulate the illumination values for pedestrian passes in the range of 1-20 lx, depending on the human traffic, and uniformity ranging from 0.1 to 0.3.

The norms also regulate architectural lighting, in the range of 3 – 10 cd/m^2 for local and flood lighting and within 8-30 cd/m^2 for artistic "definitive" lighting.

The norms also regulate commercial activity-related lighting, emergency lighting, etc., as well as glare and other parameters.

The measurement methodology

The measurement methodology is standard, on the essential working planes, via e.g. using a luxmeter; however, there are a number of issues that one needs to take into consideration for the street lighting:

1. Roads have a very large area, they are hundreds of kilometers long
2. For the streets, it is more essential the luminance of the pavement in cd/m^2 rather than the illumination level in lx.
3. Street conditions are subject to wearing, weather, nature elements and any force majeure that can substantially change the luminance levels.
4. Responsibility of correct lighting, hence the measurement validity is the factor that influences traffic accidents with human casualties.

The imaging photometers are used more and more frequently, based on CIE 140-2000 Road Lighting Calculations methodology. Road lighting for main roads is normally specified using the following parameters:

1. Average road surface luminance (L_{av})
2. Overall road surface luminance uniformity (U_O)
3. Longitudinal road surface luminance uniformity (U_L)
4. Threshold increment (T_I%)
5. Surround ratio (SR)

All these parameters are taken into consideration by the methodology that e.g. Konica Minolta 2D Color Analyser CA-2500 is using (https://www.konicaminolta.com/instruments/download/catalog/display/pdf/ca2500_catalog_eng.pdf):

> A 2D imaging photometer using high resolution CCD sensor is able to measure luminance distribution for the entire road surface area instead of just luminance of predefined points, thus providing more comprehensive information for the analysis of road lighting performance in a shorter time.
>
> The set-up and measurement time required for road lighting measurement with an imaging photometer is also much shorter as compared to conventional spot photometer as the imaging photometer captures the luminance distribution of the entire road surface area in just a few seconds. Hence, the road closures can be largely reduced.

An even more cost-effective variation of this method is being used by Russian VNISI – Russian Lighting Research Institute named after S.I. Vavilov (ООО "ВНИСИ"). It uses a digital single lens reflex camera that photographs the pavement of the roadway, and then a special developed software subtracts the luminance data (http://www.vnisi.ru/joomla/en/serviceseng/mobilelabeng). The van cruises the street at the same time making the photographs. The method is very quick compared to other pointwise measurements, yielding the maps of the roadway luminance.

Assessment of performance (audit) of lighting systems

For upgrade of the artificial lighting systems, the following issues need to be considered:

1. Energy efficiency
2. Introducing automation for more comfort, as well as for energy efficiency
3. Improving the lighting correlated color temperature, color rendering index to fit circadian rhythms.

At the same time, the upgrade may also involve:

4. Needing to satisfy the illumination or luminance levels per norms and standards

5. Needing to perform new artistic or architectural design

The energy-efficient upgrade is based on the comparison of parameters, such as the price of the light bulb, its lifetime (or longevity) in operational hours and one of these energy-efficiency parameters: luminous efficacy or overall efficiency of the light sources.

It is always possible to switch between the luminous efficacy and luminous efficiency.

Luminous efficacy, K, defines the efficiency of light sources. This is the ratio of luminous flux to radiant flux emitted by a source. In other words, luminous efficacy shows the lumens generated versus the total radiation of power.

Luminous efficiency, E, defines the physical efficiency of light sources in terms of usual percentage, W/W. This is the ratio of visible (luminous) radiant flux to total radiant flux emitted by a source. In other words, luminous efficiency shows the portion of *power* that became visible light versus the total power of radiation.

Wall Plug efficiency is the ratio of luminous flux to power consumed by a source. In other words, luminous efficacy shows the lumens generated versus the total wattage consumed from the wall plug.

In fact this parameter can be represented as I_L / P_c, where P_c is the power consumed. Manufacturers usually provide this number for a particular lighting product. It takes into account also power conversion losses, e.g. if an AC to DC or other conversion is needed. If that converter has η efficiency, then the lighting efficiency will be luminous efficacy, K, times η, and this is what one can find in the specs of a manufacturer. If talking in terms of Luminous efficiency, then total efficiency would be ηE. This parameter is very easy to use for calculations of the resulting lighting efficiency.

The logic of the economic calculation as it has been mentioned is based on comparison of the price of the light bulb, its lifetime (or longevity) in operational hours and luminous efficiency of the light sources (Figure 2.8).

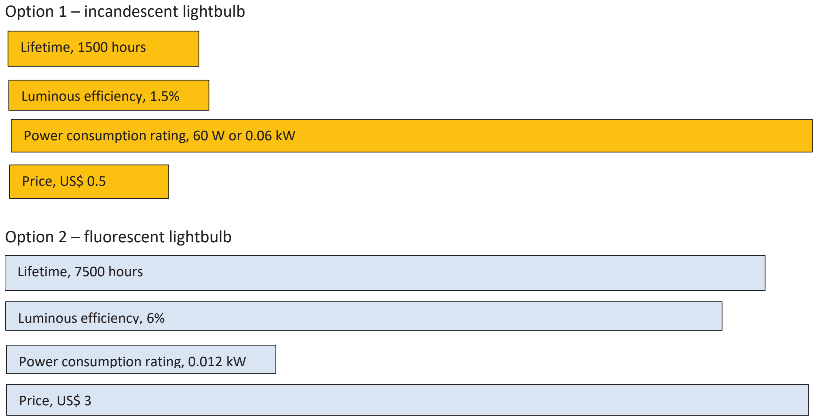

Figure 2.8. Comparison parameters between incandescent and fluorescent lightbulbs.

The next section allows combining all parameters into one decision parameter, called the levelized cost of the 1 kWh of outputted radiant visible flux ($LCOVI_{bulb}$).

2.1.3.9 - Assessment of energy saving benefits of artificial illumination – description of the methodology

A more formal and detailed calculation is described below.

In summary, the parameters that influence the performance of the light sources are the following:

Price, $, AMD, etc.

Efficacy, lm/W or efficiency, %

Longevity, hours

SPD, CRI or CQS – suitability for the application

The timing of the lighting – startup time, inertia towards AC frequency

Now let's assume that parameters ## 4 and 5 are satisfied. Than the calculation is straightforward.

Let's denote:

P_{bulb} = the power consumption rating of the lightbulb, kW

C_{bulb} = the cost of the lightbulb of the same particular consumption power rating

$UC_{1kW\ bulb}$ = the cost of the lightbulb of 1 kW consumption power rating, assuming $UC_{1kW\ bulb} = C_{bulb}/P_{bulb}$ linear relationship

$E_{bulb} = \eta E$, where η is the conversion efficiency, E is the luminous efficiency

H_{bulb} = longevity of the lightbulb, hours

I_{RV} = the radiant visible flux, $I_{RV} = E_{bulb}$ x P_{bulb}, kW

OVI_{bulb} = the total outputted radiant visible flux of the lightbulb during its whole lifetime, $OVI_{bulb} = I_{RV}$ x H_{bulb}, in kilowatt-hours (kWh)
Pr_{kWh} = price of one kWh
OC_{bulb} = the operational cost of the lightbulb during its whole lifetime, $OC_{bulb} = Pr_{kWh}$ x P_{bulb} x H_{bulb}
TC_{bulb} = the total cost of the lightbulb purchase and operation

It is easy to see that the total cost of the lightbulb purchase and operation can be expressed through the following equation:

Equation 2-5

$$TC_{bulb} = C_{bulb} + OC_{bulb} = C_{bulb} + Pr_{kWh}\ P_{bulb}\ H_{bulb}$$

Let's define also:
$LCOVI_{bulb}$ = the levelized cost of the 1 kWh of outputted radiant visible flux. Since $OVI_{bulb} = I_{RV}$ x H_{bulb}, we can define the levelized cost of each 1 kWh of the total outputted radiant visible flux as:

$LCOVI_{bulb} = TC_{bulb} / OVI_{bulb}$
$= [C_{bulb} + Pr_{kWh}\ P_{bulb}\ H_{bulb}]/[I_{RV}\ H_{bulb}]$

$= C_{bulb}/ (I_{RV}\ H_{bulb})+ Pr_{kWh}\ P_{bulb}/I_{RV}$

$= C_{bulb}/(I_{RV}\ H_{bulb}) + Pr_{kWh}/E_{bulb}$

$= C_{bulb}/(E_{bulb}\ P_{bulb}\ H_{bulb}) + Pr_{kWh}/E_{bulb}$

$= (1/ E_{bulb}) [C_{bulb}/(P_{bulb} H_{bulb}) + Pr_{kWh}]$

Thus,

Equation 2-6

$$LCOVI_{bulb} = (1/ E_{bulb}) [UC_{1kW\ bulb}/H_{bulb} + Pr_{kWh}]$$

It is easy to notice that the higher the longevity, the lesser the contribution of the bulb cost; the lower the efficiency, the higher the levelized cost of the 1 kWh output radiant visible flux.

Using $LCOVI_{bulb}$ as the single main parameter allows comparing entirely different types of light sources having different lightbulb costs, longevity and efficiency. This single parameter may serve as the only one to make lighting economic decisions, if other factors, such as aforementioned SPD, CRI or CQS – suitability for the application, the timing of the lighting – startup time, inertia towards AC frequency – are equal.

2.1.3.10 - Assessment of economic benefits of artificial illumination – examples for e.g. LED, CFL and luminescent lights

Now it is easy to perform the comparison of various sources of light by just a calculation of the $LCOVI_{bulb}$, i.e. the levelized cost of the 1 kWh of outputted radiant visible flux. The Table 2.4 shows the calculation for the incandescent and fluorescent lightbulbs from the example in the Figure 2.8 and adds a LED lightbulb with the related parameters brought in the last column. Note that all the lightbulb cost contributions are approximately the same in the output of visible kWh of light, but due to energy efficiency of fluorescent and LED lightbulbs, their power consumption related costs, i.e. operational costs are much less.

Table 2.4. Calculation of the levelized cost of the 1 kWh of outputted luminous flux, LCOVIbulb.

	Incandescent	**Fluorescent**	**LED**
E_{bulb}	1.50%	6.00%	10.00%
C_{bulb}	$ 0.50	$ 3.00	$ 8.00
P_{bulb}, kW	0.060	0.012	0.008
$UC_{1kW\ bulb}$	***$ 8.33***	***$ 250***	***$ 1,000***

H_{bulb}, hours	1500	7500	25000
Pr_{kWh}	$ 0.10	$ 0.10	$ 0.10
= (1/ E_{bulb}) [$UC_{1kW\ bulb}/H_{bulb}$], per kWh of luminous energy (lightbulb cost contribution)	***$ 0.370***	***$ 0.556***	***$ 0.4***
= (1/ E_{bulb}) [Pr_{kWh}], per kWh of luminous energy (power rating, i.e. consumption contribution)	***$ 6.667***	***$ 1.667***	***$ 1.0***
$LCOVI_{bulb}$ = (1/ E_{bulb}) [$UC_{1kW\ bulb}/H_{bulb}$ + Pr_{kWh}], per kWh of luminous energy	***$ 7.037***	***$ 2.222***	***$ 1.4***

Also note that the operational hours translate into years of operation, as shown in the Table 2.4

Table 2.5. Years of operation for the three options.

Daily usage hours	5	5	5
Days	300	1500	5000
Years	0.82	4.1	13.7

In this manner, it is extremely easy to compare options. One can compare options also for street, architectural, industrial and any other cases.

Another, simpler approach is presented below.

Upgrade of electric lighting system

Here are the steps to upgrade the electric lighting system:

1. Identify, if there are plans to remodel the building, the space or home. If so, design the lighting as needed. Take into consideration that the interior design has a significant effect on the lighting – e.g. through colors and brightness of the walls, ceiling and the floor. If no plans for remodeling, proceed to the next step.
2. Perform an audit of the existing lighting system, take data for each luminaire for its consumption, operating hours, and purpose – defining special needs for level of illuminance spectrum (color temperature), etc., and create a summary table.

The principle is simple - one needs to start from finding out which lights consume the most energy with a goal to replace them with more efficient ones.

One can start from a floor plan (Figure 2.9), where all lights are identified and labelled for a very small 1 bedroom apartment.

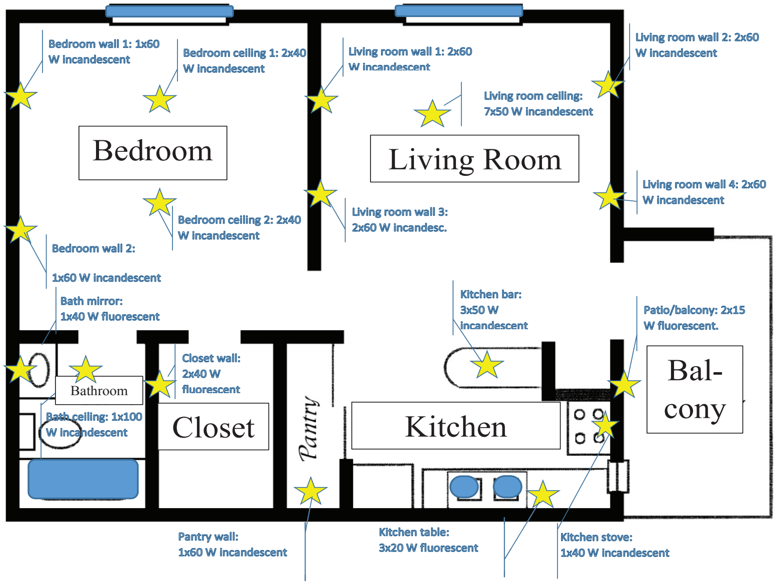

Figure 2.9. Floor plan of a one bedroom very small apartment with description of the lights.

Then comes collection of data on how many hours each luminaire is operating. Filling out a table similar to the one in the Table 2.6, e.g. in MS Excel, will help substantially.

Table 2.6. Example of an apartment's simple lighting audit[51]

Name of the luminaria, the room, wall or the ceiling.	n, # of bulbs	P, kW, power of each bulb	h, Hours of operation	Ed, daily energy needed for luminaria operation, kWh Ed = nPh	C, average tariff at hours of operation	Cd, daily cost of the luminaria operation, Cd = EdC	% of total expense	Special notes about requirements of the luminaria usage
Living room ceiling: 7x50 W incandescent	7	0.05	5	1.75	$ 0.10	$ 0.18	**41.5%**	Warm lighting
Living room wall: 8x60 W incandescent	8	0.06	2	0.96	$ 0.10	$ 0.10	**22.7%**	Warm lighting
Bedroom ceiling: 4x40 W incandescent	4	0.04	1	0.16	$ 0.10	$ 0.02	3.8%	Warm lighting
Bedroom wall: 2x60 W incandescent	2	0.06	1	0.12	$ 0.10	$ 0.01	2.8%	Warm lighting
Kitchen bar: 3x50 W incandescent	3	0.05	4	0.6	$ 0.10	$ 0.06	**14.2%**	Warm white
Kitchen table: 3x20 W fluorescent	3	0.02	3	0.18	$ 0.10	$ 0.02	4.3%	Warm white
Kitchen stove: 1x40 W incandescent	1	0.04	3	0.12	$ 0.10	$ 0.01	2.8%	Warm lighting, high CRI needed
Bath ceiling: 1x100 W incandescent	1	0.1	1	0.1	$ 0.10	$ 0.01	2.4%	White light
Bath mirror: 1x40 W fluorescent	1	0.04	0.5	0.02	$ 0.10	$ 0.00	0.5%	White light, High CRI
Patio/balcony: 2x15 W fluorescent.	2	0.015	6	0.18	$ 0.10	$ 0.02	4.3%	
Pantry wall: 1x60 W incandescent	1	0.06	0.5	0.03	$ 0.10	$ 0.00	0.7%	White light, High CRI
TOTAL Daily				**4.22**		**$ 0.42**		
TOTAL Monthly, days per month =	**30.5**			**128.71**		**$ 12.87**		

Here a simple case considered when the power tariff is flat across 24 hours. Note that the living room ceiling, wall and kitchen bar are consuming together 78.4% of the total power expense, since they are operating longer hours, with higher power consumption of incandescent lightbulbs. Naturally these three areas need to be addressed the first – however they comprise 18 lightbulbs out of total 33 in the apartment. Thus changing around half of the lightbulbs one can achieve up to 70% saving if using modern LED light with luminous efficacy of 150 Lm/W, which is 10x more economical compared with incandescent lighting that has around 15 Lm/W luminous efficacy. The Table 2.7 shows the detailed result.

[51] Certainly the user has the latitude for selection of the CCT, e.g. in general, for kitchen and bathroom the neutral white (4000 K) is preferable for sanitary (hygienic) reasons, but the user's preference can be taken into consideration as well.

Table 2.7. The same apartment lighting, with proposed changes.

Name of the luminaria, the room, wall or the ceiling.	n, # of bulbs	P, kW, power of each bulb	h, Hours of operation	Ed, daily energy needed for luminaria operation, kWh Ed = nPh	C, average tariff at hours of operation	Cd, daily cost of the luminaria operation, Cd = EdC	% of total expense	Special notes about requirements of the luminaria usage
Living room ceiling: 7x5 W LED	7	0.005	5	0.175	$ 0.10	$ 0.02	**14.1%**	Warm lighting
Living room wall: 8x6 W LED	8	0.006	2	0.096	$ 0.10	$ 0.01	**7.7%**	Warm lighting
Bedroom ceiling: 4x40 W incandescent	4	0.04	1	0.16	$ 0.10	$ 0.02	12.9%	Warm lighting
Bedroom wall: 2x60 W incandescent	2	0.06	1	0.12	$ 0.10	$ 0.01	9.7%	Warm lighting
Kitchen bar: 3x5 W LED	3	0.005	4	0.06	$ 0.10	$ 0.01	**4.8%**	Warm white
Kitchen table: 3x20 W fluorescent	3	0.02	3	0.18	$ 0.10	$ 0.02	14.5%	Warm white
Kitchen stove: 1x40 W incandescent	1	0.04	3	0.12	$ 0.10	$ 0.01	9.7%	Warm lighting, high CRI needed
Bath ceiling: 1x100 W incandescent	1	0.1	1	0.1	$ 0.10	$ 0.01	8.1%	White light
Bath mirror: 1x40 W fluorescent	1	0.04	0.5	0.02	$ 0.10	$ 0.00	1.6%	White light, High CRI
Patio/balcony: 2x15 W fluorescent.	2	0.015	6	0.18	$ 0.10	$ 0.02	14.5%	
Pantry wall: 1x60 W incandescent	1	0.06	0.5	0.03	$ 0.10	$ 0.00	2.4%	White light, High CRI
TOTAL Daily	**33**			**1.24**		**$ 0.12**		
TOTAL Monthly, days per month =	**30.5**			**37.85**		**$ 3.79**		

It might be necessary to model your needs for each season separately, and take the decision as the average either for year or with a priority for a particular season. Note that with the new, more efficient lightbulbs, the consumption percentages are changed.

3. Compare data with the indoor lighting standards and norms, making a correction for target illuminance level. Use a lux meter, if possible.
4. Implement the Pareto 20-80 rule to identify the vital sources that consume the most of energy. As it has been shown in the Table 2.6 about 78% of consumption is related to 3 out of 11 total luminaria lines, i.e. 27% - well corresponds to the Pareto rule[52].
5. Create a proposal for change, comparing consumption and comfort before and after. In the proposal, one also needs to identify the costs of the changes, i.e. the costs of the 150 Lm/W lightbulbs. Taking also into consideration the lifetime of the new lightbulbs vs. old lightbulbs, one needs to estimate the payback period, performed in the next section.

2.1.3.11 - Assessment of environmental benefits of artificial illumination, comparison of methods

Let's take a fixed period of time, e.g. 10 years. To calculate the lightbulb replacement costs, we consider only the candidates for replacement derived from the Pareto rule, i.e. for the living room ceiling, wall and kitchen bar of the described example. Thus, we will be comparing the current, incandescent heavy setup, to the proposed case with aforementioned LEDs. Naturally, there are

[52] The Pareto principle (also known as the 80/20 rule, the law of the vital few, or the principle of factor sparsity) states that, for many events, roughly 80% of the effects come from 20% of the causes (https://en.wikipedia.org/wiki/Pareto_principle).

3650 days in the 10 years. And the number of needed lightbulbs will be equal to the total amount of hours expected usage of the particular luminaire during the 10 years (3650 days x usage hours for each luminaire) divided by the statistical life expectancy of the particular lightbulb type. E.g. if the daily usage is 5 hours, during 10 years we expect to use that luminaire 5h x 3650 days = 18250 hours. Since the incandescent lightbulb life expectancy is around 1500 hours, we will need 18250/1500 =12.17 lightbulbs. Now it is easy to calculate the total cost of the lightbulbs during the fixed period. The calculation for the current case is summarized in the Table 2.8.

Table 2.8. Calculation of the number of lightbulbs and related costs for 10 years of exploitation according to the current condition with incandescent lightbulbs.

Name of the luminaria, the room, wall or the ceiling.	n, # of bulbs	P, kW, power of each bulb	h, Hours of operation	Total hours, hx3650 days	Lightbulb service time	# of lightbulbs needed	Cost of one lightbulb	Total cost of lightbulbs
Living room ceiling: 7x50 W incandescent	7	0.05	5	18250	1500	12.17	$ 1.00	$ 85.17
Living room wall: 8x60 W incandescent	8	0.06	2	7300	1500	4.87	$ 1.50	$ 58.40
Kitchen bar: 3x50 W incandescent	3	0.05	4	14600	1500	9.73	$ 1.00	$ 29.20
TOTAL colst of the lightbulbs								**$ 172.77**

Similarly, the Table 2.9 is describing the proposed case with LEDs. Do not worry for the fractional number of the LED lightbulbs – this is statistical number for the taken 10-year period of time. In reality this means that the lightbulbs will work approximately twice the period, i.e. around 20 years or more.

Table 2.9. Calculation of the number of lightbulbs and related costs for 10 years of exploitation according to the proposed replacement with LED lightbulbs.

Name of the luminaria, the room, wall or the ceiling.	n, # of bulbs	P, kW, power of each bulb	h, Hours of operation	Total hours, hx3650 days	Lightbulb service time	# of lightbulbs needed	Cost of one lightbulb	Total cost of lightbulbs
Living room ceiling: 7x5 W LED	7	0.005	5	18250	35000	0.52	$ 7.00	$ 25.55
Living room wall: 8x6 W LED	8	0.006	2	7300	35000	0.21	$ 8.00	$ 13.35
Kitchen bar: 3x5 W LED	3	0.005	4	14600	35000	0.42	$ 7.00	$ 8.76
TOTAL colst of the lightbulbs								**$ 47.66**

Thus, not only the monthly savings will be around 70%, but also during 10 years one needs to spend only $173/$48 = 3.6 times less on the lightbulbs.

Here also the forecast of the 1 kWh of electric power can be taken into consideration, as well as the forecast of lightbulb degradation with the decrease of the efficiency.

For the environmental benefits, the saved kWh of electric power is the key for the climate change, i.e. CO_2 release calculation. Depending on each country, each kWh saved is equivalent to certain amount of non-released CO_2. Since in the described example we have 70% electric power savings, respectively, we will have a monthly saving of more than 90 kWh-s. For Armenia, this is equivalent to savings of 90 kWh x 0.25 kg of CO_2 = 22.5 kg/month for the described replacement in one small apartment.

2.2 - HVAC

HVAC stands for Heating, Ventilation and Air Conditioning. It provides a number of inputs into spaces where humans live or work. However, all functions or goals of HVAC systems can be categorized into two groups:

1. **Thermal comfort** – adjustment of indoor air temperature and humidiy:
   – heating
   – cooling
   – humidity control
2. **Indoor air quality**
   – pumping in filtered fresh air and removing stale air:
   – removal of CO_2, and other contaminant gases exhaled by humans, animals and plants,
   – removal of contaminant gases accumulated or generated by actually all components of any construction interior, such as building and furniture materials, paints, lacquers, glues and adhesives. This also includes radioactive radon gas infiltrating from the ground – it penetrates into air-locked cavities in the building and may stay in these cavities, increasing the radioactive background of the interior.
   – removal of particulate matter such as cigarette smoke, bacteria and viruses, fungi and their spores, pollen, etc.

In order to perform the aforementioned functions in an energy-efficient way, to save on energy and to contribute as little as possible to global warming, recent HVAC systems, as a standard, have energy or heat recovery (reuse) capability, described in the sections below.

The diagram in Figure 10 schematically shows the HVAC functions.

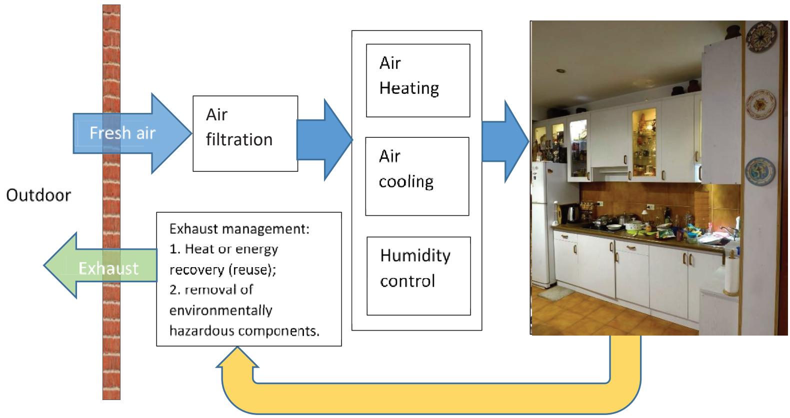

Figure 2.100 Diagram of HVAC functions.

2.2.1 - THERMAL COMFORT

In general thermal comfort is a balance between energy inputs and outputs of a body. Thus, it depends on clothing (the clothing insulation unit is the ***clo***), physical activity and metabolism, presence of air flows of certain air speeds, mean radiant temperature of the surrounding objects and walls stipulated by Planckian black body radiation or presence of other radiative sources, humidity, as well as the season of the year and the age of the human. The widely accepted temperature and statistically verified range for thermal comfort is 20^0C - 22^0C – and this range refers for a steady state with little or none of variations of the aforementioned parameters. Thermal comfort is regulated by standards, e.g. in the USA it is the ANSI/ASHRAE Standard 55.

Note that high humidity decreases the insulating abilities of clothes. It also decreases the perspiration, i.e. cooling of the body via evaporation of water. The comfort range of relative humidity is accepted to be within 30-60%; however, it very much depends on the climate-driven customs. E.g. in Armenia, most of the population is inclined to regard thermal comfort as lesser air humidity. This is dictated by mostly continental weather in Armenia – the comfort humidity range is usually below 50%.

2.2.2 - INDOOR AIR QUALITY

Indoor air quality (IAQ) is part of the indoor environmental quality (IEQ), that also includes lighting, visual impact that includes interior design and aesthetics, acoustics, thermal comfort, and potentially other physical and psychological aspects that may have impact on humans.

The indoor air quality itself includes controlling the concentrations of following contaminants:

- in gaseous form
    1. carbon monoxide, CO
    2. carbon dioxide, CO_2
    3. radon, Rn
    4. ozone, O_3
    5. volatile organic compounds (VOC)
- in particulate form
    1. cigarette smoke
    2. particulate matter from humans and animals
    3. molds and allergens
    4. legionella and other bacteria

2.2.2.1 - Carbon monoxide

CO is a product of incomplete combustion of fuels; hence any kind of combustion process in a heating furnace or a fireplace can generate CO, especially if they do not operate in their proper regime. Naturally, CO is also generated via cigarette smoking. By depriving the brain of oxygen, CO leads to nausea, unconsciousness and death. The American Conference of Governmental

Industrial Hygienists (ACGIH) recommend the time-weighted average limit CO level at 25 ppm, i.e. for 1 million fresh air molecules there should not be more than 25 CO molecules.

2.2.2.2 - Carbon dioxide

Since the CO_2 release by mankind is the main reason for climate change, it is well known that the outdoor fresh air concentration of CO_2 is around 400 ppm. However, exceeding this amount indoors to levels reaching 1000 - 1500 ppm is not recommended. Being easily measured, 600 ppm above the outdoor level is a clear indicator of inadequate ventilation level. Reaching 35,000 ppm and staying for 15 minutes usually results in fainting and loss of consciousness. For prolonged periods 5,000 ppm should never be exceeded, according to US Occupational Safety and Health Administration (OSHA).

Indoor CO_2 concentration usually builds up due to human metabolism. Since the air refresh rate needs to correspond to the CO_2 generation, the air refresh standards link to the number of occupancy in a room. How quickly might the CO_2 level reach the recommended limit in a 3.5-by-4-meter sized office with a single occupant? In less than one hour…

(https://en.wikipedia.org/wiki/Indoor_air_quality#Carbon_dioxide).

It is worth mentioning that the effect on health of CO_2 is not related to the oxygen (O_2) physical replacement by CO_2 in the indoor air but it is its own CO_2 biological effect on human body.

2.2.2.3 - Radon

Radon, **Rn**, is a radioactive gas that is constantly generated in the ground and is considered as a health hazard. Every 2.6 km2 of surface soil, to a depth of 15 cm, contains approximately 1 gram of radium, which releases radon in small amounts to the atmosphere—radon itself is the immediate decay product of radium. Radon is the second most frequent cause of lung cancer, and the number one cause among non-smokers. Accumulating in various cavities in houses it emits radioactive particles causing cancer, even without inhaling. Active ventilation, along with periodic measurements is the real solution here.

2.2.2.4 - Volatile organic compounds

In addition to contaminant gases accumulated or generated by components already mentioned at the beginning of this chapter, such as building and furniture materials, paints, lacquers, glues and adhesives, VOC also can be in the form of benzene emitted from stored fuel, acrolein and formaldehyde emitted during cooking with oils. The list includes compounds whose concentrations exceed health standards in most homes: hexachlorobutadiene, acetaldehyde, 1,3-butadiene, benzyl chloride, 1,4-dichlorobenzene, carbon tetrachloride, acrylonitrile, and vinyl chloride.

2.2.2.5 - Ozone

While ozone can be generated indoors via a number of high voltage devices, the main source of ozone is the fresh air itself. Ozone, O_3, is the highly reactive allotrope form of oxygen, which otherwise in normal conditions form the stable O_2 allotrope – its oxidizing power is far higher than that of the oxygen O_2, and it is regarded as an atmospheric pollutant. While oxygen O_2 constitutes 21% of the Earth's atmosphere, ozone O_3 is formed under UV radiation – the trace concentration of ozone in the upper layers of atmosphere protects mankind from the UV radiation by absorbing it. Concentration of 100 ppb (100 molecules per billion) of ozone is enough to feel the pleasant odor of it after the thunder. However higher concentrations are malicious due to its powerful oxidation effect –damaging mucous and respiratory tissues in animals and humans, and also tissues in plants. The Canadian Centre for Occupation Safety and Health reports that:

> *"Even very low concentrations of ozone can be harmful to the upper respiratory tract and the lungs. The severity of injury depends on both by the concentration of ozone and the duration of exposure. Severe and permanent lung injury or death could result from even a very short-term exposure to relatively low concentrations."*

Due to the enhanced amounts of ozone in the upper layers of atmosphere some planes are equipped with ozone converters in the ventilation system to reduce passenger exposure.

2.2.2.6 - Cigarette smoke

This is especially important in countries, including Armenia, where smoking rates per capita are relatively high. One needs to mention that within overall of 5000 various chemicals in the cigarette smoke, there are both gaseous contaminants, such as CO, CO_2, VOC, as well as suspension in the form of smoke aerosol. The 98 most poisonous contaminants are causes of: vascular abnormalities - stenosis, lung cancer, heart attacks, strokes, impotence, low birth weight delivery by smoking mothers, etc.

While ventilation decreases the smoking hazard for non-smokers, the radical solution is the ban of smoking. The standards prescribe the highest ventilation rates possible in the areas where there are smokers.

2.2.2.7 - House dust, particulate matter from atmosphere, humans and animals

House dust is usually composed of:

- house dust mites eat dead human skin cells, while not habitating on living humans. While people walk at home, mites with dust are brought up into the air, and it takes more than 20 minutes to settle back them down out of the air. While inhaled they cause various allergies.
- atmospheric dust, both inorganic – mineral dust and sea salt, as well as organic – both biogenic or anthropogenic. One-third of the global land area is covered by dust-producing surfaces, made up of hyper-arid regions like the Sahara which covers 0.9 billion hectares, and drylands which occupy 5.2 billion hectares[53]. Road debris and coal also contribute to the dust content.

It needs to be mentioned that aerosol particles of natural origin (such as windblown dust) tend to have a larger radius than human-produced aerosols such as particle pollution[54]. The smaller the size of the particles, the more damaging their effects. When asthmatics are exposed to these conditions with particles smaller than 10 microns, it can trigger bronchoconstriction. In fact, particles of nanometer scale can pass through cell membranes and migrate into other organs, including the

[53] Jickells, T. D.; et.al. (2005). "Global Iron Connections Between Desert Dust, Ocean Biogeochemistry, and Climate". Science. 308 (5718): 67–71.
[54] *Hardin, Mary; Kahn, Ralph. "Aerosols and Climate Change"* https://earthobservatory.nasa.gov/Features/Aerosols/

brain. One particle of 10 μm diameter has around the same mass as 1 million of 100 nm diameter, but is much less hazardous, as it unlikely to enter the lung alveoli.

2.2.2.8 - Molds and allergens

In humid spaces, especially in countries with humid climates, moisture induced growth of mold colonies can e.g. substantially increase the risk of exposure to Aspergillus - a highly dangerous mold that can be fatal for those having asthma and in general the elderly. But the primary hazard of mold growth, in relation to indoor air quality, is from the allergenic properties of the mold spore cell wall.

Tiny, even microscopic, flecks of skin shed by cats, dogs, rodents, birds and other animals with fur or feathers called dander, as well as plant pollen also contribute to the allergenic effects of indoor air.

2.2.2.9 - Legionella and other bacteria

Evaporative cooling towers create conditions - slow-moving or still, warm water - for growth of the bacterium Legionella, responsible for *legionellosis* - Legionnaire's Disease – a type of pneumonia. Legionella is a parasite amoeba, and requires conditions suitable for both organisms.

The most important and well-known bacteria in the indoor air are Mycobacterium tuberculosis, Staphylococcus aureus, and Streptococcus pneumoniae. However, there are huge number of other bacteria indoors, most of which are not yet well known and investigated.

2.2.2.10 - Asbestos

Banned in many countries, many components of constructions are still made of asbestos – a cause of lung cancer, when people are exposed for long period of time. The difficulty of coping with asbestos is related to the fact that when dismantling the asbestos construction elements, the potential damage is increased since demolishing these components causes generation of fine asbestos fibers and dust that easily may penetrate into humans' and animals' lungs.

Indoor air quality is also specified in standards. In the USA the ASHRAE standard 62.1, ASHRAE Standard 62-2001-2013 specify the needed parameters.In short, per area the standard demands that 15 l/s/100 sq. m. and plus per person 3.5 L/s/person is provided. In other countries the figures are mostly repeating or around these values. Here is an excellent formulation of Building Ecology (https://en.wikipedia.org/wiki/Indoor_air_quality#Building_ecology):

> *It is common to assume that buildings are simply inanimate physical entities, relatively stable over time. This implies that there is little interaction between the triad of the building, what is in it (occupants and contents), and what is around it (the larger environment). We commonly see the overwhelming majority of the mass of material in a building as relatively unchanged physical material over time. In fact, the true nature of buildings can be viewed as the result of a complex set of dynamic interactions among their physical, chemical, and biological dimensions. Buildings can be described and understood as complex systems. Research applying the approaches ecologists use to the understanding of ecosystems can help increase our understanding. "Building ecology" is proposed here as the application of those approaches to the built environment considering the dynamic system of buildings, their occupants, and the larger environment.*
>
> *Buildings constantly evolve as a result of the changes in the environment around them as well as the occupants, materials, and activities within them.*

2.2.3 - HVAC REQUIREMENTS, EFFICIENCY AND REALIZATIONS

Modern HVAC systems require air-tight, automated and microprocessor controlled, programmable, modular and efficient realizations. Air-tight configuration demands that input air fans operate at a higher rate than the output air fans, so that the interior is always at slightly higher pressure compared to the outdoor atmosphere. This is done to prevent air, dust infiltration into interior – incoming air is always filtered and is entering the space only via controlled ducting.

Let's repeat the functions of the HVAC systems:

- ✓ Heating
- ✓ Cooling
- ✓ Humidity control – dew point management
- ✓ Removal of contamination and supply of filtered fresh air - air tight spaces.

2.2.3.1 - Heating

Heating can be performed via:

- Burning of fuel in open fireplaces – however, since a fireplace requires a chimney, it somewhat contradicts to the air-tight concept, and requires additional expenses and efforts to be efficient. At the same time burning e.g. wood is considered as clean source of thermal energy, since biomass use is CO_2 neutral.
- Burning fuel "externally", when a special furnace does not use indoor air oxygen, but contacts only outdoor air. They are called "Direct-Vent Wall-Mounted Gas Furnaces". The principle is very simple (https://inspectapedia.com/heat/Wall_Mounted_Furnaces.php). One can see that these furnaces easily can satisfy the air-tight design concept.
- Electric heaters – being very efficient in terms of the input and output energy, clean and very easily controllable, these heaters however use expensive electricity. There are two types - the first that warms up the air, and the second that emits intense IR radiation. Both have their pluses and minuses, e.g. high temperature IR heaters dry the air, but overall are probably solutions for present and future.
- One of the most modern and efficient sources are heat pumps. Since their operation is very similar to that of refrigerators, we will discuss their operation in the corresponding section. Also, since they are regarded as clean and renewable energy sources, most substantially they are detailed in the Renewable Energy section.
- Solar thermal energy – it might be an excellent source, however its operation is limited to relatively short periods of mid-seasons, as well as for high altitude dwellings. The reason is simple – winter is cold since there is not enough solar energy. In high altitudes, in the mountains, where it is cold even in summer, and when there is plenty of sunshine, solar heating can be a legit source; however this will not work in winter.
- There are a number of experimental seasonal thermal storage cases, which, however have not received commercial success yet. Some of them can work to increase the efficiency of heat pumps, but the trade-off is an overall high cost.

2.2.3.2 - Cooling

Cooling is performed via conventional refrigeration cycle, and used in any conventional fridge. Note that the cycle is symmetrical, and it can perform both cooling as well as heating. When heating, it performs the Heat Pump function.

Basically it spends energy not for heating or cooling, but for pumping thermal energy in positive (heat pump) or negative (refrigerator or air conditioner) directions, from outdoor air or from ground to indoor air. The *coefficient of performance*, COP defines the energy balance. E.g. if a heat pump has 400% COP, it means that while it spends 1 kWh to pump in thermal energy, the result is that 4kWh heat is pumped in – here the term "efficiency" is not applicable since the energy is not converted, but used to pump from one media to the other.

2.2.3.3 - Humidity control – dew point management

In order to remove humidity, it is necessary to pass the air through a heat exchanger that has temperatures below the dew point, below which the water content of air condensates and precipitates in a pane underneath the heat exchanger. Another way is to perform absorption of humidity via a desiccant (similar to silica gel) matrix with large number of air channels or passes.

However, after the matrix has absorbed humidity to its saturation, the opposite cycle needs to take place, which requires thermal energy. That is why the usual desiccant matrices have the form of a wheel, which performs desiccation in the input direction, and regeneration in the output channel.

2.2.3.4 - Removal of contamination and supply of filtered fresh air - air tight spaces

As it has been mentioned, air-tight configuration demands that input air fans operate at higher rate than the output air fans, so that the interior is always at slightly higher pressure compared to the outdoor atmosphere, and this is done to prevent air and dust infiltration into the interior – incoming air is always filtered and is entering the space only via controlled ducting.

In fact to provide fresh air, which is also called process air, into all spaces per requirements, it is necessary to have a ducting system for fresh, filtered air supply and stale, used air removal.

2.2.3.5 - Centralized Systems

Such systems are called HVAC systems that have active centralized bidirectional, mechanical ventilation – basically 2 networks of ducting, one for supply and the other for exhaust channels.

2.2.3.6 - Heat recovery

In general it is necessary to spend a lot of energy in order to cool, heat and to perform humidity control. Modern HVAC systems prevent dumping the spent energy to atmosphere by the use of heat recovery – heat exchangers that return thermal energy from the exhaust channel, just before the outlet vent to the inlet channel, without mixing air of the inlet and outlet channels. In fact modern standards require that heat recovery efficiency is no less than 70%. However it is not difficult to reach 90%, especially with the decentralized units. E.g. 90% efficiency means that if outdoors is 0^0C, and indoors is 20^0C the system is capable and brings in fresh air at 18^0C.

2.2.3.7 - Decentralized ventilation

While centralized HVAC systems are in general more economical due to the scale of economy, they also have a few negatives. E.g. in skyscrapers the warm air always tends to be at higher floors, and the building management systems (BMS) cannot always react adequately and quickly enough to the change in the situation.

Thus, the decentralized systems, addressing HVAC goals of a room or an apartment have the following advantages:

- No ducting is needed at all, thus installation cost is less
- Total independence of units from each other
- Easy to service without otherwise stopping the large centralized system and disturbing all the beneficiaries of the centralized systems
- Easy to control and turn into waiting mode when space is empty, thus more economizing opportunities.

However, the disadvantage is that it needs to have two vents to the outdoors to provide an inlet of fresh and outlet of used air (some push-pull systems need only 1 vent).

CHAPTER 3. RENEWABLE AND CLEAN ENERGY IN ENTERPRISE OPERATIONS AND SYSTEMS

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3.1 - ENERGY EFFICIENCY VS RENEWABLE ENERGY

Priorities and costs: before deciding to implement any renewable energy option(s), one needs to carefully examine the energy efficiency potential of an enterprise or home. This is usually done via an energy audit, which will yield the breakdown of the major energy expenditures. Such an audit shall reveal the energy saving potential at the first place. In general, every dollar spent on energy efficiency is more efficient than when it is spent on renewable energy generation. If the energy efficiency potential is mostly exhausted, then the real energy needs would be known. Thus, after knowing the optimal energy demand, one can think about the sizing of the different renewable energy options, which are discussed below.

3.2 - RENEWABLE ENERGY OPTIONS

Solar hot water

Solar PV

- Principle
- Orientation and geography related
- Grid connection and net metering
- building integration and architecture

3.2.1 - SOLAR PV PANELS AND CELLS

Solar Photovoltaic (PV) power is regarded as the "quintessential source of energy" without any moving parts or fluids, without noise and pollution and with extremely low – next to zero – maintenance. The light photons are captured by the semiconductor material and converted into useful electric potential through quantum photo effect.

1. Overview of the potential in the world and in Armenia – this section is common for any solar device and not just PV.

1.1. Solar constant and reference radiation. Outside of the atmosphere layer the sun provides a flux of photons that can be converted into useful energy. That flux of energy through a normally placed 1 m^2 area is equal to 1366 W/m^2 and is called *solar constant*. However, penetrating though the atmosphere, regarded as 9 km thick, at a nice, blue-sky day, when the sun is in the zenith and this condition is called Air Mass 1 (AM1), the flux attenuates by 27%, i.e. only 73% reaches the surface at the sea level, making almost exactly **1000W/m²**, which is called the *reference radiation*. This is a huge amount of energy, enough to solve all of mankind's energy-related problems, if we could use it optimally. E.g. the total energy from the sun that enters Earth's atmosphere during one second is equal to the total consumption of energy in Armenia during one year! 10% of the Sahara desert, used at 10% efficiency yields more than double of the total energy consumed on the planet.

2. Assessment of potential at a given site.

2.1. When the sun is not in zenith, the sun rays have to pass through a path more than 9 km, attenuating more, depending on the length of the path. E.g. at 60 degrees of inclination (measured in relation to the zenith direction) we have air mass equal to 2 (AM2), and the solar flux at the sea level is equal to 730 W/m^2, and at the sunset, at which the solar rays may pass up to 39 thicknesses of Earth's atmosphere (AM39), the intensity drops by more than 200,000 times! Besides, this energy is not available during all hours of daytime across the year due to clouds and is not available at nighttime at all… Effectively engineers need to monitor the energy flux on ground or from a satellite for at least few years at a particular geographic location (e.g. in Yerevan) to have reliable data on real energy that one may expect reaching to a one square meter of solar conversion device. The monitoring at the AUA through Armenia's first solar monitoring station (SMS) yields the following data for Yerevan:

- Annual global irradiation at each square meter = 1720 kWh/m^2

- Annual average daily irradiation ≈ 4.7 kWh/m^2

However, pronounced seasonality at this geographical latitudes, yields a difference of about 6.2 times, if one compares solar flux values e.g. in January and June (Figure 3.1).

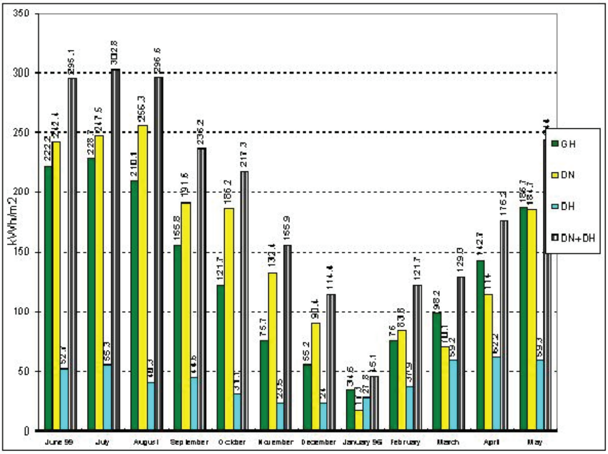

Figure 3.1. Solar monitoring data obtained through the station on the rooftop of the American University of Armenia (AUA).

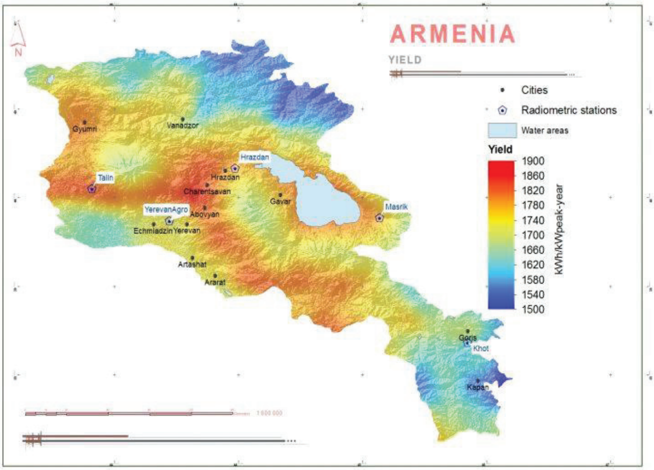

Figure 3.2. Recent solar monitoring yield map of Armenia via Renewable Energy and Energy Efficiency (R2E2) agency.

Figure 3.2 provides recent solar monitoring yield map of Armenia. More data for other countries can be found e.g. following the link: http://solargis.info/.

2.2. Building and system orientation (common to all solar devices). It is important to note that the orientation of the solar conversion devices is extremely important in harvesting the maximum amount of energy from the sun. The #1 rule is to face the solar panels towards the south. Since indexing (orienting) the solar panels to the south is usually much easier if the building's façade and its rooftop are oriented south, this should always be under a special consideration. Rule #2 is to incline the solar panels to the angle of the particular geographic latitude. Here one can archive more energy harvest in winter if panels are inclined stronger to the zenith direction (are more vertical compared to horizon), and it is possible to achieve more energy harvest in summer and also in general annually if panels are a bit more horizontal. There are maps of optimum inclination available, calculated for the entire year or seasonal optimum. Certainly tracking the sun by solar panels increases the total energy harvested, but there are two factors here to remember:

1. It is expensive to provide panels tracking the sun due to extra expenses on the rotating support structure. With the constant decrease of the prices of photovoltaic (PV) panels, the tracking system cost is becoming a substantially higher percentage of the total system. Such a tracking system, well-designed and constructed to sustain wind loads, may increase the system cost to around 35-50% or more.
2. The advantage achieved by tracking is relatively small, usually not more than around 15-25% of the total output, and the reason for this is related to the fact that when the sun is not in the zenith it needs to pass through a thicker atmosphere layer and thus gets attenuated.

However, if concentration devices are used for solar energy conversion, it is impossible to avoid tracking systems, since solar rays should always be focused on the converters. Fortunately architects almost never consider using tracking systems as elements, but usually use immovable components. However, if the architectural context dictates implementation of tracking systems, the two aforementioned factors should be taken into account. The next important consideration is to provide shadowless design, so that there is no loss of energy output due to shades from the surrounding buildings, trees, etc. For a building surrounded by large amount of trees, solar PV trees that go higher than trees can be designed.

Note that due to the fact that rooftops are already inclined, it is much more natural and economical to use them for solar panel installations.

Consumption at the site - consumption patterns and their match to the resource availability patterns. Proper sizing of the system defines how much money should be spent on power generation. Here is the sequence of steps to perform the calculation:

1. How much is the monthly expense on energy – both for electric power and for heating/cooling. How many kWh-s and cubic meters of natural gas have been spent in total

in a month. Understand seasonality – find the months when maximums and minimums have been spent.

2. How many kWh-s on average are consumed daily in each season, or the season that you are targeting? Define the target season of the year, or target the total maximum generation.

3. What is your daily consumption pattern? I.e. one needs to find out if the most of the consumption takes place at sunny hours or later? If later, energy storage technologies (see in other sections below) should be employed. In general it is necessary to find out your energy consumption pattern by filling out Table 3.1 for a typical day (here it is filled as an example):

Table 3.1. Consumption pattern in a tabular form.

Hour*[55]	kWhs
1	0.1
2	0.1
3	0.05
4	0.05
5	0.1
6	0.05
7	0.05
8	1
9	1.5
10	1.5
11	0.5
12	0.2
13	0.2
14	0.7
15	0.8
16	0.2
17	0.1
18	0.4
19	0.6
20	0.7
21	0.7
22	0.8
23	0.4
24	0.3
Total	11.1

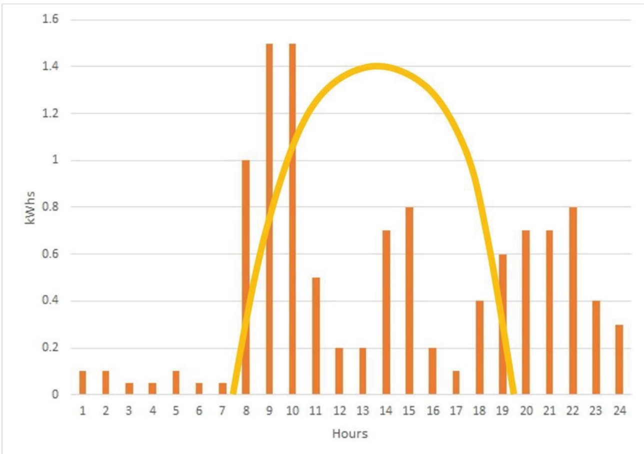

Figure 3.2. Consumption pattern corresponding to the table, in the graphical form. Note overlaid solar radiation availability curve (yellow).

[55] In most of the cases 2 hour intervals should be sufficient for definition of the pattern.

The red bars of the graph on Figure 3.2 correspond to the table at the left. In the night hours there is very little consumption, starting at 8 AM the appliances are operating, and in evening, with the return from work lights, TVs, computers, etc. are on. The orange line corresponds to the availability of solar radiation on that particular day. It is clear that if no storage technologies are applied, the solar conversion devices can only provide power to some of the demand in between 7 AM to 7 PM. If the demand at a particular hour is higher than the output of the solar device at that same hour (defined by the orange line), the difference should be taken either from the storage or from the grid. Similarly the unused generation either goes to the storage, or is lost if the storage is full, or if there is no storage or if there is no grid to feed. If capacity and storage are optimized, the area under the orange line should be equal or slightly exceed the sum of the red bars – this will define the solution of the sizing problem for that season.

It is important to take into consideration that aiming to provide all the demand in all seasons from sun through your system might not be optimal. You will have to have a system that is very big, and its generation will be adequate only during the down season, e.g. winter for northern hemisphere – during all other seasons you may have extra generation that you need to sell, otherwise it will be lost. It is worth noting, that power grid connected generation systems, in contrast to stand-alone systems, have the ability to sell the extra unused power to utilities and purchase needed power when there is no generation output from the renewable conversion device, and can be well optimized. In this way two important problems are solved. First, one does not spend on expensive and short-life cycle storage batteries that always require some kind of maintenance. Second, when the household does not use the generated energy, it is not lost but goes to the utility through a two-sided meter, allowing you to use your own generated power at any convenient time. This way the capacity usage factor (or simply the capacity factor) of the system is being increased to its possible maximum.

3. Integration of photovoltaic technologies into building components and design

3.1. Main components of the PV systems. The components of a PV system are following:

- PV modules
- mechanical support system to carry the weight of the array of modules
- charge controllers that prevent batteries from overcharge

- DC-AC inverter to convert the direct current output of the photovoltaic panels into more versatile and alternate current of 50Hz or 60 Hz frequency depending on the country
- batteries or a gridconnection device with two-sided meter to store or sell unused generated power and be able to use it when solar radiation is unavailable. In many cases credit meter and electric meter units are not separate components, but are united into one block.
- In some remote areas the presence of a back-up generator is actually mandatory.
- interconnection wires.

PV modules (panels). The main parameters of the PV modules are:

- Peak power, W_{peak}, or simply W_p – the electric power output of the solar photovoltaic panel at reference radiation (see section 1.1), measured in watts (W) or kilowatts (kW).
- Price per peak power - $/$W_{peak}$ – more important than efficiency, defines the system cost.
- Module efficiency (not to be confused with cell efficiency, which is usually higher) – is the percentage of electrical power capacity compared to the insolation capacity incident to the surface of the panel at reference radiation (1000W/m^2). The higher the efficiency, the smaller the panel that provides the same peak power. E.g., a 1m^2 panel with efficiency of 10% has peak power equal to 100W, whereas a 20% panel with the same 100W peak power capacity has only 0.5m^2 surface area. If you have plenty of surface, it is better to use low-efficiency, cheaper panels.
- Output voltage – this parameter is important only for installers – the output voltage is higher, and the wiring, inverter and the grid connection are a bit more efficient and less expensive. The voltage is usually increments of 12V – 24V, 36V, 48V, 96V, etc. This parameter does not affect the peak power or efficiency.
- Service life of the modules, in years. One would always like to purchase PV modules that can serve many years. However, with the high rate of decrease of the price of PV modules, it might be optimal to use cheaper modules with shorter service life, since by the end of that period for the same money one might be able to purchase better modules. Usually the Mono-Silicon solar cells have very long lifetimes, and the limiting factor here is the lifetime of the encapsulation – the frame, the weather sealing, etc., in this case yielding overall at least 30 years of service. Some thin film commercially available PV panels have a lifetime of about 10 years. The newest organic PV cells have even shorter lifetimes, but these cells are still in the stage of development and not yet are widely commercially available.

The main types of modules differ mostly by the semiconductor light conversion material, as well as the type of encapsulation. It is important to mention a few types of modules:

- rigid, glass or hard plastic laminated
- rigid, integrated into windows or solariums
- rigid, integrated into rooftops in the form of **solar shingles**.
- flexible, polyester or polyimide – can be folded for carrying e.g. to outdoor camps
- flexible, to cover the rooftops.

Figure 3.3. Solar PV modules. Note that solar cells cover not all the surface of the panels in the left picture, while the right panel has a higher "optical fill factor". A support structure is needed for these rigid panels.

3.2. Building Integrated photovoltaics - BIPV. If one uses solar PV cells or modules that due to their form can replace some elements of the construction, then the overall cost of the project drops. E.g. if photovoltaic *solar shingles* are used instead of installing mainstream PV modules, economy takes place: a. due to avoiding the use of the ordinary shingles; b. due to elimination of a special support structure for PV modules. Similarly, if it is possible to use part of the windows or glazing of the construction to integrate PV cells inside, one can avoid paying for the PV modules' glazing the second time, and one can also economize on the support structure. At the same time the Integrated PV is an innovative, aesthetically interesting element that can be a part of the architectural idea - recently a popular PV module placement location is the south-facing portions of the building envelope, perfectly helping to address both economizing dimensions of the integrated PV.

3.3. If a house is in a garden and heavily surrounded by beautiful trees, it might not be possible to use the building rooftops for solar photovoltaics. The solution here could be the so-called solar trees. Installed on a tall pole popping above the green trees, the solar trees provide easy orientation by an optimal southern angle, and also may bring an innovative three-dimensional effect to a new or existing design or building. The rest of the photovoltaic system remains unchanged.

No doubt special attention should be paid to the wind resistance of the total construction, e.g. by decreasing the sail effect through a number of gaps in and between the panels.

3.4. Integration of PV into a building's complex multifunction control system with involvement of the building envelope composed of smart shading devices. Authored by Abdoulmajid Karanouh and his team, the AVIVA building in central London at the bottom line during its lifecycle economizes on the HVAC operational cost by integrating shading, ventilation and PV.

3.5. To compare the options to make final decision, the following steps are advised:

1. Define consumption patterns as described in the point 2.3, for the target season. Note that Solar PV panels can provide power for electricity needs, which certainly may include e.g. water or space heating demand. At the same time one needs to remember that the space heating needs are the most important at the periods when there is not much sun – making this demand more suitable for midseason, i.e. spring and fall.

2. Make a decision if your system will be grid-connected or not.

3. Define the components of the system and their size, and match the components of the system with the architectural concept that you have. Importantly make a decision on the area of the solar panels that will need to be installed on the rooftops, façades, or solar trees. Do not forget that depending on your architectural solutions on the type of panels you decide to install, you may need to have a type of panel that has higher or lower efficiencies, thus smaller or larger required area.

4. Consider financial issues – higher efficiency panels have higher prices – consider price per peak power - $\$/W_{peak}$. At the moment this prices range from as low as $\$0.4/W_{peak}$ for conventional Silicon cells @ 17% efficiency, to $\$4\text{-}40/W_{peak}$ for thin-film, specialty (e.g. multi-junction) modules as well as for higher efficiencies. However for the space applications this price surges to $\$1000/W_{peak}$ …

5. You may need to go through a second iteration to match the solar system with your architectural idea.

3.2.2 - SOLAR THERMAL COLLECTORS

Solar thermal correctors are very much similar to greenhouses, where the higher temperatures are achieved due to blocking the convection losses through the glass insulation. Additionally solar water heating (SWH) panels are blocking the rear convection losses and the infrared back radiation from the absorber that has become hot due to solar radiation.

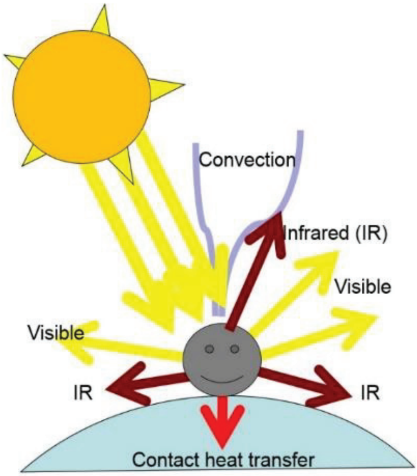

Figure 3.4. The inputs and outputs that define the temperature of a body, in this case the solar water heating working liquid temperature, are shown. Solar water heating panels work like small greenhouses, blocking the back-radiation and convection output losses.

Temperature of any construction or body is a result of an equilibrium between the input and output energy forms. Inputs are usually through solar radiation and e.g. hot wind. Outputs are through convection, reflection, contact heat transfer and infrared radiation (Figure 3.4). All greenhouses have higher temperatures inside due to shifting the balance towards higher temperatures by blocking or substantially decreasing the convection process.

1. Note that the potential in the world and in Armenia for solar thermal panels is the same as in the previous chapter on PV. The solar potential is abundant in the world, and the solar monitoring

data should be taken into consideration when designing a system in a particular geographic location.

2. Integration of SWH technologies into building components and design is relatively limited due to its design and construction related constraints. Compared to PV modules, shingles or flexible layers, the SWH panels are twice as heavier. While PV panels weight around 14kG/m^2, the SWH panels weigh 25kG/m^2 or more, plus they are much thicker, never flexible, and need to be connected through pipework. They are usually larger too.

Figure 3.5. Comparison of PV and SWH panels installed on a support structure. Please note that on the top right vacuum tube panels are shown.

Available technologies and energy yields.

The main two technologies of the solar water heating panels are the regular SWH panels and vacuum pipe solar panels. The main difference is that in contrast to the regular panels, vacuum tube panels are composed of absorbers that are placed in vacuum tubes thus eliminating the losses associated with air convection. This difference yields overall higher achieved temperatures and higher capacity factor, i.e. more operational hours while being at the same geographical location.

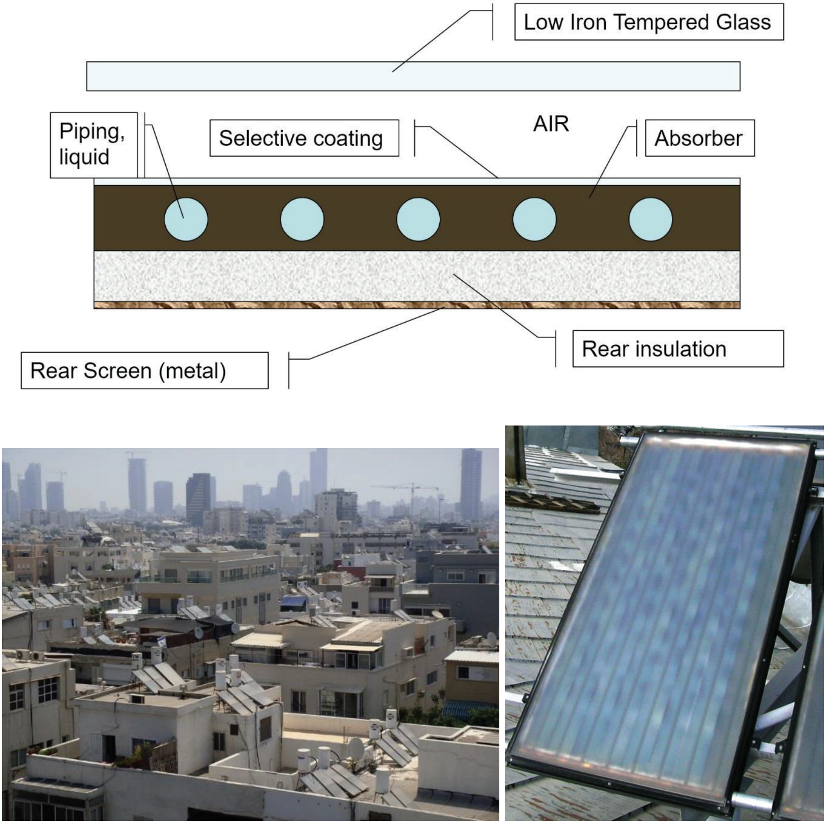

Figure 3.6. Solar water heating panels' construction and operation. Note the overall uninspiring architectural look in the bottom left picture made in Tel Aviv.

3. Design and energy decision criteria

   The solar water heating system (SWH system) configuration has two major cases: I. a system designed for those geographical locations or seasons where there are no freezing temperatures. II. If there is water inside the SWH panels and the temperature is below 0^0C, the investment in SWH is greatly jeopardized, since the temperature coefficient of expansion of the phase transfer of water to ice is positive and yields huge forces breaking the pipes in the panels. To avoid this situation antifreeze is used in a closed loop, and the heat has been transferred to the uses through a heat exchanger – fortunately these heat exchangers have very high efficiencies, so that the losses on them are actually negligible. If there is no danger of freezing temperatures, the SWH system's basic one contour (loop), convection-driven (no pumps needed, the tank is over the panel) design consists of following components (diagram A – note temperature gradient or "stratification" in the tank):

If vacuum tube panels are used, it is possible to have one-loop configuration in not very freezing climates – here there is some experience that shows that automatical control and auxiliary heaters might be optimal, in contrast to a two-loop, antifreeze loaded system. The system sizing should be based first of all upon the daily demand in of e.g. 60^0C hot water in liters. The Solar panels should be able to provide the needed heat for that volume – which can be easily calculated through the formula: $Q = C \times M \times \Delta T$. Here Q is the energy per day that panels are capable of delivering in the target season, C is the heat capacitance of water, M is the mass of water to be heated, ΔT is the desired temperature difference. Currently the cost of a SWH system averages to about $2000 per kW of capacity.

3.2.3 - SOLAR WALLS

A Passive Solar Technology

Solar or Trombe walls function like greenhouses, but their configuration allows using the intense convection from the heated walls to drive the air circulation, similar to the chimney effect - thermosiphoning. In summer, this effect allows keeping the wall masonry or concrete close to the shadow temperatures, and in winter, it allows to heat up the wall and use it as thermal storage or warm up interior air volume.

Overview of the potential in the world and in Armenia, Assessment of potential at a given site

It is important to stress that in order to estimate the potential for solar walls at any geographical location, the target season should be defined, and average inclination of the sun should be taken into account. It would be approximately correct to assume that vertical solar walls have approximately at least 90% of the solar monitoring data for a horizontal surface. Thus, in the most of the cases this parameter is not much different from the usual monitoring data. It is also straightforward that energy expected from the solar wall is proportional to the surface area of the wall that is used as a solar wall.

1. Understanding solar walls and their use in buildings, including industrial and institutional/public buildings.

   Figure 3.7 illustrates the air warming effect of the Trombe wall – cold air supplied from the interior through the bottom vents is being warmed by sun-heated masonry and enters back to the interior through the top vents. At the same time the warmed-up masonry also radiates in the infrared spectrum to the interior.

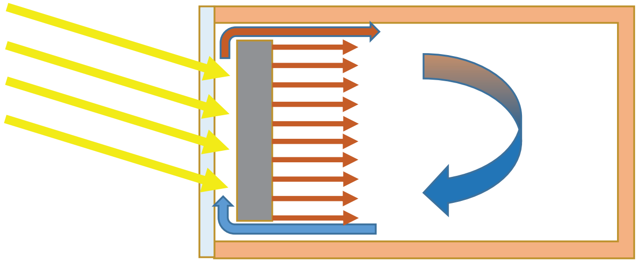

Figure 3.7. Trombe wall warming effect: convection (a); infrared radiation (b)

The cooling effect of the Trombe wall is illustrated in Figure 3.8.

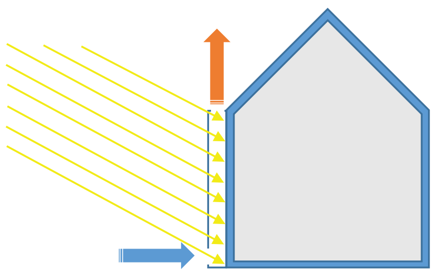

Figure 3.8. The chimney effect of the Trombe wall is yielding a cooling effect: convection in the "chimney" prevents the wall from being heated to high temperatures and keeps it close to the ambient temperature (temperature in the shade). This chimney effect is performed through two external, bottom and top vents.

3.2.4 - WIND TURBINES

– Overview of the potential in the world and in Armenia

While the wind potential worldwide is actually abundant, it is not distributed evenly, and Armenia's potential is restricted by about 400MW capacity – equal to the Metsamor nuclear powerplant if fully employed. Figure 3.9 shows the wind map of Armenia prepared in 2007. Taking into account that the most efficient wind turbines are the ones that are really huge, e.g. more than 1.5 MW, with really long blades installed in the high potential areas, as well as the fact that the high potential areas are usually remote areas in the mountains making really hard to prepare the wind farm area and to transport the huge blades, the wind power in Armenia may easier play a smaller, local role with implementation of small wind turbines that correspondingly require smaller upfront investment, as the smaller turbines are easier to integrate into any architectural concept.

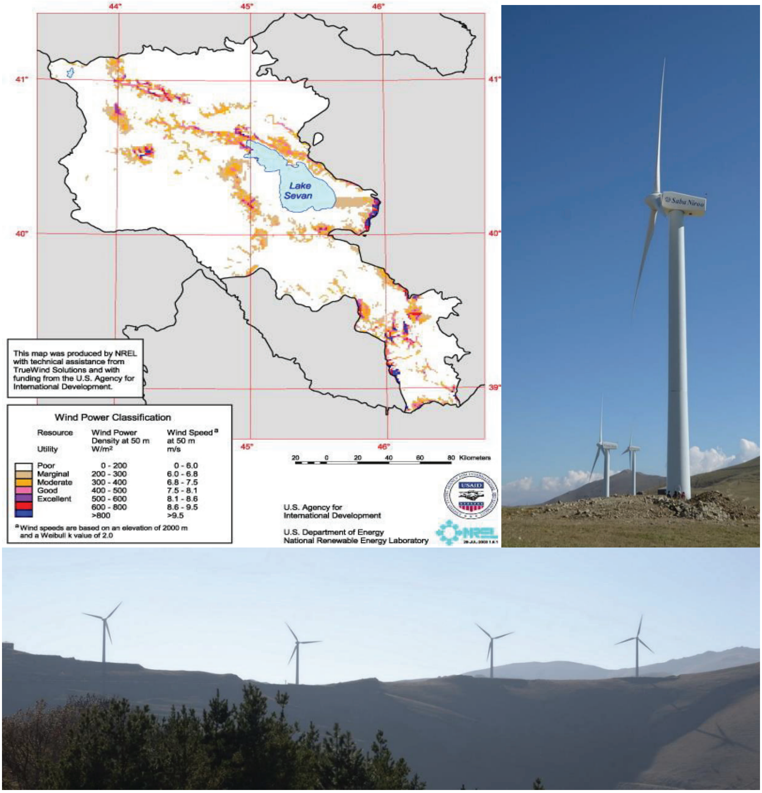

Figure 3.9. Wind map of Armenia. The pictures at the right and bottom show the only wind farm in Armenia at the Pushkin Pass with 4 wind turbines, 650 kW capacity each, 2.6MW total.

– Assessment of potential at a given site

At least a one year monitoring of the wind speeds and directions is necessary in the location under consideration, at several heights implementing a special tower and automated data-logging technique. While for the commercial use at least 80 meter towers are used, for uses integrated to architectural concepts, smaller heights can be appropriate. The data is analyzed statistically and a distribution function is defined that in turn helps to calculate the capacity factor, i.e. the ratio of hours that the wind turbine will annually operate to the total annual 8760 hours. Usually this number is in between 10-35%, but in the majority of Armenia, it is below

15% with wind speeds lower than 6m/s and average energy density below 200W/m2 of the area that wind turbine rotor sweeps.

- Integration of wind turbine technologies into building components and design so far has been very exotic and rare. The pictures below show the realized and planned projects.

The small wind turbines, with power capacity of 1-50 kW, are the most interesting, and probably easiest to be integrated into particular architectural concepts, also to the variety of forms and sizes. Similar to PV, they can be assembled into trees and can be combined with the panels.

- Available technologies and energy yields. One needs to take into consideration that wind turbine integration into a construction is an extremely responsible and engineering-intensive work, due to large wind loads, as well as the vibrations spectrum induced by a wind turbine rotor. For this purpose using a stand-alone wind post with a mass-produced small wind turbine is the simplest decision. The pictures below are related to that option and also explain the wind power system design. The system design and options are quite similar to that of a PV with solar modules replaced by a wind turbine. Here instead of providing sun rays incidence on the panels, one needs to make sure that winds are not obstructed. The higher the rotor, the more wind is available – the generated energy is proportional to the cube (!) of the wind speed, (i.e. doubling average wind speed increases the energy generation by a factor of 8) and reciprocal to the air pressure that is linearly related to the elevation from the sea level.

The wind turbines are categorized into classes, corresponding to the average wind speed areas that they are designed for, see also fig. 22, thus area classes range from Class 1 - 200 W/m2 or less at 50 m height - to Class 7, 800 ÷ 2000 W/m2. Most of the large wind farms are sited for Class 3 or higher geographical areas, although Class 1 area will be of the most interest for architects. Wind turbines are classified by the wind speed they are designed for, from class I to class IV, with A or B referring to the turbulence.

It is necessary to remember that the efficiency of the wind turbines is restricted by the so called Betz Limit, approximately equal to 59%. Usually wind turbines are fulfilling only about 65-85% of this range, thus it is acceptable to talk about Coefficient of Performance (COP) and not efficiency. Thus most turbines have COP of 0.65 – 0.85.

– Design and energy decision criteria. Here one needs to look at the price of the wind turbine per installed kW of capacity, for a particular class of the average wind speed. At the moment the price is around $1200/kW, but has a tendency to grow. It is necessary to remember that correct categorization of the geographical area per wind speed is very important, although in the most of the cases, e.g. in Armenia that is going to be Class I, a low wind speed turbine will be among the most wanted.

3.2.5 - GEOTHERMAL HEAT PUMPS

Heat pumps are spending electrical energy to pump thermal energy from one media, e.g. ground or ambient atmosphere, to the target space – e.g. living interior. In fact, they employ the same principle as in conventional refrigerators; the difference is that instead of pumping the heat from the refrigerator to the ambience, they pump the heat from the ambience into the interior. The "geothermal heat pumps" (GHP) are using the heat energy of the ground, instead of the atmosphere – they extract the heat from the ground and direct it to the space to be heated.

The principle of the operation is rather simple: the compressor increases the pressure in the working fluid – gas or liquid – in the heat exchanger (condenser) that is located in the target media (for instance in the interior of the house) until it condenses into a high-pressure, moderate-temperature liquid which causes some of the internal energy (heat) of the working fluid to be transferred to the needed space. Then the expansion valve allows the gas to be moved to another, "expansion" heat exchanger (evaporator) located outdoors or in the ground, where by expanding, the gas obtains substantially lower temperatures than the media that surrounds it. Due to the fact that this temperature of the working gas is lower than the media where the expansion heat exchanger is located, e.g. in the atmosphere or in the ground, thus the gas recovers its internal energy, the heat that has been lost in the compression side. After this, the working gas is moved back to the compressor. The cycle is repeated. In this way, it is possible to move the heat from a colder space to a hotter space, and this direction is opposite to the natural, spontaneous heat flow from a hotter space to a colder space. See Figure 3.10 below.

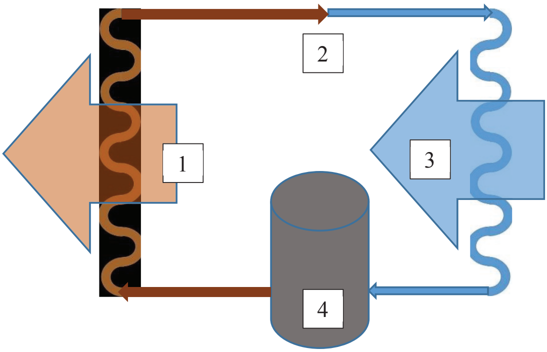

Figure 3.10. Heat pump's vapor-compression refrigeration cycle: 1) condenser, 2) expansion valve, 3) evaporator, 4) compressor.

Due to the fact that underground temperatures are very consistent across the seasons, and the ground, especially when saturated by underground waters, can absorb or provide large amounts of heat, also the needed temperature differential is limited, the so called geothermal, i.e. the underground evaporator heat pumps deliver higher coefficient of performance – COP – amounts of heat energy extracted and moved per unit energy spent. Note that here, similar to the wind power, COP is the appropriate term to use to characterize the heat pumps. The COP for a GHP may reach to a stunning 8 = 800% and beyond, which means that by spending 1kWh you move 8kWh of heat to your target space!

For air source heat pumps the COP is usually 3-4, and values of 8 or beyond are achievable through GHPs only. The depth to which the evaporating heat exchanger should be buried largely depends on the ground water depths – it is always good to heat a layer where ground waters are present, since the water has the highest heat capacity factor in nature. Usually approximately 3 meter depths are required to provide consistent temperatures, but with the presence of underground waters, this depth can be less or more.

Heat pumps are more effective for heating than for cooling an interior space if the temperature differential is held equal. This is because the compressor's input energy is also converted to useful heat when in heating mode and is discharged along with the transported heat via the condenser to the interior space. But for cooling, the condenser is normally outdoors, and the compressor's dissipated work (waste heat) must also be transported outdoors using more input energy, rather than being put to a useful purpose.

There are a multitude of schematics that combine the heat pumps with thermal storage, hot water solar systems, PV and other renewable sources and energy efficiency technologies. Currently this field is developing quickly, and every year one can see new, improved achievements and off-the-shelf products.

Naturally, the potential is abundant in both the world and Armenia for the GHP implementation and is an excellent resource to target energy independence and environmental preservation.

Assessment of the potential is mainly related to the easiness of digging or drilling for the underground heat exchanger targeting to reach the underground waters, if they are available. The integration of geothermal heat pumps into building or community design is mostly no problem and is very much similar to placing a centralized mechanical ventilation system or a community heating system. Sometimes a very simple cooling or heating function is performed using the underground energy. The main decision criteria are related to the cost of the system. The average cost of residential systems is $1.90 per Watt, or about $26,700 for a typical (4 ton = 14 kW in Armenian weather) well-insulated home system.

There are only few companies in Armenia dealing with GHP systems; R&R is one of them. It is necessary to mention that the bad design of these systems may be a reason for lower COPs, thus good experienced companies need to be involved.

CHAPTER 4. GUIDANCE ON EE TECHNOLOGIES

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Contents

4.1 - GENERIC AND CROSS-SECTOR GUIDANCE ON EE TECHNOLOGIES

These and others provide generic guidance on EE opportunities, but are largely aimed at general / cross-sector technologies, including:

- Motors and drives
- Refrigeration systems
- Pump systems
- Fan systems
- Compressed air systems
- Lighting
- Boilers and steam/hot water distribution
- Heat-recovery systems

Much of the existing advice is good and there would be little value in re-writing this Guidance[56]. Three major cross-sector issues are:

- Motor and motor related systems typically account for 60-65% of industrial power use; therefore only 25-30% will be used for sector-specific technologies. Generic/cross-sector guidance on motors and motor related opportunities, includes:
  - correct specification and sizing of the motor unit;
  - system optimisation (particularly fans, pumps, compressors);
  - minimisation of misuses, leaks, or other avoidable waste;
  - use of variable-speed drives rather than valves or chokes;
  - selection of higher efficiency motors, which regularly offer 30-50% EE savings, sometimes more.

ENERGY EFFICIENCY

1) "Energy efficiency improvements refer to a ***reduction in the energy used for a given service or level of activity.*** *" [World Energy Council]*

2) "Energy efficiency encompasses all changes that result in decreasing the ***amount of energy used to produce one unit of economic activity.*** *Energy efficiency is associated with economic efficiency and includes technological, behavioural and economic changes." [World Energy Council]*

3) "Energy efficiency is ***the use of technology that requires less energy to perform the same function.*** *"[Energy Information Administration]*

4) "Energy efficiency is the process of ***substituting energy by capital****, usually to generate profit after a certain amount of time. "[M. Pehnt, Energieeffizienz]*

5) Energy efficiency' means the ratio of output of performance, service, goods or energy, to input of energy "EC Directive 27/2012/EC"

6) "Energy efficiency is the fuel of the future" [Unknown]

[56] It would also require an order-of-magnitude extra additional effort to do so.

Advice and information is regularly updated, and there are many organisations already providing tailored training in motor optimisation, policy and system optimisation.

(1) Lighting typically accounts for perhaps a further 5-10%. EE lighting has developed considerably over the past 5-10 years, particularly with people sensors and automatic controls (PIR) and with the growth of EE fluorescent followed by rapid developments in LED lighting. Focused advice on EE lighting can offer 70-90% EE savings.

(2) Boilers and steam/hot water distribution accounts for the majority of the thermal energy needs in all but the very large and bespoke industrial organisations, such as power-generation, metals, cement/glass/ceramics, etc. It often dominates the thermal needs for food & drink, chemicals, paper, engineering, textiles, etc. Again, there is excellent pre-existing advice and info on: correct "sizing" of the boiler unit, boiler controls, fuel-air optimisation and waste-heat recapture, optimum distribution systems - including leak-avoidance and suitable insulation, end-use metering and controls – primarily to reduce unnecessary demand or misuses is the biggest generic/cross-sector thermal energy consumer.

Secondly, for EE, many cross-sector technologies first focus on system optimisation (SO), rather than on the EE of actual energy-consumption center. These can only be identified during the site visit/field work. Most EE solutions will also be bespoke to the site and the process itself. Good examples include: [57]

- mis-use or inappropriate use of compressed air,
- steam leakage and/or poor insulation,
- badly designed air or liquid handling systems – for fans and pumps
- waste heat recovery: the optimum solution is dependent on the layout of the site and whether it is practical or cost-effective to capture heat for another process.

It is recommended that these Guides be used as the "best practice" guidance for EE in cross-sector technologies. They will need to be referenced and used by auditors, along with their own knowledge and experience of the technology.

[57] Further information available in EN16247: 3 (2014) "*Energy audits Part 3: Processes*"

Energy Audit Protocol

Good audit protocol tends to work backwards from the end-use to the energy center.

For example, in a compressed air system:

- What is the energy being used for? Can a less energy intense system, such as mechanical or servo motor, be used to do the same function?
- How good is the distribution system: leaks/dead-ends/water traps/etc.?
- Is the equipment at the optimum pressure and cleanliness? Would decentralisation for specific high-pressure uses be more cost-effective?
- How is the pressure modulated? Variable-speed drives?
- What is the quality of the air intake? Is it clean/cool air?

Combined, SO can offer 50% energy-savings, sometimes more, without needing to invest in a new compressor or sometimes even more. Secondly, if a new compressor is required, it need only be a fraction of the rating (therefore a smaller investment cost).

4.1.1 – INDUSTRY-SPECIFIC GUIDANCE

Generic guidance becomes less useful for sector-specific type technologies, including:

- High temperature kilns and furnaces: coke ovens, sinter plant, blast furnaces, basic oxygen furnaces, electric arc furnaces (EAF), glass melting tanks, cement kilns, brick tunnel kilns, rapid fire white-ware furnaces, etc.
- These tend to be thermal units, although EAFs are electric-powered. In countries where industry includes large and diverse metal-based mineral ores, much of the primary and secondary metal-processing guidance will be interesting,
- Process engineering energy-intense equipment: chemical reactor vessels, distillation columns, refinery crackers, primary paper digestion, combined heat and power (CHP) generation, etc.
- Renewable or low-carbon energy sources: wind, solar PV, solar thermal, hydro, waste-as-a-fuel (combustion or anaerobic digestion), etc

These tend to be industry-specific (or technology-specific), therefore there is less generic, good-practice guidance available. Instead, one needs to call on specialist expertise. However, it is not a simple task to build up expertise in these sectors or technologies; normally the skills and expertise come from years of experience of working in the sector.

Industry is very different to buildings in that most industrial sites have:

1) One or more large, sector-specific, energy-consuming technologies,
2) Cross-sector technical equipment (such as refrigeration, compressors) and
3) Non-technical equipment (such as lighting and space-heating).

Building Energy Audits tend to focus on non-technical equipment: boilers & heating, ventilation/air-con, insulation and glazing (to reduce heating or cooling requirements), lighting and office equipment.

Secondly, there are approximately 15 major industrial sectors, each with up to 20 sub-sectors. It would not be realistic (or practical) to provide audit analysis detail for all industrial sectors and their technologies; the volume and detail would be enormous. Instead, it is recommended to draw from existing, available, information on best-available technologies and techniques for particular sectors, combined with the auditor's own built-up knowledge of the sector.

4.1.2 - MAIN ECONOMIC POTENTIAL FOR EE IN INDUSTRY

Based on the 2012/27/EC, the EU and associate member countries must develop programs to encourage SMEs to undergo energy audits including support schemes to cover costs of audits, whereas energy audits are mandatory for large enterprises. By definition, energy audits must deliver the following:

a) be based on up-to-date, measured, traceable operational data on energy consumption and (for electricity) load profiles;
b) provide a detailed review of the energy consumption profile of buildings or groups of buildings, industrial operations or installations, including transportation;
c) be built, whenever possible, on life-cycle cost analysis (LCCA) instead of Simple Payback Periods (SPP) in order to take account of long-term savings, residual values of long-term investments and discount rates;
d) be proportionate, and sufficiently representative to permit the drawing of a reliable picture of overall energy performance and the reliable identification of the most significant opportunities for improvement

The basic practices to pursuing energy efficiency in industrial companies are geared towards the following objectives:

1. Avoiding unnecessary energy consumption

Unnecessary consumption causes neither additional production/service nor increase in comfort.

e.g.: - avoid unnecessary idling of machines

- avoid unnecessary heating or cooling phases
- review process parameters and safety reserves

2. Decrease of specific energy consumption

The specific energy consumption can be reduced by technical measures.

e.g.: - drying using mechanical rather than thermal energy

3. Improving the efficiency and utilization ratio

The utilization ratio is under normal conditions, often well below the rated efficiency of the systems. Reasons for this are low-capacity utilization and a poor state of maintenance.

e.g.: - high utilization of production

- proper sizing
- good and accurate maintenance and control

4. Heat recovery

e.g.: - utilization of waste heat in the same process or within the company

- Introduction of heat pumps for low-temperature heat recovery in specific application

5. Utilization of renewable energy sources

e.g.: - utilization of ground source heat pumps for space Heating/Cooling

To estimate energy efficiency potential, the energy consumption of a production process is related to the number of produced goods (general: to the outcome, the so-called "functional unit"). For example, industrial energy efficiency very often means to install a machine with higher production capacity (kWh/Production). Consequently, energy efficiency will achieve an increase in absolute energy consumption and decrease in specific energy consumption.

	Unit	Old machine	New machine
Production	Measurement units	1.0	1.4
Absolute energy consumption	kWh	0.50	0.60
Specific energy consumption	kWh/Production	0.50	0.43

Based on empirical experience, the energy saving potential that is economically justified in the industrial sector based on the areas of energy use (energy centers) is as follows:

Area	Potential Energy savings
Compressed air	**5 - 30%**
Lighting	**5 - 70%**
Heat supply	**5 - 30%**
HVAC	**5 - 25%**
Refrigeration, chilled water	**5 - 30%**

4.1.3 - BENCHMARKING AND BEST AVAILABLE TECHNOLOGIES

To compare specific energy consumption figures of the client enterprise with international norms and make suggestions towards the achievement of best practices, the comparison should as much as possible correspond to a similar baseline to avoid risks of giving wrong signals.[58]

Best Available Technology Reference Notes, also known as BAT Ref or BREF notes, provide a wealth of information of the best available technologies for energy-intense or potentially high-pollutant industrial sectors, including several of most energy intensive sectors:

- Ferrous metal processing industry
- Iron & Steel

[58] For resources on benchmarking refer to **Indicative links**
http://www.unido.org/fileadmin/user_media/Services/Energy_and_Climate_Change/Energy_Efficiency/Benchmarking_%20Energy_%20Policy_Tool.pdf
http://www.iea.org/publications/freepublications/publication/tracking_emissions.pdf

- Non-ferrous metals
- Cement & Lime
- Glass
- Ceramics
- Organic and inorganic chemicals
- Chloro alkalis
- Food and drink

These documents are updated periodically. (All existing BREF Notes can be found at http://eippcb.jrc.ec.europa.eu/reference/ Note: several of these BREF sector documents are > 600 pages in length.[59]).

Best available techniques Reference documents (BREFs) were developed under the EC Directives for Integrated Pollution Prevention and Control (IPPC)[60] and Industrial Emissions Directive (IED)[61].

4.1.4 - TYPICAL ENERGY LOSSES AND EFFICIENCY CONSIDERATIONS BY INDUSTRIAL ENERGY CENTERS

4.1.4.1 - Motors and Drives

The consumption of electricity of drive systems depends on:

- motor efficiency factor
- proper motor size
- operational control
- electrical power supply quality
- mechanical gear transmission system/ratio
- maintenance practice
- energy efficiency of the driven end-device.

[59] There are also numerous guidebooks on the details within an Energy audit. Examples include:

1. "Industrial Energy Audit Guidebook: Guidelines for Conducting an Energy Audit in Industrial Facilities" Berkely College, USA 2010
2. "Applied Industrial Energy and Environmental Management", by Zoran Morvay, Dušan Gvozdenac including Toolbox 2: "Energy Auditing In Industry".

[60] IPPC Directive can be found at https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:334:0017:0119:en:PDF

[61] Directive can be found at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:334:0017:0119:en:PDF

The energy efficiency of drives and their components depends on the following key elements:

- Energy efficiency of motors (EEM)
- Correct design
- EE motor reparation (EEMR)
- Adjustable speed drive (ASD)
- Electrical power supply quality
- Lubrication, alignment, fine-tuning in operation and maintenance

There are different efficiency standards for asynchronous motors internationally. One of the most accepted guideline on this topic, which also the EU policy is based on in this field, is the International standard IEC 60034-30 (Rotating electrical machines – Part 30: Efficiency classes of single-speed, three-phase, cage-induction motors (IE code)). Low voltage asynchronous motors are grouped in new efficiency classes for IE - International Efficiency, including the following sub-groups:

- IE1(Standard efficiency)
- IE2 (High efficiency)
- IE3 (Premium Efficiency)

In addition to the selection of the efficiency class of the motor, the following energy efficiency measures can be applicable depending on industry and ability/willingness to invest:

<u>Low-cost measures</u>

- Shutting off motors during peak times of electricity demand (if this is acceptable for the consumer).
- Switch of consumption from high tariff time to low tariff time
- Changing from delta connection to star connection if the motor is over-dimensioned
- Using synthetic lubricants for large gearboxes.

<u>High-cost measures</u>

- Replacement of an old inefficient motor by a high-efficiency motor: Standard motors operating for more than 3,000 hours per year are good candidates for replacement with high-efficiency motors when they fail, and can achieve 3-7% efficiency improvement. Operational standard motors should be replaced with HE motors if they operate for over

6,000 hours/year. The decision should be supported with a detailed economic analysis. A transition from 82.5% to 90% efficiency can result in cumulative loss reduction of up to 38% from respective reductions in:

    - Stator losses
    - Rotor losses
    - Core losses
    - Friction losses
    - Stray load losses

  - Replacement of an oversized motor by an appropriately dimensioned new motor is an applicable measure if the maximum load of the driven equipment is significantly lower than the motor capacity (e.g. motor operates at <50%). If the motor is oversized, an appropriately dimensioned new motor is more efficient as part-load losses are lower.
  - Variable speed drives (VSD) - the use of VSDs in pumping systems, fans, mixers and compressors has shown substantial electricity savings and process improvements.
  - Soft starters (allow a smoother start and also allowing a higher maximum number of starts per hour - useful for motors with frequent starts and stops)

4.1.4.2 - Pumps and Fans

Pumps are used in industrial systems to perform a number of functions, such as follows:

- Material transport (e.g. water)
- Energy transmission (e.g. hydraulic press)
- Process-specific tasks (e.g. condenser, chemical process)

Pumping systems consist of subsystems including the pump itself, transmission (pipes, valves, etc.), a motor, and a controller.

- Replacement of inefficient motors
- Replacement of pumps with more efficient ones
- Optimization of impeller design
- Minimization of transmission losses
- Optimization of transmission
- Optimization of flow control

- No cost measures

4.1.4.3 - Boilers

Typical energy losses in boilers are found in waste heat in flue gases, radiation from boiler surface, incomplete burning of the fuel and excessive blowdown water. These are summarized by sources, their potential share in energy loss and their respective causing factors.

Sources	**Range**	**Factors**
Heat in flue gases Heat in moisture content of flue	from 8-35%	Exit temperature, excess air
Radiation from boiler surface	about 3%	Casing
Unburned gases		CO
Combustibles in ash	2-5% (coal)	Poor air distribution
Blowdown water	1-6%	Correct checking and maintenance

The main efficiency measures to reduce the energy losses from boilers, based on their cost-effectiveness, can be summarized as follows:

<u>Low-cost measures</u>

(payback time 0 to 2 years)

- readjustment of excess air of the burners to achieve optimum flue gas parameters
- retrofit of pipeline insulation
- repair of leakages
- repair insulation
- load management (avoidance of peaks and load variations)

<u>Intermediate-level cost measures</u>

- installation of an economizer
- installation of an air preheater
- installation of a new burner
- heat recovery from blowdown

<u>High-cost measures</u>

- replacement of the existing boiler by a new boiler

For industry operators, to maintain the boiler in its desired condition, the local energy manager and use the following checklist:

- Maintain efficient combustion
- Maintain good water treatment
- Repair water and steam leaks
- Recover heat from flue gas and boiler blowdown whenever possible
- Preheat combustion air with waste heat (watch out for NOx concentration increase)
- Ensure good operational control; consider sequence control for multi-plant installations
- Clean burners, nozzles, strainers etc.
- Attempt to match boilers to heat demand. Valve off idle boilers to reduce radiation losses
- Use flue dampers where appropriate to minimise flue losses when plant not firing
- Ensure that boilers and heat distribution systems are adequately insulated
- Blow-down steam boilers only when necessary or automate it
- Ensure as much condensate as practicable is recovered from steam systems
- Insulate oil tanks and keep steam or electric heating to the minimum required

4.1.4.4 - Heat Recovery

Depending on the type of industry, from 20 to 80% of the generated process, heat can be wasted. Common sources of waste heat in industry can be found in the following main areas:

- from exhaust air, e.g. rotary heat exchanger
- from flue gases, e.g. recuperator, economizer
- from hot products (before storing)
- from effluents

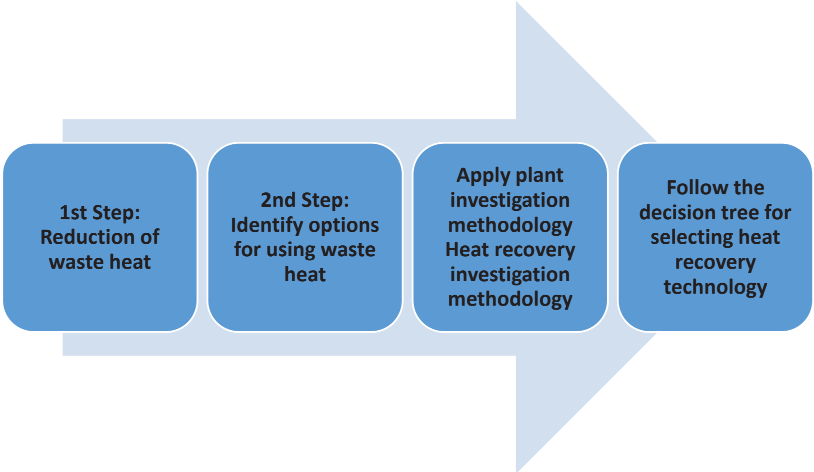
Some of the common heat-recovery sources are recovered hot air from processes, through heat exchanger systems (plate, rotary, heat pipes), refrigeration plant (utilization of condenser heat, heat from compressor cooling, heat in plant room from compressors and electric motors), waste water, boiler blowdown, compressor cooling water.

To improve the efficiency of energy use, the waste heat can be recovered and put to beneficial use in the following potential areas:

- Preheating of combustion air for boilers and furnaces

- Preheating ventilation air
- Hot water generation including boiler feed water preheating
- Space heating
- Drying
- Heating at industrial processes
- Power generation (CHP)

Once identified, to implement heat recovery measures, the following process should be applied.



A selection of heat recovery measures can be found in various engineering reference manuals. One such resource is the US Department of Energy's Guidebook on Technology and Opportunities in Waste Heat Recovery in Industry (https://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/waste_heat_recovery.pdf).

4.1.4.5 - Heat Storage

In addition to heat recuperation, heat storage can be applied as an energy conservation measure. Heat storage can be applied when there are peaks, pulses and/or modulation in heat demand, or there is a mismatch between heat and electricity demand (e. g. at concentrated solar power plants).

Applying heat storage can be a great energy efficiency solution since in the case of peaks, the capacity of the energy supply installation and respective capital expenditures can be decreased.

A pulsatory heat generation in order to cover pulsatory heat demand would be inefficient.

In the case of demand mismatch, a part of heat will be lost as it cannot be used. For more detail about Thermal Energy Storage see, for example, the Technology Brief by IEA-ETSAP and IRENA, which can be found at https://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E17%20Thermal%20Energy%20Storage.pdf.

4.1.5 - CRITERIA FOR DECIDING COST-EFFECTIVENESS OF EE OPPORTUNITY

The most commonly accepted and recommended criteria for deciding on the cost-effectiveness of selected EE opportunities is by following the below scheme:

1. Optimisation before Investment.
2. Recognize the high risk associated with long payback period.
3. Differentiate between simple payback vs. payback on marginal additional.
4. Explore other Financial Appraisal techniques.
5. Take into consideration future legislation and other drivers.

These are expanded upon in the text box below:

Decision-Making Tips for Prioritization of Energy Efficiency Investments

1. Optimisation before Investment:

   It is recognized good EnMS practice to first consider no-cost and low-cost EE opportunities prior to making investment decisions. Not only does this help optimise the process and the systems – reducing energy costs - it also means that later investment decisions are based on (a) an optimised system and (b) accurate data.
   No/low cost EE will also provide measureable energy-performance improvements, helping maintain the momentum of the campaign.
   Once the process or system is optimised, the demand from that energy center will be reduced. If an upgrade is still required, this would mean that the site needs to invest in a smaller (less expensive) unit.

   A good example would be compressed air: reducing misuses or leaks can easily save 20-40% of the generation requirements; if later it is agreed that the compressor itself needs replacing, then a smaller, less expensive unit can be specified.

2. High risk associated with long payback period:
   Normally, 5-year payback is considered reasonable. It is less risky, yet still leaves plenty of good investment decisions to be made.

3. Simple payback vs. payback on marginal additional:
   EE programs should treat "necessary" upgrades (for instance, older equipment that has to

be replaced, or upgrades needed to meet environmental legislation) differently from upgrades carried out simply to improve a site's performance. For "necessary" investments, payback on marginal investment should be used. The marginal investment is the additional cost over-and-above the minimum investment cost (of the basic unit) to do the job.

4. Other Financial Appraisal techniques:
   For larger investments, payback is not the best financial appraisal technique. Net present value, NPV, is a better metric. This sums up the total savings over the lifetime of an investment (discounting the cash value over time but factoring in energy inflation, etc), then subtracts the initial investment cost to end up with a figure of how much money the investment has saved to that point and over its life.
   It allows larger investment opportunities to show their true, long-term potential. A simple investment that offers a fast payback can offer much smaller total savings over the investment life, than a larger investment with longer payback but bigger annual savings.
   Prioritization would be better if it were based on the NPV over the investment life. Typically, the bigger the NPV, the better the investment. The ratio of NPV over investment cost gives an assessment of risk. If NPV/investment (NPV/I) is only a little over 0, then the savings will have paid back for the investment, but with only a small excess. If NPV/I > 1, then the investment will have paid for itself twice over during its lifetime, so it would be a relatively low- risk investment. Investors will need to agree a NPV/I value that they consider reasonable for investments.

5. Future legislation and other drivers:
   One always needs to look at future legislative or other drivers, for instance: projected unit energy costs over next 5-10 years, any value to CO_2 reduction. Both of these can significantly alter the situation.

4.2 - UTILIZATION OF ENERGY AUDITS TO IDENTIFY EE OPPORTUNITIES IN ENTERPRISES

4.2.1 - GENERAL

When reporting the results of the energy audit, the energy auditor shall:

- Ensure that the energy audit requirements agreed with the organization have been met;
- Identify the relevant measurements made during the energy audit, commenting on;
  - rationale for the measurements and how they contribute to analysis;
  - consistency, accuracy and repeatability of data;
  - difficulties encountered in data collection and field work;
- State clearly whether the results of the analysis are on the basis of calculation, simulation or estimation;
- Summarise the analyses, detailing any assumptions. Where possible, state the margin of error

and the limits of accuracy for both the savings and costs;

- Report the ranking of the EE/ RE/ WHR opportunities and, based on this, suggest recommendations and an implementation program.

This would be the basis of an Action or investment plan, - see "Audit report" below.

4.2.2 - AUDIT REPORT

The energy audit report shall cover the following topics:

(1) Executive summary

To cover:

- Background and rationale for the audit. This may include a description of the parent enterprise, how the site fits into the portfolio, what other sites are being audited;
- What the site makes: output, main process, largest energy centers, energy consumption and fuel split;
- Summary of details and ranking of EE (RE and other) opportunities for improving energy performance, generally based on the agreed investment criteria [It is recommended that these be presented as an "Action Plan" priority list – see "Conclusions and Recommendations" below.]

(2) Background/ introduction

Brief description / general information on:

- The parent enterprise;
- The site, why it was selected for auditing (if relevant), how it fits within the parent enterprise;
- The energy audit team and energy audit methodology, including what was done; [Details can be provided in an Appendix to the main report]
- Context of the audit and audited object(s);
- Any relevant legal and other requirements;
- Statement of confidentiality.

(3) Basic energy and production data

- Summary site energy data: total and fuel split;

- Summary site production data and product split;
- List of main energy centers and what they do;

(4) Observations made during site audit

Covering:

- The process as a whole, including layout and how it fits together, ideally with a schematic of the site processes;
- Energy management, including metering/sub-metering and how this data is used;
- The main processes/key energy centers – what was observed/measured;
- Main utilities and services such as CHP plant, boilers (hot water or steam systems), compressed air systems, etc.;
- Large fans/pumps/conveyors/etc.;
- Observations of staff behavior, energy-awareness, attitudes, etc.

(5) EE/ Energy saving opportunities

- Follows from the observations;
- Basis for the proposed implementation program; [Depending on the level of detail for the energy audit, this can include feasibility for implementation, action steps, etc.]
- Assumptions used for calculating;
  - costs of investment or implementation, and the resulting accuracy/margin of error;
  - energy savings and the resulting accuracy of calculated savings and benefits;
  - non-energy savings (such as reduced maintenance) or additional operating costs;
- Financial appraisal of the EE opportunity, including known financial incentives, such as grants or subsidies;
- Potential interactions with other proposed recommendations;
- Measurement and verification methods recommended for post-implementation assessment of the recommended opportunities.

(6) Conclusions and Recommendations, including Action Plan

- Follows from (4) and (5) above and is summarized in an Action Plan.
- It is recommended that these be presented as an "Action Plan" priority list. The priority will be based on the agreed criteria for evaluating the opportunities; for instance if payback were to be used, then the shorter payback opportunities will be the first, and the longer payback opportunities will be last.

  However, this order will be strongly influenced by:

  - Whether the opportunity is necessary: for instance meeting new legislation or replacing business critical kit that is reaching the end of its life;
  - Ensuring the existing system is first operating close to optimum. There is little point in investing in, say, a large pump or compressor if the size/power rating requirement can first be reduced through system optimization/leak reduction/ etc.;
  - Allocating a higher priority to "enabling" investments, such as sub-metering. These may not save energy per se, but enable effective energy management at the site and the proper monitoring and verification of larger EE investments.
- For major investments or business-critical investments, considering the costs and benefits over the whole life of the investment, not just the short-term benefits. As commented earlier, NPV would be a better investment appraisal technique, particularly for larger investments.
- The Action plan should make it clear which opportunities are:

  (1) Energy management: therefore important enabling steps for energy control and better understanding of energy consumption patterns.

  (2) No/low cost EE opportunities, including training/awareness and attention to staff behavior. These typically offer rapid payback, as well as better optimizing the process or system, therefore should be undertaken as soon as possible.

  (3) Investment opportunities that have been financially analyzed and meet or exceed the mandatory investment criterion, with a planned date for implementation. This date may depend on investment cycles and be when an existing technology or piece of equipment is due to reach the end of its serviceable life and is to be replaced.

  (4) Investment opportunities that need further investigation. These will mostly be larger investments that need detailed energy audits of the particular energy center, but which is

outside the scope (or ability) of the general audit team. Nonetheless, these opportunities will need to be logged as part of the audit findings for follow-up.

(7) Energy audit description

Note: this section would logically fit after the background, but is intended for information only to provide an idea of the activities undertaken and the robustness of the recommendations/action plan. Often, description of the audit activities are better placed in an Appendix, which can be referenced if required. The danger is that including audit description in the body of the report will bulk-up the report and the flow can be lost.

The audit description should cover:

(1) Scope, boundary, audit objective, timeframe, level of detail;
(2) Data collection information, including:
 - Measurement plan
 - Statement about data used (if estimated, calculated or measured and, if measured, the acquisition frequency);
 - A copy of key data, test reports and equipment calibration certificates;
(3) Analysis of energy performance and energy performance indicator(s);
(4) Basis for calculations, estimates and assumptions;
(5) Criteria for ranking opportunities for improving energy performance.

PART 3: WATER FOR SUSTAINABILITY AND RESILIENCE

CHAPTER 5. WATER POLLUTION: PREVENTION AND MANAGEMENT

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5.1 - WATER QUALITY AND WATER POLLUTION

The notion of "water quality" is highly dynamic and constantly changing, depending both on new knowledge in the individual scientific water management disciplines and also on the overall situation of human society. Politics, social awareness, economics and legislation play very important roles in the area of water quality protection. This can also be demonstrated by the new dimension in the area of water protection which came about when EU Directives in water protection were adopted. From the economic perspective, the adoption of EU Directives and their implementation in practice will require substantial funds, but on the other hand, they will raise water protection to a higher level.

Water quality is construed as affording the possibility of using water for the required purpose. However, the purpose itself is neither precisely defined nor essential. In practice, this means that it is not the chemical purity but its usable properties that determine the quality of water. For instance, distilled water can be used as accumulator filling, etc., but it is not suitable as drinking water. Conversely, drinking water is not suitable as accumulator filling. Hence, what is an inappropriate component of water (e.g. minerals) in one case is precisely the desirable component in another.

It is necessary to bear in mind that, if achieving or maintaining a good water status is the purpose of water use (see the definition, for instance, in WFD 2000/60/EC), it is also necessary to take into account the degree of toxicity for water organisms, or organisms bound to aquatic ecosystems, as well as the degree of toxicity for the environment in general.

It is also necessary to realise that the notion of water quality is a relative notion, i.e. it changes in time and space.

Water protection is considered to be a basic water management activity toward which most of the activities performed in water management are directed. The integrated protection of water resources, which currently constitutes one of the limits to the development of human society, is the goal of this activity.

Politics and economic interests may also play a negative role in the area of water protection. Economic forecasters predict that, just as there currently are wars for oil, in the future there will be wars for water, which is becoming a restricting factor on the development of society in some locations, due to the depletion or deterioration of water resources.

The statement that life is not possible without water sounds like a platitude but it nevertheless remains valid. However, it should be added that life is not possible without *good quality* water, i.e. without water meeting the requirements for its use in terms of its quality – either as drinking, utility, irrigation or other water. Thus, water quantity and quality become the basic parameters of the utility value of water; this can be expressed as the resultant product of these two parameters. Hence, if one of these two parameters (water quantity or quality) is zero, the total utility value of the water is also zero (there is more water in a small pure spring that in a dirty river).

The role of water managers is not to maintain water in nature in an absolutely pure condition; after all, that is probably not even possible (with the exception of areas with strict nature and landscape protection). Their role in terms of sustainable development is rather to maintain water quality at an adequate level, i.e. at such a level as to ensure the exploitation of water resources for the required purpose, or to ensure universal water protection, including aquatic ecosystems and ecosystems dependent on water, the improvement of water status and the effective and economical utilisation of waters. It is necessary to recognise that the requirement of "returning to the original state" is no longer feasible today, not to mention that it is not possible to define the "original state" of waters.

The development of human society over the centuries has also led to pressure on water quality protection, not only in order to ensure basic human requirements (drinking water) but also to utilise water in other spheres of human activity (industry, recreation, urban sanitation, etc.). At the turn of the 19th and 20th centuries, water managers virtually became some of the earliest protectors of nature and also users of biotechnologies (waste water treatment processes). The traditional philosophy was based on the principle of *protecting man from nature*. The increased sensitivity of the population to essential nature protection and the popularisation of environmentally-friendly perspectives have also been reflected in the ambit of water protection, hence in the introduction of a new concept of nature protection. That means that new, opposing opinions of environmental protection prevail today, as well as the related requirements of *protection of nature against man*.

5.1.1 - EUROPEAN WATER CHARTER

The European Water Charter was one of the first documents adopted jointly within the European Community. It was prepared by the European Committee for the Conservation of Nature and Natural Resources of the Council of Europe and adopted on May, 6th 1968 in Strasbourg. The Water Charter defines the basic principles of water protection and management that were later reflected in the overall EU policy.

I. There is no life without water. It is a treasure indispensable to all human activity

II. Freshwater resources are not inexhaustible. It is essential to conserve, control, and wherever possible, to increase them

III. To pollute water is to harm man and other living creatures which are dependent on water

IV. The quality of water must be maintained at levels suitable for the use to be made of it and, in particular, must meet appropriate public health standards

V. When used, water is returned to a common source it must not impair the further uses, both public and private, to which the common source will be put

VI. The maintenance of an adequate vegetation cover, preferably forest land, is imperative for the conservation of water resources

VII. Water resources must be assessed

VIII. The wise husbandry of water resources must be planned by the appropriate authorities

IX. Conservation of water calls for intensified scientific research, training of specialists and public information services

X. Water is a common heritage, the value of which must be recognised by all. Everyone has the duty to use water carefully and economically

XI. The management of water resources should be based on their natural basins rather than on political and administrative boundaries

XII. Water knows no frontiers: as a common resource, it demands international co-operation.

5.2 - EU LEGISLATION IN THE AREA OF WATER PROTECTION AND ITS BASIC PRINCIPLES

In this chapter, we explain the basic principles of EU legislation related to water protection.

With regard to the scope of the individual legal documents, we may divide EU legislation into two basic groups: the so-called horizontal legislation which covers the entire environmental area (e.g. EIA, nature and landscape protection regulations, etc.) and the so-called vertical (specific) legislation which is focused more on the individual components of the environment (e.g. water, soil, air quality protection, etc.).

The EU legal system in the area of water protection uses the following three forms of legislative documents:

- Directive;
- Regulation;
- Decision.

An EU Directive expresses an endeavour to introduce common legal norms whereby, however, it is possible to maintain traditional practice and adapt to the degree of development in the given countries. A Directive is a legal document which does not take precedence over the legislation of a Member State. However, Member States are required to "indirectly" apply a Directive, i.e. to apply the principles of the Directive which have to be absorbed into the legislation of the given Member State. However, the principle is that a Member State may adopt measures going "beyond the framework" of the respective Directive, but it must not adopt less strict criteria than those stipulated by the given Directive. To date, within the EU only Directives are being applied in water management. Absorbing the principles of EU Directives into the national legislation is referred to as transposition of the law; implementing the adopted measures is referred to as implementation of the law.

An EU Regulation is a generally valid legislative document directly applicable within the territory of all Member States. From the legal perspective, a Regulation takes precedence over national law.

A decision is a highly specific legal document, directly binding only for those for which it is determined. It is usually issued only when one of the Member States violates the provisions of EU legislation; it can be compared to a court decision.

It is evident that harmonisation of the legislative requirements of EU Member States is quite a demanding role, due not solely to differences of opinion on environmental protection, but largely due to the varying levels of protection in the individual Member States, which are related to the levels of economic and social development. That is why the EU bodies adopted the principle of the so-called "lowest common denominator", i.e. of the primary determination of the minimal environmental protection requirements which are common and acceptable to all Member States. Following approximation and implementation, these minimal requirements will be increased incrementally until they achieve the target status (protection level) common for all Member States.

EU environmental legislation recognises the following common principles:

- Environmental protection must not infringe on the protection of the EU internal market, nor constrain competition within the EU;
- Prevention is emphasised;
- The greening of economy, social policy (ultimately, of all activities);
- The polluter pays principle (PPP);
- Harmonisation and unification of Member States' legislation;
- Right of citizens to information on the status of the environment.

In addition to the above principles, specific principles also apply to water management and water protection. We list at least some of these principles here:

- Payment of all costs incurred by activities in the area of water management (WM must be self-fundable);
- Management of water-management activities based on natural river basins;
- Achievement (or maintenance) of the so-called good status of water bodies within the EU.

5.2.1 - WATER FRAMEWORK DIRECTIVE (WFD, 2000/60/EC)

The Water Framework Directive (WFD, 2000/60/EC) is the basic legislative document for water quality (but also for the entire EU water management policy).

The WFD introduces a new approach to water management based on river basins, natural geographical and hydrological units; it imposes specific deadlines on EU Member States to develop river basin management plans including programmes of measures. The new approach to water protection makes it possible to create a unified system for water evaluation within the EU Member States, affording reliable and comparable results of the condition of water bodies in any European region, as well as the same procedure for the determination of objectives and implementation of all necessary measures for the protection and improvement of water status. The WFD deals with surface waters (rivers, lakes), transitional, coastal waters, groundwaters and, under certain specific conditions, also terrestrial ecosystems dependent on water and wetlands. The WFD introduces several innovative approaches into water management, such as public participation in the planning, the integration of economic approaches into the planning and integration of water management with other economic sectors.

The main objective of the WFD is to achieve the so-called "good status of waters" in Member States, which will ensure the protection and improvement of the state of aquatic ecosystems and sustainable, balanced and equitable water use. This status should have been achieved by 2015, or 2027.

The European Commission developed a basic document for the EU Member States – the WFD Common Implementation Strategy adopted by the Member States in May 2001. This Strategy is regularly updated at two-year intervals for the subsequent period.

5.2.2 - COUNCIL DIRECTIVE 91/271/EEC CONCERNING URBAN WASTE WATER TREATMENT

The main objective of this **Directive** concerning urban waste water treatment is the protection of aquatic ecosystems from the adverse effects of discharges of untreated or insufficiently treated urban waste water.

The requirements of this Directive can be characterised as follows:

- The requirement to build a public sewage system and two-stage waste water treatment in agglomerations of over 2,000 p.e. (population equivalents);
- Each discharge of waste water must be permitted by the respective authority;
- More stringent criteria in agglomerations of over 10,000 p.e., in the food industry and in sensitive areas – elimination of nutrients – nitrogen (N) and phosphorus (P);
- Permits for waste water discharges are subject to review;
- Emphasis on the reduction or disposal of pollution at the point of origin, reuse of treated water;
- Sludge must not be disposed of to surface waters, and it should be recycled.

The emission requirements of Directive 91/271/EEC on Urban Waste Water Treatment are complemented by qualitative – immission water protection requirements which are formulated in the related directives, mainly:

- Directive 76/160/EEC concerning the quality of bathing water;
- Directive 75/440/EEC concerning the quality required of surface water intended for the abstraction of drinking water;
- Directive 78/659/EEC on the quality of fresh waters requiring protection or improvement in order to support fish life.

Based on the requirements of this Directive, it is quite evident that the implementation of these requirements requires major measures and costs, mainly investments in the construction of new sewage systems and waste-water treatment plants (WWTP), and in the renovation of the existing systems and reconstruction of existing WWTPs (alteration of technologies to extended disposal of bionutrients).

5.3 - WATER POLLUTION SOURCES, POLLUTANTS, TOXICITY

5.3.1 - POLLUTION SOURCES

Any activity or phenomenon resulting in a deterioration in water quality is a source of pollution. Based on the geographical form, each water pollution source can be divided as follows:

- **Point sources** (sewage system outflow, oil spillage, etc.);
- **Line sources** (transport structures or pipelines, etc.);
- **Diffuse sources**;
- **Areal sources** (e.g. agricultural pollution – fertilisers, pesticides, herbicides, exhaust gases, precipitation, etc.).

Significant water pollution sources are usually included in tabular or map form in the basic water management land-use planning documents.

A point source of water pollution is a pollution source with a concentrated input of pollution into waters which is limited to a relatively small area or almost confined to a single geographical point. These pollution sources are usually precisely quantifiable; it is usually easy to monitor them, and the impact of every individual source can be accurately determined. As a result of diffusion and transport of the pollutant, a line or areal contamination of groundwater or surface waters can occur.

Line sources of pollution usually represent leaks of pollutants along transport and traffic structures, such as highways, railways, or along other transport facilities (oil pipelines, large sewage collectors, etc.).

In the literature, **diffuse sources** of pollution are usually understood as several point sources of pollution together, whereby it is not possible to determine the impact or effect of the individual (point) source. A typical example would be a municipality with leaking cesspits or septic tanks which, in combination, act almost as an areal source of pollution but where, in this case, there are several point sources of pollution.

Areal sources of pollution are those where the pollutant is input over a large area. It is usually not possible to quantify the pollutant, nor to accurately demarcate the point of penetration of the pollutant. In these cases, this is primarily groundwater pollution. Agricultural activities are a typical example – e.g. aerial application of fertilisers, pesticides, etc.

5.3.2 - POLLUTANTS, PRIORITY AND HAZARDOUS SUBSTANCES

As stated in the above definitions, a pollutant is understood as a substance capable of causing pollution which can jeopardise the quality or health integrity of waters. This definition appears to be relatively loose and imprecise. Currently, a large number of substances and chemical substances meeting this definition are registered. All of these substances cannot be exhaustively named in legislation; hence, the legislation focuses rather on the description of the properties of these substances (mainly toxicity, bioaccumulation, biodegradability), or it names only the basic groups of pollutants, groups of hazardous or priority substances.

A priority substance is a substance which represents a significant risk for the aquatic environment or via the aquatic environment; such substances include priority hazardous substances which are toxic, persistent and capable of bioaccumulation.

Toxicity is the ability of a substance to cause considerable negative impacts on organisms even in small quantities or concentrations; persistent substances are those that have the ability to persist in the environment, are exceptionally stable and effectively are not degradable. These substances are usually not very volatile and generally tend to accumulate in live organisms and in the environment.

5.3.3 - MICROPOLLUTANTS

Currently, research teams focus their attention on the effects of various types of pollution which can occur in waste water, on so-called micropollutants. These substances are often found in minuscule quantities but are nevertheless capable of negatively affecting the biocenosis in the recipients. There are various types and groups of substances such as drugs, medicaments, hormones, various specific substances with toxic, persistent or bioaccumulative properties, or even various residues or metabolites of these substances.

There are several factors contributing to this interest in micropollutants such as, for instance, a change in the composition of waste water due to the use of a wide range of chemical preparations in households, in industry, an increase in the consumption and availability of medical drugs and medicaments, hormonal preparations, etc. Naturally, even the development and possibilities of their detection play a role in the increased interest in these substances – currently, we have the capacity to detect many substances at the level of $ng.l^{-1}$ (Mackuľak, Bodík, & Birošová, 2016).

Unlike macropollutants which constitute the prevalent part of pollution in ordinary urban waste water, micropollutants are not usually readily degradable by the technologies in current use. That is because present urban waste water treatment technologies are focused on the elimination of the macropollution contained in urban waste water – biodegradable organic substances (e.g. sugars, fats, proteins) or bionutrients (eutrophic substances, nitrogen and phosphorus compounds).

Many studies (e.g. (Mackuľak, Bodík, & Birošová, 2016)) examining the incidence of these substances as a function of the water basin size and nature, customs of the population, presence of large producers of these substances (e.g. hospitals, illegal drug production), but also of the season of the year (psychoactive substances, psychopharmaceuticals occur mainly in the winter months), days of the week (so-called "weekend drugs") or events in the river basin of the WWTP (music festivals), were developed with regard to the concentration of micropollutants in waste water or the WWTP effluent. The concentrations of the above micropollutants in waste water frequently differ in comparing neighbouring districts, not to mention other countries or even continents. However, the *effluent from waste water treatment plants* can generally be considered to be a *continuous source of pollution* of surface waters with micropollutants. It is estimated that up to 70% of the total amount of the active substance of medicaments, drugs and their metabolites is excreted from the organisms in an unchanged form into the urban waste water. Several factors affect the treatment plant's effectivity in the elimination of these micropollutants but, all in all, it may be stated that the effectivity of elimination is low and it is a more or less random or by-process of biological treatment.

Accordingly, intensive research into the possibilities of the reduction of the individual types of micropollutants is currently underway. The aim is to identify simple and relatively universally applicable methods that could degrade complex micropollutant molecules to smaller or simpler molecular fragments in order to render these fragments relatively harmless or to subject them to further degradation. Thereby, various technological procedures are utilised, from the simplest adsorption through membrane reactors, the Fenton reaction, ozonisation, heterogeneous catalysis, ultrasound, UV radiation, as well as aquatic plants (see Mackuľak, Bodík, & Birošová, 2016).

The overwhelming majority of medicaments and drugs occur in incrementally lower concentrations in rivers than in the WWTP effluents. The main reason for this phenomenon is dilution by surface waters. These compounds can be degraded by means of micro-organisms and their communities directly in the water or in the river sediment or abiotically, or by various combinations thereof. The microorganisms found in rivers are able to effectively degrade some types of medicaments and drugs into smaller molecular fragments. In addition to *biodegradation,* direct and indirect *photodegradation* can also occur in surface waters. The decomposition of compounds is also affected by the *intensity of solar radiation* over the course of the year and the location in which the given molecule in the river is at the moment. Radiation is less intensive in the deeper parts of the river course as it is absorbed by water molecules and the quantity of compounds present. Medicaments and drugs are degraded in rivers mainly by the *radical mechanism* via singlet oxygen or hydroxyl radical (Mackuľak, Bodík, & Birošová, 2016).

5.3.4 - ACTION AND EFFECTS OF POLLUTANTS AND PRIORITY SUBSTANCES, TOXICITY

The adverse effects of pollutants and priority substances may be manifested:

- directly in the water (**disruption of the biocenosis**);

- **by acting on higher organisms** (plants, animals, humans).

The pollutants in water directly affect the water course biocenosis; hence, it is necessary to determine limits for the discharge of these substances, i.e. such concentrations of these substances that do not disrupt the water course biocenosis (not even in the short term). The effects these substances have on higher organisms mean that these substances may not have a direct effect on the water course biocenosis or can be harmless for lower organisms, but in migrating and being transported, they enter the bodies of higher organisms where their adverse effects can be manifested and may disrupt the functions of these higher organisms.

The acting mechanism of pollutants (toxic substances) based on the time period may be divided as follows:

- **Acute** toxic substances
- **Cumulative** toxic substances

Acute toxic substances are substances with negative effects on organisms manifested within a short time horizon, i.e. in hours or days at the most. Cumulative toxic substances are usually those substances which the organisms find difficult to expel, and they accumulate in the organism. Accordingly, the negative effects on organisms are usually manifested after achieving a certain quantity (concentration) of the given substance in the organism; they are usually long-term (chronic).

Currently, the notion of xenobiotics is often used in toxicology for a certain group of toxic substances – these are all substances which are foreign to living organisms and are able to cause poisoning of the organisms.

The adverse effects of toxic substances (toxicity) on organisms themselves may be defined as:

- **terminal** toxicity;
- **replication** (self-replicating) toxicity.

Following the exposure of the organism, terminal toxicity has an immediate effect which is proportional to the intensity of the exposure and usually ends with serious damage to the vital functions or with the death of the organism. By contrast, replication toxicity is toxicity with an effect deferred by a significant part of the length of life of the organism; it might be manifested only in the new generation of organisms (mutagenic effects). Many substances acquire replicating toxic properties only after biotransformation, hence after passing through the organism.

The general effects of toxic substances on higher organisms may be summarised as follows:

- **systemic** (damage to organs);
- **irritative** (corrosion);
- **suffocating** (suffocation, blockage of blood pigment);
- **allergies** (sensitivity to certain substances);
- **mutagenic** (hereditary changes);
- **carcinogenic** (cancer);
- **teratogenic** (morbid changes in the prenatal phase of development of higher organisms).

With regard to toxic substances, their monitoring and evaluation currently represent very important tasks, as we are frequently unable to calculate the long-term effects of some substances currently in use in industry, agriculture, food industry, etc. The diversity of the effects of these substances in a certain combination (so-called synergism – the enhanced effect of several toxic substances when acting mutually, or antagonism – the reduced effect of several toxic substances when acting antagonistically) or the impacts of the biotransformation of substances are also a problem. The whole issue is concisely characterised by a statement used in pharmacy: "the difference between medicine and poison lies in the dose."

5.3.5 - EUTROPHICATION, PROCESSES

Nitrogen (N) and phosphorus (P) are classified among the basic biogenic elements, but their presence in waters may cause technical, technological, sensoric and health problems, depending on the form of their incidence and concentration. The eutrophication of waters with all its negative consequences represents a global problem relating to the incidence of these elements.

Eutrophication is understood as the enrichment of water with nutrients, mainly nitrogen and phosphorus compounds, leading to an increased growth of cyanobacteria, algae and higher aquatic plants which may result in an undesirable deterioration in ecological stability, reduction of biodiversity and water quality. Hence, eutrophication is a set of natural and artificially created processes leading to an increased concentration of biogenic elements (predominantly forms of nitrogen and phosphorus) in waters and soil. An increased nutrient content and favourable climatic conditions support, especially in stagnant and slow-flowing waters, the excessive development of the biomass of lithotrophic organisms, i.e. cyanobacteria, algae and macrophytes (of higher vegetation). The increased intensity of the biological processes and the subsequent decomposition of the dead phytomass, the emerging algal bloom or vegetative coloration of water negatively affect the water quality and its use for drinking and utility purposes, as well as for recreation (bathing). Eutrophication is linked with oxygen consumption, with the production of substances that are toxic for aquatic organisms and substances causing health problems in humans. Eutrophication also threatens water courses but occurs predominantly in water reservoirs. These are the main symptoms of eutrophication:

- an increase in nitrogen and phosphorus concentrations;
- an increase in chlorophyll concentrations;
- an increase in the quantity (biomass) and production of algae and cyanobacteria (phytoplankton);
- a reduction in water transparency (Secchi disk depth);
- an overall decrease in water quality (sensoric properties of water);
- a decrease in oxygen concentrations in lower layers of water (hypolimnion).

The multiplying diatoms and algae cover the surface of surface waters and drain the oxygen from the water. This lack of oxygen, in turn, causes the death of algae and other living organisms. The decomposition of the dead matter adds further organic nitrogen, phosphorus and many other elements to the water, but their mineralisation further reduces the oxygen in the water.

Accordingly, a vicious circle ensues in which organic substances accumulate in the water, but the oxygen decreases to such an extent that aerobic mineralisation is transformed into anaerobic decomposition. Hydrogen sulphide and ammonia emerge in the process of the decay and fermentation, the water becomes turbid and smells unpleasantly, and fish and other animals die. (Čermák, 2008)

Eutrophication is supported by:

- long water retention;
- thermal stratification of stagnant waters (lakes and reservoirs);
- temperature and light.

The first condition supporting eutrophication – the water retention period – is purely physical. Water retention can change dynamically.

The other physical factors that might affect eutrophication are the thermal stratification of stagnant waters (lakes and reservoirs), temperature and light. Thermal stratification may also be caused by the differing density of the water layers which occurs in lakes or even in slow-flowing rivers – the upper and lower layers do not mix. An increase in water temperature and improvement in the light conditions in spring and summer could explain the phenomenon of eutrophication found mainly in these two seasons. However, the eutrophication process itself is also influenced by the permeability of the water for light penetration, as the growing algae cast shadows and negatively affect photosynthesis in the deeper water layers and, hence, also the growth of aquatic macrophytes at the bottom. (Zatkalík, 2004)

Eutrophication especially affects the oxygen availability for aquatic organisms. If a huge amount of biomass is accumulated, all the oxygen available is consumed in the oxidation of the organic mass created in the sediment at the bottom of the water body. Some bacteria even utilise the oxygen contained in sulphates (SO_4^{2-}). This process releases sulphur (S^{2-}) which immediately combines with the oxygen still present in the upper water layers. In this way, the water is gradually deprived of oxygen, and all aerobic life disappears from it. In such a situation, the water starts to rot and sulphuric gases with the typical stench of rotten eggs are released. (Čermák, 2008)

Along with these changes in the oxygen concentration, other changes in the aquatic environment can also be observed (Čermák, 2008):

- **Changes in the algal population.** During eutrophication, macroscopic algae, phytoplankton (diatoms, green algae) and cyanobacteria, dependent on the supply of nutrients, light, temperature and water movement, start to proliferate. Some of these organisms may release toxins into the water or may contain toxins directly in their bodies.
- **Changes in the zooplankton**, **fish and mollusc populations**. If eutrophication occurs, changes are first observable in this part of the aquatic ecosystem. These organisms are acutely sensitive to oxygen availability, and should there be a lack thereof, they die—or else they die due to alterations in the chemical composition of water (e.g. the toxicity of ammonia increases at a higher level of pH).

A further problem of eutrophication is the ability of some cyanobacteria to create toxins, i.e. bacterial toxins of animal or plant origin. Toxins seriously threaten human health and even that of farm animals and other animals. Toxins are either found in the cyanobacteria cells (70 to 90% of the total amounts of toxins in young cells are bound in the cell), or they are released from cells into the water (in older cells the share of free toxins can amount to 70%), especially after they die. The elimination of free toxins from water during the purification to drinking water quality is very costly. It is more convenient to eliminate the cause of the increase in the toxin concentration, i.e. the increase in cyanobacteria.

People may be exposed to toxins after drinking contaminated water, in direct contact with water or by inhaling aerosols. Human and animal organisms are damaged by toxins at the molecular level with subsequent damage to cells, tissue and organs. The nervous, digestive and respiratory systems and skin may be affected. Secondary damage may also affect other organs. The age and overall health condition of the affected individual influence the extent and severity of the damage. Toxins can induce a whole range of symptoms, starting with lethargy and headaches, followed by diarrhoea, vomiting, sore throat, fever and skin irritation, conjunctivitis, allergic reactions, bladder inflammations, gynaecological problems. Some cases of acute poisoning may have a lethal effect. (Fargašová, 2007)

As stated above, eutrophication processes are most pronounced in water reservoirs. The eutrophication of such waters may lead to an impairment of their quality and debar them from recreational use. National legislation stipulating the requirements for natural bathing areas may set the limit value for the concentration of “chlorophyll a” (e.g. 50 $\mu g.l^{-1}$). In addition, the presence and number of cyanobacteria capable of creating an algal bloom affords a similar criterion for assessing the suitability of water for bathing, where the limit value is 100,000 cells per ml of water. That is why natural water reservoirs used as bathing venues are regularly monitored by the competent public health (hygiene) authorities which regularly publish the monitoring results. If any of the limit values are exceeded, the competent authority declares the water body in question to be unsuitable for bathing, erects information boards and informs the public.

A plain transparent glass is all that is needed to indicatively determine the presence of dangerous cyanobacteria or other algae in the water. It is necessary to extract a sample of water from the natural swimming venue into a glass and to allow the sample to stand for about 20 minutes to 1 hour. If a continuous green film forms on the surface, that means that there are cyanobacteria in the water; if no film is created but a column of dispersed green particles can be observed, other algae are present in the water. The colour of the ring depends on the type of cyanobacteria, but it is usually green. If the water in the glass is turbid and a sediment is formed at the bottom, then algae are present in the lake. It is also necessary to simply visually evaluate the turbidity of the water. Sometimes the mass growth of cyanobacteria can also be seen with the naked eye – there are green films visible on the water at the shore. If the outbreak is extensive, an algal bloom is created on the water surface, and the condition becomes even more dangerous. Something that resembles plant detritus forms on the water surface.

5.4 - PROTECTION OF WATER RESOURCES

5.4.1 - INTEGRATED PROTECTION OF WATER RESOURCES

In accordance with the EU Water Framework Directive, the protection of water resources in use or resources prepared for use to meet a water management need should be construed as the **integrated protection of quality and quantity** of groundwaters and surface waters. The issue of the sources of water pollution, with either direct or indirect impact on water resources, is the decisive factor in the protection of water resources' quality. (Hyánek et al., 1991)

The protection of water quantity, the so-called **quantitative** protection is based on increasing the accumulative capacity of the land and on the control of the observance of values calculated for the quantities of water extracted. For this purpose, limits on the use of groundwater resources (ecological limits) and binding minimal flow levels (ecological flow levels on water courses) are determined based on the principles of surface water management in the individual river basins.

Qualitative protection, i.e. water quality (purity) protection is based on maintaining the possibility of utilising the water (water resources) for the required purpose. Accordingly, the objective is not to totally restrict the transport of pollutants into the waters, but to maintain their quantity and concentration at such a level that the long-term utilisation of water is rendered possible (MŽP SR, December 2015).

5.4.2 - FORMS AND METHODS OF WATER PROTECTION

Both aspects of water protection, qualitative and quantitative, come under the aegis of the so-called system of territorial water protection, especially in significant resource areas in terms of water management. The system comprises three types of protection:

- general protection, ensuing from the Water Act (**general legislative protection of water**);

- broader protection – regional protection implemented in the form of protected water management areas;
- more stringent special protection – the so-called narrower protection of water resources utilised for drinking purposes implemented mainly in the form of hygienic protection zones.

5.4.3 - LEGISLATIVE PROTECTION OF WATERS

The general protection of waters and water resources is applied in full over the entire territory of the state without the need for any further measures on the part of the Government or water management authorities.

The requirements relating to the general protection of groundwaters and surface waters are implemented by provisions in the law which stipulate that the water users are to pay heed to the protection and purposeful utilisation of water; the law further stipulates that, when generally using waters, their quality or hygiene and safety must not be threatened or impaired, or the environment damaged.

Owners or users of agricultural or forest land and ponds are obliged to manage these resources in such a way as to not only maintain suitable water management conditions in terms of water quantity and quality, but also to even enhance these conditions.

The protection of surface and groundwater quality is specifically emphasized by the obligation, imposed by law, to dispose of discharged waste water so as not to threaten or impair the quality of surface or groundwaters.

As for water quality, the Government may issue an ordinance of a lower level complementing the general Water Act which shall stipulate the indicators for an admissible degree of water pollution and limit the concentrations of pollution in the discharged waste waters. The values of admissible water pollution indicators are then provided separately for the individual types of water bodies.

Hence, the general protection of water resources is, in practice, reflected in the obligations imposed on all those who handle and deal with waters.

5.4.4 - TERRITORIAL WATER PROTECTION

In compliance with the water protection legislation valid in the given country, the territorial protection of waters usually defines the following types of protected territories:

a) Protected water management areas;
b) Sensitive areas;
c) Vulnerable areas;
d) Territories with surface water designated for the extraction of drinking water;
e) Territories with water suitable for bathing;
f) Territories with surface waters suitable for the habitat and reproduction of indigenous fish species; and
g) Protected territories and their protective zones pursuant to specific regulations.

5.4.4.1 - Broader Territorial Water Protection

Protected water management areas are territories in which surface and groundwaters are naturally accumulated as a result of favourable natural conditions and, accordingly, the Government of the respective state may declare them to be a Protected Water Management Area (PWMA) in the law.

As these are areas with decisive significance with regard to the creation of water resources, their protection is secured within a broader context in connection with the natural conditions, emphasising prevention against jeopardizing the creation of water resources and against interventions in the natural hydrological cycle with any negative impacts on their quality and quantity. For this reason, the production, non-production and other interests in the PWMAs must be harmonised with PWMA requirements at the stage of developing territorial development concepts and territorial-planning documentation.

Those surface water bodies are considered to be **sensitive areas** which are at risk of impairment of water quality by eutrophication due to a higher concentration of nutrients or where the water quality is already impaired, especially if these water bodies are intended for use as water resources. This also entails those water bodies that require a higher level of treatment of the discharged waste water. Hence, these are waters that have an impaired quality or that are potentially at risk in respect of two indicators – total nitrogen (N_{tot}) and total phosphorus (P_{tot}), due to discharges of untreated or insufficiently treated urban waste waters. That is why it is necessary to ensure a higher level of urban waste water treatment in sensitive areas, such as secondary treatment. With regard to the quality of waste water discharged from agglomerations with over 10,000 population equivalents (p.e.) in sensitive areas, there is a requirement that waste water treatment plants must also have biological treatment for the elimination of nutrients.

Legislation relating to sensitive areas should also stipulate the criteria for the identification of a water body as a sensitive area, even in those cases where these are water bodies that already are or may become eutrophic if protective measures are not taken against these trends.

Water bodies used or utilisable as water resources (i.e. resources determined for supplying the population with drinking water) are also classified as sensitive areas regardless of the concentration of nutrients in them, with regard to possible eutrophication. Directive 91/271/EEC stipulates the general requirements for the discharge and treatment of urban waste waters and, in addition, the requirement of the protection of recipients from an increased nutrient load (nitrogen and phosphorus) in sensitive areas.

All surface water bodies located within the territory of the given state or flowing through this territory could be stipulated as sensitive areas (e.g. the entire territory of the Slovak Republic was determined to be a sensitive area).

Territories used for agriculture are deemed to be **vulnerable areas** when rain water flows into surface waters or infiltrates groundwaters and when they already have a concentration of nitrates in groundwaters higher than 50 $mg.l^{-1}$, or when that level could be exceeded in the near future.

The criterion for the identification of vulnerable areas is, in particular, the fact that surface or groundwater for drinking purposes already contain or may contain a higher concentration of nitrates than that stipulated in a special regulation, the so-called Nitrates Directive (91/676/EEC).

Water is protected against nitrate pollution from agricultural sources, in particular, in territories used for agriculture, by taking the necessary measures in the warehousing, handling and application of natural and industrial fertilisers and by appropriate land cultivation methods (the so-called Code of Good Agricultural Practice).

Groundwater bodies used for the abstraction of water for drinking water purposes or utilisable for supplying more than the number of persons as defined by legislation (e.g. 50 persons), or enabling water abstraction for such a purpose in a quantity greater than the defined limit (e.g. 10 m^3 per day) are considered to be protected "territories with surface or **groundwater intended for the extraction of drinking water"**.

Waters intended for bathing are natural expanses of water with a long-term satisfactory quality of water and a historically high number of visitors. Pursuant to a specific regulation, any surface water can be declared to be a bathing water venue which is used by a large number of bathers and for which no permanent bathing ban or permanent recommendation not to bathe has been issued. The number of bathers is assessed by the Public Health Authority with regard, in particular, to past development, the built infrastructure or facilities and measures taken in the past to support bathing. A natural swimming venue is a designated natural expanse of water used for bathing and the related operational surfaces and facilities which have an operator.

These water bodies are usually classified as protected territories with predetermined environmental objectives. The quality indicators appropriate to water suitable for bathing, their limit values and extent and the frequency of checks are stipulated by national legislation. The list of water venues suitable for bathing is published by the competent state water administration authorities or by lower-level legislation.

Qualitative objectives of waters suitable for the **life and reproduction of indigenous fish species** are determined separately for the individual water zones (e.g. salmonids, cyprinids zones, etc.). The individual limit quality indicators of these waters and also the recommended values of the surface water quality indicators, including the minimal number of samples to be taken and the measurement frequency, are stipulated in the respective legislation.

In the territory of EU Member States, the NATURA 2000 European system of protected areas, amongst others, is used for the protection of animal and plant species; this system is implemented by way of national nature and landscape protection legislation.

NATURA 2000 designates the system of protected areas in European Union Member States which should ensure the protection of the rarest and most threatened wild flora and wild fauna and natural habitats found within the territory of EU Member States and, via protection of these species and natural habitats, also ensure the maintenance of biodiversity throughout the entire European Union.

NATURA 2000 comprises two types of protected areas:

- Special Protection Areas (SPA) which are declared on the basis of Council Directive 79/409/EEC on the Conservation of Wild Birds – protected bird areas;
- Special Areas of Conservation (SAC) declared on the basis of Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora – protected areas of European significance.

We may cite the system of nature and landscape protection implemented in Slovakia as an example of the **national system of protected areas**. The special nature and landscape protection contributes to water protection by a system of protection levels valid in the individual protected territory categories:

1st level of protection – valid for the entire territory of the state;

2nd level of protection – protected landscape areas (CHKO) and protective zones (OP) of national parks (NP);

3rd level of protection – national parks and protective zones of protected sites (CHA) or nature preserves (PR), natural monuments (PP), national nature preserves (NPR) and national natural monuments (NPP);

4th level of protection – protected sites and PR, PP, NPR and NPP protective zones;

5th level of protection – PR, PP, NPR and NPP territories.

We may consider all territories containing swamps, moors and peat bogs, as well as territories with waters retained either naturally or by artificial influences with the presence of natural habitats, dependent on the aquatic environment, to be a **special type of protected areas – wetlands**.

Wetlands are protected on both the national and international levels. The international protection of wetlands is entrenched in the Convention on Wetlands signed in 1971 in Ramsar (Iran), known as the Ramsar Convention. In this international document, the contracting parties undertook to protect wetlands within their territory and to develop and implement relevant protective measures related to these wetlands.

5.4.4.2 - More Stringent Territorial Water Protection – Hygienic Protection Zones of Water Resources

Waters in surface water bodies and groundwater bodies used for the abstraction of water for drinking water or utilisable for supplying more than the number of persons defined by legislation (e.g. 50 persons), or a certain volume (e.g. 10 m^3 per day) are deemed to be water resources.

We may again cite an example from Slovakia – in accordance with legislation, protective zones of water resources are divided into three levels:

1. A protective zone of the I. level serves to protect it close to the water abstraction point or interception facility. It includes the location immediately adjacent to the abstraction point or immediately surrounding the interception facility. It is established in order to ensure protection and prevent the possibility of direct negative influence or threat to the water source.
2. A protective zone of the II. level serves to protect the water resource from a threat emanating from more distant locations. It is established to protect the yield, quality or health integrity of the water resource from threats from more distant locations. It is intended, in particular, for protection against microbial pollution and toxic substances pollution. Its extent is stipulated so as to ensure a 50-day retention of the water in the mineral environment in the direction of the abstraction point.
3. A protective zone of the III. level may be established to increase the total protection of the water resource. It is established to ensure protection of the water resource only for surface waters against adverse interventions in the hydrological cycle of water which could lead, in particular, to a reduction in the yield of the water resource, but also to protect the water

resource against pollution and the input of biogenic substances. It includes the entire river basin above the water abstraction point.

5.5 - MANAGEMENT AND PLANNING ACTIVITIES IN THE RIVER BASINS

The system of sustainable integrated river basin management is a continuous conceptual activity performed mainly for purposes of the universal protection of waters and the accomplishment of environmental objectives, the creation of appropriate conditions for the sustainable utilisation of water resources, the delivery of water management services and the protection against harmful impacts on waters.

In principle, activities have to be harmonised not solely in water management but across virtually all domains (e.g. in agriculture, forestry, territorial planning, etc.) in order to preserve an optimal, as natural as possible, quantitative and qualitative water regime in the river basin while, at the same time, satisfying requirements for water. According to the WFD, River Basin Management Plans constitute the main river basin water management document.

River basin water management usually includes the following activities:

1. performance of tasks related to determination of the incidence, quantity, regime and quality, and to the evaluation of the status of surface waters and groundwaters;
2. expert preparation and update of river basin management plans;
3. monitoring the effect of point pollution on water quality in recipients;
4. identification of areal water pollution;
5. collaboration in development of the Programme of Anti-Erosion Measures, Measures for Increasing the Retention Ability of Partial River Basins and Coordination in the Performance thereof;
6. coordination of water management tasks with the creation and utilisation of water management effects of the ecological stability territorial system;
7. development of economic analyses of handling water and imposition of charges for the use of waters;

8. securing consultations related to the application of river basin management plans, securing basic technical documentation and other basic expert documentation for decision-making and other administrative activities of state water administration authorities;
9. administration of significant water courses in terms of water management and supply;
10. care for open groundwaters with regard to the protection of incidence, quantity and quality of water, water ecosystems and ecosystems in the countryside directly dependent on waters;
11. provision of the concept and coordination of measures for the reduction of adverse impacts of floods and drought.

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CHAPTER 6. INDUSTRIAL WASTEWATER

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The characteristics of industrial wastewaters depend on the nature of industry and vary greatly in both flow and pollution strength. In general, industrial wastewaters may contain suspended, colloidal and dissolved (mineral and organic) solids (Alturkmani, 2004; Ron and George, 1998). In addition, they may be either excessively acidic or alkaline and may contain high or low concentrations of coloured matter (Alturkmani, 2004, Munter 2003). These wastes may contain inert, organic or toxic materials and possibly pathogenic bacteria. Thermal pollution, e.g., the addition of large quantities of heat to a recipient, possesses the potential of causing ecological harm (Alturkmani, 2004, Munter 2003).

The industrial wastes either join the streams or other natural water bodies directly, or are emptied into the municipal sewers. These wastes affect the normal life of stream or the normal functioning of sewerage and sewage treatment plant. Streams can assimilate a certain amount of wastes before they are polluted (Alturkmani, 2004).Separate treatment of industrial wastes before discharging them into the water bodies is the most environmentally friendly and efficient means of reducing the negative impact of industrial wastewater on the receiving environment (REF).

6.1 - TREATMENT

Regardless of the designated fate of industrial wastewater, whether the water is going to be reused or released back into the environment, it has to be treated (Tchobanoglous. Water treatment technologies are used to reduce the level of pollutants and to enable businesses to reuse and recycle water, to reduce their reliance on potable freshwater, and/or minimize the negative environmental impact on the surrounding environment.

Achieving the desired level of water quality from wastewater generally is complex and requires multiple stages of treatment. The efficiency of the chosen method depends on the designated end use of treated wastewater, wastewater characteristics and environmental regulations; therefore these factors dictate specific designs and approaches.

Water treatment technologies are used for three purposes: water source reduction, wastewater treatment and recycling. At present, unit operations and processes are combined together to provide what is called primary, secondary and tertiary treatment (Qasim, 2017; Tchobanoglous et al., 1991). Primary treatment includes preliminary purification processes of a physical and chemical nature, while secondary treatment deals with the biological treatment of wastewater (Qasim, 2017; Tchobanoglous et al., 1991). In tertiary treatment processes, wastewater (treated by primary and secondary processes) is converted into good quality water that can be used for different types of purpose, i.e. drinking, industrial, medicinal etc. supplies (Qasim, 2017; Tchobanoglous et al., 1991). In the tertiary process, up to 99% of the pollutants are removed, and the water is converted into the safe quality for a specific use. In a complete water treatment, all these three processes are combined together for producing good quality and safe water (Hendricks, 2016; Qasim, 2017; Tchobanoglous et al., 1991).

There are four main methods of wastewater treatment – physical, biological, chemical and thermal (Hendricks, 2016; Qasim, 2017).

Physical methods of wastewater treatment accomplish removal of substances by use of naturally occurring forces, such as gravity, electrical attraction, and van der Waal forces, as well as by use of physical barriers. In general, the mechanisms involved in physical treatment do not result in changes in chemical structure of the target substances. In some cases, physical state is changed, as in vaporization, and often dispersed substances are caused to agglomerate, as happens during filtration (Hendricks, 2016; Qasim, 2017).

Chemical methods of wastewater treatment are based on chemical reactions to remove the pollution.

In **biological treatment** pollutant is removed/converted by microorganisms. Oxygen-consuming pollutants (BOD, COD, ammonia, organic nitrogen), suspended solids and nutrients (nitrogen and phosphorous) are mainly treated by this approach (Hendricks, 2016; Qasim, 2017).

Thermal treatment refers to incineration/combustion of waste material to convert into heat, gas, steam and ash either on or off-site. Thermal treatment is not very common, because of its high costs, and because of regulations about the discharge of hazardous materials into air (Crini and Lichtfouse, 2019).

6.1.1 - PHYSICAL TECHNOLOGIES

The most commonly used waste treatment technologies based on physical methods are flotation and basic filtration, and membrane filtration.

1. **Flotation and basic filtration:** These physical treatment methods can be applied either as a pre-treatment, improving the efficiency of subsequent treatment processes, or to meet waste standards prior to discharge into sewers. These methods are based on solids-liquid or liquid-liquid separation as a result on density differences of the particles and that of the liquid they are in.

   Flotation is generally used to remove liquid grease and oil, and some part of suspended solids, from wastewater. There are three types of flotation: natural (if the difference in density is naturally sufficient for separation), aided (when external means are used to promote the separation of particles that are naturally floatable) and induced flotation (when the density of particles is artificially decreased to allow particles to float. This is based on the capacity for certain solid and liquid particles to link up with gas (usually air) bubble to form « particle-gas » with a density lower than the liquid.).

Larger solids can be removed using basic filtration. Basic filtration involves removal of particles by filtration through fine physical barriers distinguished from coarser screens or sieves by the ability to remove particles smaller than the openings through which the water passes (Hendricks, 2016; Qasim, 2017).

Membrane filtration: Membrane processes are increasingly used for removal of bacteria, microorganisms, particulates, and natural organic material, which can impart colour, tastes, and odours to water and react with disinfectants to form disinfection byproducts. A membrane is a thin layer of semi-permeable material that separates substances when a driving force is applied across the membrane. Membrane technology has made some major advances in recent years and now has broad application. Membranes are available in four main types: microfiltration, ultrafiltration, reverse osmosis and nano-filtration. The latter two are particularly effective at removing salts, dissolved solids, enhanced organics and pathogens (Hendricks, 2016; Qasim, 2017).

6.1.2 - BIOLOGICAL TECHNOLOGIES

Wastewater treatment technologies that apply biological conversion of pollutants are of utmost importance. Many different types of biological treatment methodologies have been developed (Hendricks, 2016). Although due to biological activities these technologies are extremely cost-effective and energy-efficient, sudden environmental and operational change can compromise the efficiency of these processes. There are two types of biological treatment process: aerobic and anaerobic (Hendricks, 2016).

Aerobic wastewater treatment is a biological process that takes place in the presence of oxygen. Aerobic wastewater treatment encourages the growth of naturally-occurring aerobic microorganisms as a means of renovating wastewater. Since anaerobic treatment is preferred when the dissolved organic concentrations of untreated wastewater are high, aerobic treatment is often used as a secondary treatment process and follows an anaerobic stage. Yet, implication of aeration into the process can increase the operational costs of these systems. In these systems, about 50% of biodegradable organic matter is converted to sludge, which must be disposed of.

Anaerobic wastewater treatment is the biological treatment of wastewater without the use of air or elemental oxygen. Many applications are directed towards the removal of organic pollution in wastewater, slurries and sludges. The organic pollutants are converted by anaerobic microorganisms to a gas containing methane and carbon dioxide, known as "biogas". The biogas can be used to generate electricity and heat and thus reduce greenhouse gas emissions. Depending on waste composition, other beneficial compounds, like soil conditioners, fertilizer can be produced. Anaerobic treatment is a slow process and can take up to 3 months; also due to septic decomposition, unpleasant odours may occur.

While certain systems operate on strictly aerobic or anaerobic modes, combined anaerobic/aerobic treatment systems such as constructed wetlands have been proven to be extremely efficient in dealing with many types of pollution.

The most commonly used bioreactor types for wastewater treatment are:

1. **Membrane bioreactors (MBRs):** A membrane bioreactor is a biochemical engineering process involving the use of both a suspended growth bioreactor for biochemical reactions (such as fermentation, bio-oxidation, nitrification, and denitrification) and a membrane separator for subsequent solids/liquid separation. MBRs have applications for both domestic wastewater and industrial waste treatment. While in domestic water treatment MBR output alone produces water of sufficient quality to be released to waterways or used in urban irrigation, in industrial wastewater treatment extra measures might be required to produce water of the desired quality. For example, membrane suspension combined with a suspended-growth bioreactor is effective (Brindle and Stephenson, 1996; Iorhemen et al., 2016).
2. **Activated sludge process:** The activated sludge process (ASP) is an aerobic biological wastewater treatment process that uses microorganisms to speed up decomposition of organic matter requiring oxygen for treatment. In this process, microorganisms are thoroughly mixed with organics under conditions that stimulate their growth, and waste materials are removed (Gernaey et al., 2004).
3. **Trickling filters:** Trickling filters are intended to treat particularly strong or variable organic loads. They are typically circular filters filled with open stone or synthetic filter media to which wastewater is applied at a relatively high rate. The design of the filters allows high hydraulic loading and a high flow-through of air. On larger installations, air is forced through the media using blowers. The resultant liquor is usually within the normal range for conventional treatment processes (Hendricks, 2016; Shahriari and Shokouhi, 2015.
4. **Constructed wetlands:** Although not the most commonly used wastewater treatment technology currently, constructed wetlands are gaining attention because of relatively lower costs and simplicity of operation. Constructed wetlands are treatment systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality (Vymazal, 2007).

6.1.3 - CHEMICAL TECHNOLOGIES

Chemical processes which induce chemical reactions are called chemical unit processes, and they are used alongside biological and physical cleaning processes to achieve various water standards. There are several distinct chemical unit processes, including chemical coagulation, chemical precipitation, chemical oxidation and advanced oxidation, ion exchange, and chemical neutralization and stabilization, which can be applied to wastewater during cleaning.

1. **Ion exchange:** This method is widely applied in the treatment of water for refined end-uses, including the semi-conductor and pharmaceutical industries (which require ultra-pure water), and boiler-feed water, and is used to remove trace contaminants. The concentration of organics and inorganics can be reduced by up to 95%. In the ion exchange process toxic ions present in wastewater are exchanged with the non-toxic ions from a solid material called an ion exchanger. Ion exchangers are of two types, i.e. cation and anion exchangers which have the capacity to exchange cations and anions respectively (Hendricks, 2016).
2. **Disinfection:** This includes processes such as chlorination, and the use of ozone and ultra violet light, and is effective at killing pathogens such as viruses, bacteria and protozoa. It is usually applied as a secondary treatment in situations where there is a risk that treated water will come into contact with the human population (Hendricks, 2016; Qasim, 2017; Tchobanoglous et al., 1991).

6.2 - TREATMENT AND DISPOSAL OF SLUDGE SOLIDS

The treatment of all liquid wastes generally produces high volumes of sludges. Due to characteristics of industrial wastewater sludges, e.g., elevated levels of specific compounds not found in municipal wastewater, their disposal becomes a major problem. There are several methods of handling industrial sludges:

1. **Anaerobic digestion:** This is a common method of sludge volume and strength reduction. All solids settled out in treatment basins are pumped to an enclosed air tight digester, where they decompose in an anaerobic environment. After digestion, the sludge is dried and/or burned or used for fertilizer or landfill (Hendricks, 2016, Lettinga, 1995).
2. **Vacuum filtration:** This is a means of dewatering sludge solids. In a typical vacuum filtration unit, a porous cylinder overlying a series of cells revolves about its axis, its lower

portion passing through a trough containing the sludge to be dried. A vacuum inside the cylinder picks up a layer of sludge as the filter surface passes through the trough, and this increases the vacuum. When the cylinder has completed three quarters of revolution, a slight air pressure is produced on the appropriate cells, which aids the scraper or strings to dislodge the sludge in a thin layer (Chen et al., 2002).

3. **Sludge drying beds:** Sludge drying beds remove moisture from sludge, thereby decreasing its volume and changing its physico-chemical characteristics, so that sludge containing 25% solids can be moved with a shovel or garden fork and transported in watertight containers (Chen et al., 2002).
4. **Sludge stabilization ponds or lagoons** may be defined as natural or artificial earth basins used to receive sludge. In lagoon sludge is treated and stabilized by aerobic and anaerobic microorganisms (Crites et al., 2014).

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PART 4: SOLID WASTE AND SUSTAINABLE MATERIAL FLOWS

CHAPTER 7. HAZARDOUS WASTE MANAGEMENT

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7.1 - IDENTIFICATION

> **Love Canal Disaster**
>
> Love Canal was named after the late 18th century entrepreneur William T. Love who built a canal connecting the two levels of the Niagara River which is separated by Niagara Falls to provide hydroelectric power to the Niagara area. His plan ultimately failed due to the economic collapse of 1892 after only 1 mile - at fifteen feet wide and ten feet deep - had been dug.
>
> Love Canal was sold in 1920 at a public auction to the city of Niagara Falls which began using the land as a landfill for chemical waste disposal, and later the U.S. Army began burying waste from chemical warfare experiments. Hooker Chemical and Plastics Corporation acquired the use of the site for private use in 1947 and buried 21,000 tons of toxic waste there over the next five years. After the site was filled, Hooker filed the canal in 1952. The rapid expansion of Niagara Falls' population led to the city buying the Love Canal for $1. The subsequent construction of the school punctured a copper barrier Hooker had used to contain the chemical waste. Additionally, sewers were constructed around the site as well. Health reports and strange odors were reported the following years, but not until the President of the Love Canal Homebuilders Association, Lois Gibbs, investigated was the severity of the situation realized. In 1978, President Jimmy Carter declared the site a federal emergency area. Scientists were brought in and were able to determine that the dumped chemicals seeped into basements and the air and were responsible for the ill health of the residents. Over 800 families relocated and the Environmental Protection Agency sued Hooker's parent company then Occidental Petroleum, for $129 million.
>
> The clean-up site was the flagship of the Superfund program. The Environmental Protection Agency cleaned up 21 tons of toxic chemicals on the 16 acre site.

Hazardous wastes refer to solid or liquid wastes which because of quantity, concentration or physical, chemical or infectious characteristics, may cause increased mortality or severe illness and pose a substantial potential hazard to human health or environment, when improperly treated, stored, transported or disposed.

The criteria used to determine the nature of hazard include toxicity, phytotoxicity, genetic activity, and bio-magnification. For a waste to be deemed hazardous waste, it must cause, or significantly contribute to, an increased mortality or an increase in serious irreversible or incapacitating reversible illness, or pose a substantial hazard or threat of a hazard to human health or the environment, when it is improperly treated, stored, transported, disposed of, or otherwise mismanaged.

The information in this chapter is based on the United States Environmental Protection Agency (EPA) hazardous waste management website (https://www.epa.gov/hw)

The identification of waste as hazardous requires evaluation of the waste belonging to one of the following categories: characteristic wastes and listed wastes.

Characteristic wastes are wastes that exhibit any one or more of the following characteristic properties: ignitability, corrosivity, reactivity or toxicity. Listed wastes can be determined from the list provided by government agencies declaring that substance as hazardous.These wastes originate in common manufacturing and industrial processes, as well as specific industries, and they can be generated from discarded commercial products.

7.1.1 - CHARACTERISTIC HAZARDOUS WASTES

The regulations define characteristic hazardous wastes as wastes that exhibit measurable properties posing sufficient threats to warrant regulation. In other words, if the wastes generated at a facility are not listed in the F, K, P, or U lists, the final step to determine whether a waste is hazardous is to evaluate it against the following 4 hazardous characteristics:

(i) **Ignitability**: A waste is an ignitable hazardous waste if it has a flash point of less than 60C; readily catches fire and burns so vigorously as to create a hazard; or is an ignitable compressed gas or an oxidizer. A simple method of determining the flash point of a waste is to review the material safety data sheet, which can be obtained from the manufacturer or distributor of the material.

(ii) **Corrosivity**: Corrosive wastes are acidic or alkaline (basic) wastes which can readily corrode or dissolve flesh, metal, or other materials. These wastes have a pH of less than or equal to 2 or greater than or equal to 12.5.

(iii) **Reactivity:** Unstable materials or material that cause violent reactions when in contact with another material.

(iv) **Toxicity**: Wastes that are hazardous due to the toxicity characteristic are harmful when ingested or absorbed. Toxic wastes present a concern as they may be able to leach from waste and pollute groundwater.

7.1.2 - LISTED HAZARDOUS WASTES (PRIORITY CHEMICALS)

A specific list showing certain materials as hazardous wastes minimizes the need to test wastes as well as simplifies waste determination. In other words, any waste that fits the definition of a listed waste is considered a hazardous waste. Four separate lists cover wastes from generic industrial processes, specific industrial sectors, unused pure chemical products and formulations that are either acutely toxic or toxic, and all hazardous waste regulations apply to these lists of wastes.

F-list: The F-list contains hazardous wastes from non-specific sources, that is, various industrial processes that may have generated the waste. The list consists of solvents commonly used in degreasing, metal treatment baths and sludge, wastewaters from metal plating operations and dioxin-containing chemicals or their precursors.

K-list: The K-list contains hazardous wastes generated by specific industrial processes. Examples of industries, which generate K-listed wastes include wood preservation, pigment production, chemical production, petroleum refining, iron and steel production, explosive manufacturing and pesticide production.

P and U lists: The P and U lists contain discarded commercial chemical products, off-specification chemicals, container residues and residues from the spillage of materials. These two lists include commercial pure grades of the chemical, any technical grades of the chemical that are produced or marketed, and all formulations in which the chemical is the sole active ingredient. An example of a P or U listed hazardous waste is a pesticide, which is not used during its shelf-life and requires to be disposed in bulk. The primary distinction between the two lists is the quantity at which the chemical is regulated. The P-list consists of acutely toxic wastes that are regulated when the quantity generated per month, or accumulated at any time, exceeds one kilogram, while U-listed hazardous wastes are regulated when the quantity generated per month exceeds 25 kilograms.

7.2 - HAZARDOUS WASTE MANAGEMENT RULES

In cases when the hazardous waste is changed, either by mixing it with other wastes or by treating it to modify its chemical composition, several rules and policies determine the hazardousness of resultant waste.

7.2.1 - MIXTURE RULE

A mixture of any amount of hazardous waste and a solid (nonhazardous) waste is considered a hazardous waste.

There is no minimal concentration that qualifies for an exclusion from the mixture rule except for certain mixtures in wastewater treatment systems. For example, if an employee mixes spent ethyl ether with an absorbent clay to reduce the liquid content, the entire mixture is classified as hazardous.

An exception to the mixture rule is as follows: if the mixture is hazardous solely because it exhibits a characteristic and the resultant mixture no longer exhibits the same characteristic, it is not considered a hazardous waste (EPA, 2005).

It must be emphasized, however, that such wastes become nonhazardous only by the inadvertent, unavoidable mixing occurring during standard processes at the facility. In other words, a facility cannot deliberately mix a nonhazardous waste with hazardous waste to render it nonhazardous.

7.2.2 - THE DERIVED-FROM RULE

The derived-from rule states that any solid waste generated from the treatment, storage, or disposal of a hazardous waste including any sludge (pollution control residue), spill residue, ash, emission control dust, or leachate (not including precipitation runoff) is a hazardous waste.

Thus, in the case of residues generated from the treatment of a listed waste, all residues remain hazardous unless specifically delisted. The generator is required to prove that the waste is no longer hazardous through the delisting process, or the treatment residues are managed as hazardous waste.

A facility that treats F-listed hazardous wastes, for example via incineration, must manage the incinerator ash as hazardous waste although the toxicity of the waste may be greatly reduced. This rule also applies to treatment of hazardous wastes during a corrective action (EPA, 2005).

7.2.3 - THE CONTAINED-IN POLICY

The contained-in policy relates to the incorporation of typically natural materials (e.g., soil, groundwater) with a hazardous waste.

The policy indicates that the media themselves may need to be managed as a hazardous waste until they no longer contain hazardous constituents at a level of concern.

For example, if a surface impoundment leaks a listed hazardous waste into local groundwater, the resulting contaminated groundwater is to be managed as a hazardous waste (EPA, 2005).

7.3 - HAZARDOUS WASTE MANAGEMENT

Hazardous waste management should follow cradle-to-grave tactics, i.e., wastes are to be tracked from the point of their initial generation through storage and transportation, to final treatment and disposal (https://www.epa.gov/hw/learn-basics-hazardous-waste).

Generation

Hazardous waste generators are the first link in the hazardous waste management system. As a first step in this management framework, the waste generator is required to determine if any solid wastes generated at their facility are hazardous so that the wastes will be managed and tracked properly. Furthermore, generators must ensure and fully document that the hazardous waste that they produce is properly identified, managed, and treated prior to recycling or disposal. The degree of regulation that applies to each generator depends on the amount of waste that a generator produces. Hazardous waste generators are classified as large quantity generators (LQGs), small quantity generators (SQGs), and conditionally exempt small quantity generators (CESQGs), based on these monthly volumes.

LQGs generate 1,000 kilograms per month or more of hazardous waste or more than one kilogram per month of acutely hazardous waste. Major requirements for LQGs include:

- LQGs may only accumulate waste on-site for 90 days.
- LQGs do not have a limit on the amount of hazardous waste accumulated on-site.
- Hazardous waste generated must be managed in tanks, containers, drip pads or containment buildings subject to the regulatory requirements.
- LQGs must comply with the preparedness, prevention and emergency procedure requirements.
- LQGs must submit a biennial hazardous waste report.

SQGs generate more than 100 kilograms, but less than 1,000 kilograms of hazardous waste per month. Major requirements for SQGs include:

- SQGs may accumulate hazardous waste on-site for 180 days without a permit (or 270 days if shipping a distance greater than 200 miles).
- The quantity of hazardous on-site waste must never exceed 6,000 kilograms.
- SQGs must manage hazardous waste in tanks or containers subject to the regulatory requirements.
- There must always be at least one employee available to respond to an emergency. This employee is the emergency coordinator responsible for coordinating all emergency response measures. SQGs are not required to have detailed, written contingency plans.

CESQGs generate 100 kilograms or less per month of hazardous waste or one kilogram or less per month of acutely hazardous waste. Requirements for CESQGs include:

- CESQGs must identify all the hazardous waste generated.
- CESQGs may not accumulate more than 1,000 kilograms of hazardous waste at any time.
- CESQGs must ensure that hazardous waste is delivered to a person or facility who is authorized to manage it.

7.3.1 - STORAGE AND COLLECTION

Onsite storage practices are a function of the types and amounts of hazardous wastes generated and the period over which generation occurs. Usually, when large quantities are generated, special facilities are used that have sufficient capacity to hold wastes accumulated over a period of several days. When only a small amount is generated, the waste can be containerized, and limited quantity may be stored. Containers and facilities used in hazardous waste storage and handling are selected on the basis of waste characteristics. For example, corrosive acids or caustic solutions are stored in fiberglass or glass-lined containers to prevent deterioration of metals in the container. Great care must also be exercised to avoid storing incompatible wastes in the same container or locations.

The waste generator, or a specialized hauler, generally collects the hazardous waste for delivery to a treatment or disposal site. The loading of collection vehicles is completed in either of the following ways:

(i) Wastes stored in large-capacity tanks are either drained or pumped into collection vehicles;

(ii) Wastes stored in sealed drums or sealed containers are loaded by hand or by mechanical equipment onto flatbed trucks.

The stored containers are transported unopened to the treatment and disposal facility. To avoid accidents and the possible loss of life, two collectors should be assigned when hazardous wastes are to be collected. The equipment used for collection vary with the waste characteristics: for example, for short-haul distances, drum storage and collection with a flatbed truck is often used. As hauling distances increase, the larger tank trucks, trailers and railroad tank cars are used.

Figure 7.1.Drum containers used for the storage of hazardous waste (https://www.newpig.com/expertadvice/hazardous-waste/)

7.3.2 - TRANSFER AND TRANSPORT

The economic benefits derived by transferring smaller vehicle loads to larger vehicles are applicable to hazardous wastes. However, the facilities of a hazardous waste transfer station are quite different from those of a solid waste transfer station. Typically, hazardous wastes are not compacted (i.e., mechanical volume reduction) or delivered by numerous community residents. Instead, liquid hazardous wastes are generally pumped from collection vehicles, and sludge or solids are reloaded without removal from the collection containers for transport to processing and disposal facilities.

It is unusual to find a hazardous waste transfer facility where wastes are simply transferred to larger transport vehicles. Some processing and storage facilities are often part of the material handling sequence at a transfer station. For example, neutralization of corrosive wastes might result in the use of a lower-cost holding tank on transport vehicles. As in the case of storage, great care must be exercised to avoid the danger of mixing incompatible wastes.

7.3.3 - PROCESSING

Processing of hazardous waste is done for purposes of recovering useful materials and preparing the wastes for disposal. Processing can be accomplished on-site or off-site. The variables affecting the selection of processing sites include the characteristics of wastes, the quantity of wastes, the technical, economic and environmental aspects of available on-site treatment processes and the availability of the nearest off-site treatment facility (e.g., haul distance, fees, and exclusions). The treatment of hazardous waste can be accomplished by physical, chemical, thermal or biological means. In practice, the physical, chemical and thermal treatment operations are the most commonly used, while biological treatment processes are used less often because of their sensitivity. Depending on the type of wastes being treated, one or more of these methods may be used.

7.3.4 - DISPOSAL

Regardless of their form (i.e., solid, liquid, or gas), most hazardous waste is disposed of either near the surface or by deep burial. Although controlled landfill methods have been proved adequate for disposing of municipal solid waste and limited amounts of hazardous waste, they are not suitable for the disposal of a large quantity of hazardous waste, due to the following reasons: possible percolation of toxic liquid waste to the ground water; dissolution of solids followed by leaching and percolation to the ground water; dissolution of solid hazardous wastes by acid leachate from solid waste, followed by leaching and percolation to the ground water; potential for undesirable reactions in the landfill that may lead to the development of explosive or toxic gases.

Therefore, in general, hazardous waste is disposed separate from municipal waste, and additional care must be taken in the selection of a hazardous waste disposal site and its design. To avoid the co-disposal of incompatible wastes, separate storage areas within the total landfill site should be designated for various classes of compatible wastes.

Liquid wastes are usually stored in a tank and will be placed in the landfill by trenches or lagoons. Sludges are also placed in trenches. When containerized wastes are to be disposed of, precautions must be taken to avoid the rupturing of containers: the containers should be unloaded and placed in position individually. The covering of the containers with earth should be monitored and controlled carefully to ensure that a soil layer exists between each container and the equipment placing the soil does not crush or deform the container.

While designing a landfill site for hazardous waste, provision should be made to prevent any leachate escaping from the landfill site. This requires a clay liner, and in some cases, both clay and impermeable membrane liners are used. A layer of limestone is placed at the bottom of the landfill to neutralize the pH of leachate. A final soil cover of 25 cm or more should be placed over the liner. The completed site should be monitored continuously, both visually and with sample wells.

7.4 - HAZARDOUS WASTE TREATMENT

Prior to disposal, hazardous wastes need appropriate treatment, depending on the type of waste.

7.4.1 - PHYSICAL AND CHEMICAL TREATMENT

Physical and chemical treatments are an essential part of most hazardous waste treatment operations and include the following:

i. Filtration is a method for separating solid particles from a liquid using a porous medium. The application of filtration for treatment of hazardous waste falls into the following categories:

Clarification, in which suspended solid particles less than 100 ppm (parts per million) concentration are removed from an aqueous stream; and *dewatering of slurries* of typically 1% to 30 % solids by weight. The filtration treatment, for example, can be used for neutralization of strong acid with lime or limestone, or precipitation of dissolved heavy metals as carbonates or sulphides followed by settling and thickening of the resulting precipitated solids as slurry. The slurry can be dewatered by cake filtration, and the effluent from the settling step can be filtered by depth filtration prior to discharge (Krishna et al., 2017).

ii. Chemical precipitation is a process by which the soluble substance is converted to an insoluble form, either by a chemical reaction or by change in the composition of the solvent to diminish the solubility of the substance in it. Settling and/or filtration can then remove the precipitated solids. In the treatment of hazardous waste, the process has a wide applicability in the removal of toxic metals from aqueous wastes by converting them to an insoluble form (Krishna et al., 2017).

iii. Chemical oxidation and reduction (redox) are reactions where the oxidation state of one reactant is raised, while that of the other reactant is lowered. Such reactions are used in treatment of metal-bearing wastes, sulphides, cyanides and chromium and in the treatment of many organic wastes such as phenols, pesticides and sulphur-containing compounds. In general, chemical treatment costs are highly influenced by the chemical cost. This oxidation and reduction treatment tends to be more suitable for low concentration (i.e., less than 1%) in wastes (Krishna et al., 2017; Vallero, 2011).

iv. Solidification and stabilization: In hazardous waste management, solidification and stabilization (S/S) is used to reduce the mobility of pollutants, thereby making the waste acceptable under current land disposal requirements. *Solidification* refers to a process in which materials are added to the waste to produce a solid. *Stabilization* refers to a process by which a waste is converted to a more chemically stable form (Krishna et al., 2017; Vallero, 2011).

v. Evaporation is the conversion of a liquid from a solution or slurry into vapor, commonly used as a pre-treatment method to decrease quantities of material for final treatment. It is also used in cases where no other treatment method was found to be practical, such as in the concentration of trinitrotoluene (TNT) for subsequent incineration (Krishna et al., 2017; Vallero, 2011).

vi. Ozonation is used to detoxify industrial organic wastes, containing aromatic and aliphatic polychlorinated compounds, ketones and alcohols (Krishna et al., 2017; Vallero, 2011).

7.4.2 - THERMAL TREATMENT

Thermal treatment involves high temperatures in the processing of the hazardous waste feedstock.

i. Incineration can be regarded as either a pre-treatment of hazardous waste, prior to final disposal or as a means of valorizing waste by recovering energy. It can include both the burning of mixed solid waste and the burning of selected parts of the waste stream as a fuel (Muralikrishna and Valli Manickam, 2017; Vallero, 2011).
ii. Pyrolysis is a thermal process for transformation of solid and liquid carbonaceous materials into gaseous components and the solid residue containing fixed carbon and ash by heating in the absence of oxygen. The application of pyrolysis to hazardous waste treatment leads to a two-step process for disposal. In the first step, wastes are heated, separating the volatile contents (e.g., combustible gases, water vapour, etc.) from non-volatile char and ash. In the second step volatile components are burned under proper conditions to assure incineration of all hazardous components (Krishna et al., 2017; Vallero, 2011).

7.4.3 - BIOLOGICAL TREATMENT

Although hazardous materials are toxic to living beings, biological treatment in order to exploit the full potential of hazardous wastes in terms of removal efficiency and cost is an emerging application. Because of toxicity of hazardous waste, generally only low-concentration wastes pass through biological treatment (Krishna et al., 2017; Vallero, 2011).

i. During land treatment the waste is mixed with or incorporated into the surface soil and is degraded, transformed or immobilized through either plants or microbial community. Compared to other land disposal options (e.g., landfill and surface impoundments), land treatment has lower long-term monitoring, maintenance and potential clean up liabilities; because of this, it has received considerable attention as an ultimate disposal method.
ii. Enzymes capable of transforming hazardous waste chemicals to non-toxic products can be harvested from microorganisms grown in mass culture and are the foundation of enzymatic process of hazardous waste treatment.
iii. Composting is another biological application of hazardous waste treatment. The main problem of using compositing for hazardous waste treatment is that certain types of

hazardous waste molecules can be degraded by only one or a very few microbial species, which may not be widely distributed or abundant in nature. Nevertheless, optimization of the process proves to be an efficient means.

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PART 5: SUPPLY CHAIN AND LOGISTICS

Chapter 8. SUSTAINABLE/GREEN SUPPLY CHAIN: APPROACHES AND SOLUTIONS

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Photo: G. Gabrielyan

8.1 - LEARNING OBJECTIVES:

- After studying this chapter students should be able to:
- Describe the main characteristics of the sustainable supply chain and green supply chain, as well as their interrelationship and differences
- Appreciate the importance of sustainable/green supply chain management for overall sustainable development
- Outline the main trends in relation to supply chain strategies, supply chain design and operation
- Outline the main trends in the contemporary business environment: the effects of globalization on the ability to achieve sustainable supply chains
- Identify how green practices may affect business performance.
- Describe what are the international standards applied in the field of relevant international organizations
- Highlight examples of green/sustainable supply chain solutions in various industries.

8.2 - SUSTAINABLE AND GREEN

The terms Sustainable Supply Chain and Green Supply Chain are often used interchangeably, even by professionals, but they are different things, though are very much interrelated. In a nutshell, the Sustainability concept is about a firm's performance in three broad aspects - economic, environmental and social, while the Green concept is focused mostly on the environmental impact of firm's performance. Thus, the Sustainability concept is broader than Green and includes Green. Green is one of the three colors of Sustainable, though Green is very closely linked and includes many shades of the economic color as well.

The most commonly referenced definition of sustainable development is the definition by the World Commission on Environment and Development (Brundtland Commission of the United Nations) – "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Brundtland Commission, 1987

In a firm performance context, the "Triple Bottom Line (TBL)" is often used as a framework for understanding and measuring sustainability of a firm's operations and evaluating a firm's social responsibility. The TBL framework was developed by Elkington in the 1990's (Elkington, 1997). TBL is a notion that corporations must consider three objectives while designing and implementing their strategies and decisions, and that sustainability can be achieved through finding optimal balance between these three objectives: ***economic, environmental, and social***.

- **Economic**, i.e. delivering profits for firms' shareholders and creating value for their stakeholders. To be sustainable, businesses need to be profitable. But profit shall not come at any expense. In some instances environmental requirements are hard or impossible to implement, because they may lead to loss of profit. Firms need to develop economically feasible ways to reduce global warming; to avoid depleting ozone layer; and to handle sewage, hazardous waste, and garbage.

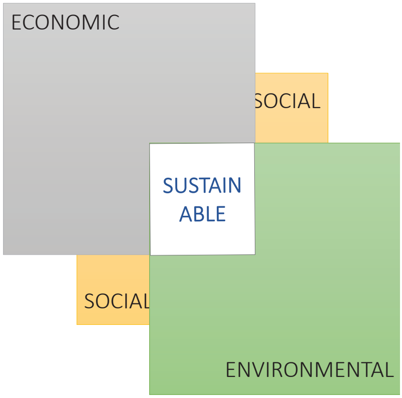

Figure 8.1. Sustainable vs Green

- **Environmental**, i.e. protecting the natural environment. This is about reducing and/or eliminating negative impact on the environment, including water, air, land, forests, biodiversity, and ecosystems. Many businesses have understood that environmentally friendly measures can also have a positive financial impact and help them increase profitability.
- **Social**, i.e. enhancing the general welfare of society. This is related to a firm's workforce, firm's customers, and the society at large. Workforce-related factors include employment quality, work safety, employee health, training and development opportunities, and diversity. Customer-related factors include accurate product information and labeling, consumer health and safety. Social issues include human rights, impact on local communities, poverty reduction, etc.

The TBL dimensions are also commonly called the three Ps ***(3Ps): people, planet and profits***. In other words, sustainability is about considering and balancing "people, planet, and profits". In practice, balancing the three dimensions can be mutually beneficial (Willard B., 2002), but achieving the balance is not easy and often requires negotiation and compromise. (Savitz A. & Weber K., 2006)

Historically, the TBL and Corporate Social Responsibility (CSR) concepts emerged due to growing concerns about negative social and environmental impacts of operations of multinational corporations (MNCs) due to intensifying international competition for low-cost labor and resources in Asia, Latin America and Africa (including China, India, Pakistan, Brazil, Mexico, etc.). The negative environmental impacts included, for instance, the deforestation (in Amazon basin), dumping hazardous chemicals into the nature, increasing CO_2 emission due to the use of fossil fuels, depletion of the ozone layer of Earth's stratosphere. The negative social impact included exploitation of cheap labor, exploitation of child labor, low work safety and workplace standards, harm to indigenous people, local habitats and communities. The growing understanding and awareness about these hazardous practices have led to increased pressures on MNCs by various stakeholders - consumers, civil society, scientists, local communities, governments and international organizations - to adopt sustainable policies and practices. Many MNCs revised their approaches and policies to make them environmentally and socially more responsible.

Box 1. Seventeen Sustainable Development Goals (SDG)

Goal 1. End poverty in all its forms everywhere

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Goal 3. Ensure healthy lives and promote well-being for all at all ages

Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

Goal 5. Achieve gender equality and empower all women and girls

Goal 6. Ensure availability and sustainable management of water and sanitation for all

Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all

Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Goal 10. Reduce inequality within and among countries

Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable

Goal 12. Ensure sustainable consumption and production patterns

Goal 13. Take urgent action to combat climate change and its impacts

Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land loss degradation and halt biodiversity loss

Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

Source: *Global indicator framework for the SDGs and targets of the 2030 Agenda for Sustainable Development (document: A/RES/71/313).*

International organizations such as the UN, the World Bank, Asian Development Bank (ADB), and Food and Agriculture Organization (FAO) have undertaken significant efforts to promote the incorporation of TBL concepts into policies and operations of private and public organizations. For instance, social and environmental impact assessment has become a required integral part of the design and implementation of projects financed and/or implemented by international organizations.

The three components – economic development, social development and environmental protection - were adopted also by the United Nations as interdependent and mutually reinforcing pillars of sustainable development, in the 2005 World Summit of the United Nations.[62]

In September 2015, at the UN Summit the world leaders officially adopted 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development. The seventeen SDGs have more comprehensive coverage and reflection of all the three dimensions of development - environmental, social and economic dimensions, including areas that are directly related to business operations such as Responsible Consumption and Production (see Box 1).

8.3 - SUSTAINABLE/GREEN SUPPLY CHAIN

8.3.1 - WHAT IS THE SUPPLY CHAIN?

There are many definitions of the supply chain used in academic and business circles. In broad terms "a supply chain consists of all stages involved, directly or indirectly, in fulfilling a customer request." Below are a few definitions and a brief description of a supply chain, to form a general picture of it.

Supply chains involve "Business processes from end-user through original supplier that provides products, services and information that add value for customers and value to shareholders." (Lambert, 1998, 2003).

According to the Council of Supply Chain Management Practitioners (CSCMP), "1) starting with unprocessed raw materials and ending with the final customer using the finished goods, the supply chain links many companies together. 2) the material and informational interchanges in the logistical process stretching from acquisition of raw materials to delivery of finished products to the end user. All vendors, service providers and customers are links in the supply chain."[63]

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[62] United Nations. 2005. *World Summit Outcomes.*
[63] CSCMP Glossary:
http://cscmp.org/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms.aspx?hkey=60879588-f65f-4ab5-8c4b-6878815ef921

The supply chain is a network of people and firms, facilities and equipment, technologies and activities, and materials and products involved in the creation and sale of a product or service, from the delivery of source materials from the supplier to the manufacturer, through to its eventual delivery to the end user.

Supply chains involve not only physical flows, i.e. flow of raw materials, work-in process and finished products, but also flow of information and financial means (see Figure 8.2). Physical flows, which are the well-known and visible part of the supply chain, involve the transformation, movement, and storage of finished and work-in-process products and materials. However, information flow is necessary to coordinate plans and actions between various stages and participants upstream and downstream the supply chain, and to control the day-to-day operations and movement of materials and products across the supply chain. Financial flows involve the transfer of money among and between stages and participants of the supply chain.

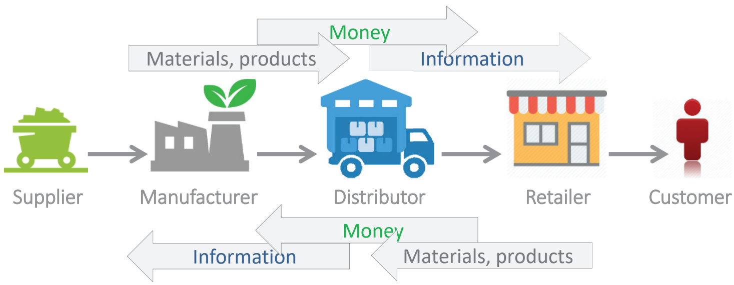

Figure 8.2. Supply chain stages/participants and flows

Participants of a supply chain include, *inter alia*, suppliers of raw materials, manufacturers of parts or completed products, distributors, transporters, retailers, and final consumers. Each stage is a customer for the previous stage, and each previous stage is a supplier of the next stage. For instance, a rubber producer is a supplier for tire producers, and a tire producer is a customer for rubber supplier. Further down the supply chain, the tire producer becomes a tire supplier for the car manufacturer, i.e. the car manufacturer becomes a customer for the tire supplier. Within each company, the supply chain includes all functions involved in fulfilling a customer request - product design and development, marketing, operations, distribution, finance, and customer service.

Supply chain and logistics are not the same thing. Logistics is a major part of supply chain management, but not all.

Distinction shall be made between supply chains and logistics. Logistics is important, but is still only a part of a supply chain. For depicting and analyzing a supply chain performance, Chopra & Meindl (2016) suggest two sets of drivers for a supply chain – ***logistics drivers and cross-functional drivers.***

Logistics drivers include:

- **Facilities** – places where inventory is stored, assembled, or fabricated, i.e. production and storage sites.
- **Inventory** – raw materials, work in process (WIP), and finished products in the supply chain.
- **Transportation** – various transportation modes (their combinations) and routes involved in moving raw materials, WIP and finished goods from one point to another in a supply chain.

Cross-functional drivers include:

- **Information** - data and analysis regarding facilities, inventory, transportation, as well as other factors and indicators throughout the supply chain.
- **Sourcing** – decisions on what operations and/or functions (such as purchase, production, storage, transportation, information, financial, and etc.) a firm wishes to perform itself and to outsource to other firms.
- **Pricing** – decisions on prices associated with goods and services provided by a firm.

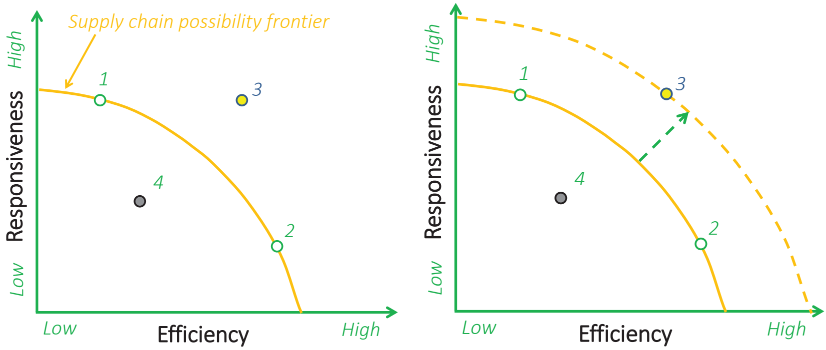

Figure 8.3. Supply chain responsiveness vs. efficiency (Borrowed and modified from Chopra & Meindl, 2016)

In general, a supply chain's performance can be viewed as its ability along two key dimensions - responsiveness and efficiency. **Responsiveness** is a supply chain's ability to respond to customer demand/request. It is not just about the ability to deliver fast (in time) and meet short lead times, but also about the ability to handle a large variety of products, meet wide ranges of quantities and qualities demanded, innovate and offer innovative products and services, provide a high service level, and handle supply uncertainty.

There is always a cost to achieving responsiveness. Increasing responsiveness results in higher costs that lower efficiency (Figure 8.3). A supply chain **efficiency** is the inverse of the cost of making and delivering the product or service to the customer.

Figure 8.3 provides a graphical interpretation of the trade-off between supply chain responsiveness and efficiency. A supply chain operating on its possibility frontier line, i.e. points 1 and 2 in Figure 8.3, performs at its maximum capability. At point 1, a supply chain focuses more on responsiveness, but incurs higher costs and, thus, is less efficient. For instance, a fresh fruit supplier shipping apricots from Yerevan to Moscow via airplane would be very fast (responsive) in delivering freshly picked fruits to the customer within 3-4 hours, but would incur high transportation cost. Alternatively, the fresh fruit supplier may decide to ship apricots in trucks, which would take more time, 3-4 days, but would cost less, i.e. the supply would be less responsive, but less costly or more efficient. For another example, a retailer wishing to be responsive to demands of its customers in terms of product variety would need to purchase a large variety of products, secure sufficient warehouse space to store the products, and hire additional workers or technology to handle the wide variety of products. All these extra efforts come at extra cost.

A supply chain operating at point 4 suffers from underutilization of its capability, i.e. operates below the maximum responsiveness and efficiency that the supply chain could achieve. Point 3 (on the left side graph of figure 3) is impossible given the current level of resources and technology. In order to achieve point 3, the supply chain would need to increase its capability by adding resources or enhancing technology that would allow to shift up the possibility frontier itself (to the dotted line, on the right side of Figure 8.3).

To a large extent, **supply chain management** is aimed at finding the effective balance between supply chains responsiveness and its efficiency. Supply chain management is about establishing and achieving optimal combination and interaction between and among the drivers of a supply chain to maximize the profit of the overall supply chain. A comprehensive approach, i.e. viewing the supply chain in its entirety, is important for avoiding internal conflict of objectives between various stages of a supply chain. The profit maximization effort shall be for the ***overall*** supply chain, but not for individual stages of the supply chain.

According to CSCMP's, "Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies."[64]

8.3.2 - WHAT IS THE SUSTAINABLE/GREEN SUPPLY CHAIN?

Sustainable supply chain management (SSCM) is, in effect, the integration of sustainability into supply chain management. Pagell and Wu (2009) broadly define SSCM as specific managerial actions that are taken to make the supply chain perform well on all elements of the triple bottom line (TBL) with an end goal of creating a genuinely sustainable supply chain.

Green supply chain management (GSCM) is focused on environmental responsibility. It consists of "… environmentally conscious management (ECM) and supply chain management (SCM). GSCM integrates environmental responsibility into all SCM activities, including product design, material selection, and manufacturing, transportation, and information manipulation. GSCM extends the SCM coverage beyond the point of sale and leads to extended production responsibility (EPR). ERP holds producers accountable for their product's end-of-life (EOL) impact, and this way, forces them to manage their products throughout their lifecycles." (Wang, H.-F. & Gupta, S.M. 2011).

8.4 - WHY DO FIRMS ADOPT SUSTAINABLE/GREEN SUPPLY CHAIN MANAGEMENT PRACTICES?

Sustainability and environmental issues have got a growing importance in the contemporary business environment, and finding efficient solutions towards a more sustainable supply chain is increasingly important for managers. There are a number of reasons or motives that lead firms to apply sustainable/green supply chains, and these could be grouped into the following categories:

- **Increasing the efficiency of firm operations.** For instance, environmental practices such as energy savings and use of renewable energy resources can help firms to reduce their energy costs. Moreover, material innovation (e.g. packaging material) can help to both reduce costs and improve the quality of products and services, adding value for customers.

[64] CSCMP website:
http://cscmp.org/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms.aspx?hkey=60879588-f65f-4ab5-8c4b-6878815ef921

Additional examples are technologies such as drip irrigation in agriculture and Recirculating Aquaculture System (RAS) in fish production allow saving water and reducing soil and water pollution, while achieving significant productivity gains and reduction of production costs.

- **Reduction or elimination of risks of business failure.** Businesses whose operations are highly dependent on access to natural resources, such as those in the oil and gas sectors, forestry sector and agriculture. Similarly, businesses whose operations pose significant health and safety hazards to workers or have significant socioeconomic impacts on local communities, such as mining, often face a high level of social risk. Starbucks, for example, focused on sustainability of its coffee supply sources, because a supply failure, especially for high quality coffee, would have significantly limited its ability to grow. To address this challenge Starbucks developed sourcing guidelines to ensure that produced coffee met environmental and social performance criteria at each stage of the supply chain.
- **Government regulation.** In some instances government regulations force industries to adopt sustainable strategies. For example, Waste Electrical and Electronic Equipment (WEEE) and Restriction of Hazardous substances (RoHS) directives of the EU forced cell phone manufacturers to change their design and sourcing strategies. Similarly, the decision by some governments to prohibit the use of petroleum- and diesel-engine automobiles in their countries and shift to electric automobiles, affects and will affect strategic choices of the whole automobile and related industries and companies. Another example is the EU Strategy for Plastics in the Circular Economy, which will transform the way plastics and plastics products are designed, produced, used and recycled. By 2030, all plastics packaging should be recyclable. The strategy aims also at reducing the impact of single-use plastics, particularly in seas and oceans.
- **Pressure by customers, civil society organizations, and communities.** In the recent three decades, there has been increasing pressure on businesses to adopt sustainable policies and operations. The increasing awareness among customers and other stakeholders of the supply chain and cultural changes in many societies have made customers and the public more demanding in relation to sustainability.
- **Marketing.** Sustainability adds to the value of a firm's brand name and has become an important element of branding. Through sustainable policies firms can build a positive reputation and attract customers who value environmental protection and sustainability.

To succeed in achieving sustainability of the supply chain, businesses need to ensure effective coordination among various participants of the supply chain, and effective engagement of all stages in the supply chain strategy. Adoption of sustainable business practices often can enhance a firm's profitability while helping to protect the environment. Fair and ethical attitudes and behavior towards a firm's stakeholders are often in the best interest of the firm.

However, there are situations when this is not the case! There are a number of difficult questions that do not have clear-cut or easy answers. These issues shall be given due consideration when designing and operating a supply chain. It is critical to include them at the very beginning – the strategy formation phase.

8.5 - STRATEGIES AND PRACTICES TO ACHIEVE SUSTAINABLE / GREEN SUPPLY CHAINS

From a strategic point of view, it is critical that firms view the environmental and social impact of the whole supply chain, not just the stage under their direct control. In other words, it is critical to consider also the actions of a firm's suppliers, retailers, and, eventually, final consumers. This is critical also in terms of measuring the impact of environmentally friendly actions. Effective collaboration with participants upstream and downstream the supply chain may significantly enhance the economic, environmental, as well as social impact of green supply chain management practices.

8.5.1 - SUSTAINABLE/GREEN SUPPLY CHAIN CONCEPTS AND STRATEGIES

The recent five decades of thinking about efficient use of resources, reduction of waste, and environmental protection have led to the emergence and development of sophisticated concepts on sustainability such as the Product Life Cycle approach, Closed Loop approach, Circular Economy Concept, and Cradle-to-Cradle concept. In essence, these concepts are similar and are about transformation from the ***"linear"*** view of the supply chain, which involves "extract-produce-use-throw away" steps, to the **"circular"** view, which includes reuse, recycling, and recovery of goods and materials.

- **Product life cycle approach** goes beyond the traditional supply chain focus on the production stage to include all other processes of the entire product life cycle, including those after the point of sale such as product/service use and its disposal. Note that, in this context, the product disposal includes reuse, recycling, recovery and discarding the used products or wastes in landfills (see Figure 8.4). The objective of the product life cycle approach is to reduce resource use and emissions to the environment as well as improve its social and economic performance through the entire product life cycle.
- **Closed Loop Supply chain:** The Closed Loop approach is based on the principle of controlling material inputs to maximize recycling and recovery of materials and minimize waste to landfill whilst greatly reducing the environmental footprint. In contrast to a traditional supply chain where materials and products flow in one irreversible direction "from cradle to grave", in a closed loop supply chain, material and product flow is reversible. In a closed loop supply chain the used products and waste must be managed even after they leave the supply chain and are used by consumers; the materials and products must be re-used, recycled or recovered.
- **Cradle-to-cradle (C2C) approach** is another sophisticated approach similar to Closed Loop and Circular Economy ones. C2C is a sustainable business strategy that is based on the imitation of the regenerative cycle of nature in which waste is reused. In nature, when a tree or animal dies or creates waste, that waste breaks down and becomes nutrients for another process. This is the goal of the cradle-to-cradle approach: creating a cyclical process instead of a linear one like the cradle-to-grave approach. The main objective of the cradle-to-grave approach is to decrease waste. The cradle-to-cradle approach goes a step further and attempts to eliminate waste altogether. (McDonough, W. & Braungart, M. 2002), (Kalogerakis K. et al. 2015).

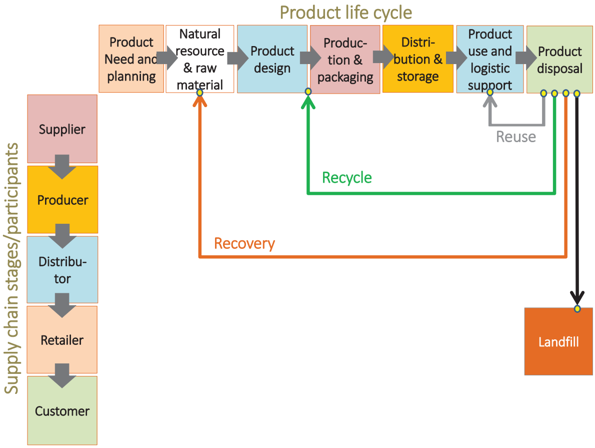

Figure 8.4. Supply chain participants (stages) and product life

Firms and organizations may adopt a wide range of strategies to ensure sustainability of their activities, starting from simple reduction of resource use and ending with a sophisticated Closed Loop Supply Chain approach. Below is a brief discussion of some sustainable/green supply chain strategies:

- **Reduction of resources used** in the production, storage, and delivery of products and services. This may include the reduction of energy use; cutting the amount of water use; soil saving techniques; the use of renewable energy.
- **Reduction of waste or pollution**, including the elimination or neutralization of water contamination; reduction or elimination of the emission of greenhouse gasses (GHGs), carbon dioxide, ozone-depleting substances, nitrogen and sulfur oxides, and wastewater; reduction of quantities of waste; reduction of packaging material.
- **Material, product or process innovation** such as the creation of new, more environment saving materials (e.g. water-degradable packaging materials, renewable energy materials, electric cars); recycling techniques; recirculation aquaculture systems (RAS); drip irrigation; hydroponics and similar technologies in crop production; the use of oil from algae for some paints as a low-carbon alternative to traditional petroleum-based oil.

Figure 8.5. Nairian store

- **Reverse logistics,** which, in simple wording, is any process that involves moving things from the customer back to the producer. This includes business processes to move products from distribution end points such as retail stores back in the supply chain to warehouses, production sites, etc.

  Rogers and Tibben-Lembke (1999) define reverse logistics as "the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal."

  According to the Council of Supply Chain Management Professionals, reverse logistics is "a specialized segment of logistics focusing on the movement and management of products and resources after the sale and after delivery to the customer. Includes product returns for repair and/or credit."[65]

  Some common types of reverse logistics include:

  - Returns, i.e. handling customer return of goods under a warranty.

[65] CSCMP website: http://cscmp.org/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms.aspx?hkey=60879588-f65f-4ab5-8c4b-6878815ef921

- Returns avoidance, processes that seek to minimize returns such as support websites or local repair shop partners.
- Remanufacturing, building products with a combination of reused, repaired and new parts.
- Refurbishing, reconditioning used goods for resale.
- Packaging, the use of durable packaging that is continuously reused, e.g. return and reuse of beverage bottles, cosmetics bottles or jars. *Nairian*, an Armenia-based natural cosmetics producer, uses reusable bottles and jars for its creams. After use, customers can take their containers to *Nairian* store and refill them (and save money by paying only for the refilled creams).
- Unsold Goods, in some cases, unsold goods may be returned by distribution partners according to the terms of their contract.
- End-of-Life, accepting goods at the end of their life for reuse and recycling. *Kiehl's,* a US-based cosmetics company, offers an in-store recycling program that accepts full-size, sample size, and complementary product packaging. If 10 full-size bottles are returned for recycling, the customer will receive a free travel size Kiehl's product. Similarly, *MAC Cosmetics* currently accepts primary packaging for recycling and provides a free lipstick for every six products turned back.
- Delivery Failure, deliveries that don't complete such as refusal of delivery by customers.
- Rentals and Leasing, customers returning things that are on loan such as an equipment rental.
- Repairs & Maintenance, returning things to the producer for repair and maintenance.

A number of effective production and supply chain management concepts and strategies, which directly and indirectly contribute to sustainability, were developed in Japan after WWII and then adapted in many other countries.

- **Total Quality** is an approach to doing business that attempts to maximize an organization's competitiveness through the continual improvement of the quality of its products, services, people, processes, and environments (Goetsch D. et al. 2016).

- **Lean approach,** which in short means "To produce better products or deliver better services using fewer resources" or "Doing more with less and doing it better". The Lean approach is based on Just-in-Time Toyota Production Systems.

8.5.2 – SUSTAINABILITY / GREEN STRATEGIES AND SUPPLY CHAIN PERFORMANCE

To understand and measure the effects of sustainable or green strategies on the supply chain performance, it is helpful to examine how each of the drivers of the supply chain is affected by sustainable/green strategies. It can be done by looking at drivers from two angles: (i) what sustainability challenges are associated with each driver; and (ii) how each driver contributes to achieving sustainability objectives.

Facilities include production facilities, warehouses, distribution centers, retail stores, etc. Facilities provide good opportunities for establishing effective synergies between a firm's environmentally friendly performance and its financial performance.

Sustainability solutions in relation to facilities may include:

- The optimal choice of the location of facilities, which can help to reduce costs of transporting material and finished goods, as well as fuel and energy used for transportation and cargo handling.
- Efficient layout design of facilities to minimize movement of goods and materials in the production process, and the use of equipment.
- The use of construction materials and design that would allow saving energy and heat. For instance, the LEED (Leadership in Energy and Environmental Design) certification system applied in the US is widely used to rate buildings in terms of their energy efficiency and environmental footprint.
- The use of energy efficient equipment and/or machines, and use of electric machines instead of fuel-based machines.
- The use of efficient and effective production processes and techniques, such as Lean, Just-in-Time Lean, Six Sigma, and Total Quality Management (TQM), which allow cutting costs, and reducing defective products and production waste.

8.5.2.1 - Inventory

Inventory includes raw materials, work in process, and finished products. Effective inventory management techniques help to reduce the amount of inventory stored in warehouses or production sites across the whole supply chain. The reduction of inventory helps to achieve cost savings thanks to decreasing the warehouse size (space) and labor required for inventory storage, energy saving for refrigeration or heating, cutting emissions from inventory handling machines and equipment, and lessening product loss and/or damage, etc. The reduction in warehouse size is essential for cutting the footprint from heating, refrigeration and cooling, air conditioning and lighting.

From environmental perspective, it is critical to note that the disposal of products in the landfills causes significant costs to the society as a whole, though it does not cause costs directly to the supply chain (the producer). Traditionally, this aspect of inventory was not considered to be part of the supply chain. Mc Donough & Braungart (2002) put forward a "cradle-to-cradle" design framework that suggests designing products which can be decomposed in the soil or products which can be returned to industrial cycle to supply high quality raw materials for new products. A Cradle-to-Cradle Certification program was established in 2005 to recognize high levels of sustainability achieved by its clients and to inspire others to optimize their products and "rethink the way they make things."[66]

Fichtinger J. et al. (2015), in their study of the environmental impact of inventory management on warehouse-related GHG emissions, suggest that decisions on supply lead times, reorder quantities, and storage equipment all have an impact on costs and emissions, and therefore this integrated approach will inform practical decision making.

8.5.2.2 - Transportation

Similar to facilities, transportation is an area where firms have opportunities to simultaneously reduce negative environmental impact and their costs. Any supply chain design innovation that

[66] http://www.mcdonough.com/cradle-to-cradle/

lowers transportation costs also tends to reduce fuel consumption and emissions and waste from transportation.

Solutions in the transportation may include particularly:

- Product design that reduces transportation costs (e.g. modular furniture design at IKEA, which allows using less of a space when transporting, see below)
- Optimization of facility location that allows reducing transportation costs
- Effective management of orders and delivery, e.g. order aggregation that can allow achieving more efficient loading of transportation vehicles
- Use of energy-saving transportation means or transportation using renewable fuel.

8.5.2.3 - Sourcing

With globalization and the search for cheap raw materials and labor, there is higher risk for firms to have a negative environmental and social impact. To reduce negative environmental and social impact, firms need to establish and implement effective monitoring mechanisms to make sure that their suppliers apply sustainability principles. Sourcing may have considerable impact on firm reputation in the market among consumers. Many corporations such as Nike, Starbucks CAFÉ program, IKEA, and Coca Cola apply policies of responsible sourcing.

8.5.2.4 - Information

Well-structured, accurate, complete and timely information is critical for the effective operation of any supply chain. Collection of good information is a challenge across the supply chain. The challenges to be tackled include particularly: (a) design and standardization of the data and information necessary to be transmitted from one stage of the supply chain to another; (b) coordination among various stages of the supply chain. The use of modern information technologies allows facilitated and effective use of information for the planning and operation of supply chain. These include technologies such as:

- EDI – Electronic Data Interchange
- Internet

- ERP systems (Enterprise Resource Planning)
- Supply Chain Management software
- RFID (Radio frequency Identification) technology.

8.5.2.5 - Pricing

Effective use of differential pricing can improve the utilization of assets, leading to resource reduction. For example, the effective use of differential pricing by air transport companies helps to achieve better occupation of passenger seats and thus reduce transportation cost per passenger of per cargo. It is very important to evaluate how much consumers are willing to pay for sustainably produced products and/or services. This in turn depends on how much consumers and the society as a whole value sustainability and environmentally-friendly production.

8.5.3 - EXAMPLES OF SUSTAINABLE/GREEN SUPPLY CHAIN STRATEGIES AND PRACTICES

Many companies in various industries all over the world, especially in developed countries, have adopted one or more of the strategies or approached described above. They set out high standards for sustainable business and implement sophisticated practices towards achieving effective balance between economic, environmental and social objectives.

Figure 8.6. Water and energy saving record at Coca Cola Hellenic Bottling Plant in Yerevan, Armenia. Photo G. Gabrielyan

For instance, IKEA uses modular design for its furniture, which allows the company, among other things, to tightly pack its parts when delivering from manufacturing sites to its stores and/or warehouses. This modular design thus helps to cut transportation costs and reduce air pollution. In addition, modular design helps also to reduce production costs by reducing set-up costs in the manufacturing process.

Coca Cola Hellenic Bottling Company adopted a policy of environmental protection via water and energy saving. Figure 8.6 presents the Environmental Commitment Board of the company's branch in Yerevan, Armenia. The board shows monthly targets for saving water (used for production of 1 liter of Coca Cola or another soft drink produced by the company) and energy.[67] Water and energy saving helps to both reduce production costs and protect the environment. Importantly, the company goes beyond saving water in just the production process in its facilities. It adopted a comprehensive approach and cooperates with its suppliers to help them reduce waste of water **in all**

[67] The target for saving water was to reduce the amount of ware used for producing 1 liter of a drink to 2.32 liters of water (during November 2017). The company actually achieved a better result – 2.08 liter per 1 liter of a drink.

stages of the supply chain. The company also invests in water resource saving projects in the communities of the country. Since 2011, Coca Cola Hellenic Armenia established and operated a sophisticated wastewater treatment facility, which filters and cleans all the wastewater to make it safe for the environment.

HP Inc. adopted Design for Environment Program (DfE) - an engineering perspective where the environmentally related characteristics of a product, process or facility are optimized. Through this program, HP considers environmental impact in the design of every HP product and solution. The program has led to numerous innovations. HP determined that over 93% of its carbon and water footprint occurs in its supply chain and when customers use HP products and solutions. Product use impacts come mostly from energy consumption, associated water use, and paper manufacturing. Therefore, in its DfE program HP decided to reduce these environmental impacts through the design of its products. HP's DfE program focuses on: "…(i) energy efficiency via reduction of the energy required to manufacture and use our products; (ii) material innovation to use less material, increase recycled and recyclable content, and use materials with lower environmental impact; (iii) design service models to reduce environmental impacts and increase product longevity through support (for example, Care Packs and upgrades) and new business models; (iv) end of product life options to make responsible return and recycling easier."[68]

[68] HP's official website: http://www8.hp.com/us/en/hp-information/environment/design-for-environment.html

AREA OF IMPACT	GOAL	FY16	APRIL 2017 PROGRESS
SOURCING COMMITMENT	*100% ethically sourced coffee*	99%	99% ethically sourced coffee
PLANTING TREES	*Provide 100 million trees to farmers by 2025*	9M	25 million trees donated through our One Tree for Every Bag Commitment initiative
GLOBAL FARMER FUND	*Invest $50 million in farmer loans by 2020*	$21.3M	We have $21.3 million currently committed or invested in farmer loans
OPEN-SOURCE AGRONOMY	*Train 200,000 coffee farmers by 2020*	new goal	We offer current training to farmers through our eight Farmer Support Centers and will begin reporting impact in the FY17 report
GREENER CUP	*Double the recycled content, recyclability and reusability of our cup by 2022*	new goal	Our cups currently contain 10% post-consumer fiber (PCF), we have front-of-house recycling in over 50% of our U.S. company-owned stores and 1.4% of our beverages are sold using a reusable cup
GREENER STORES	*Build and operate 10,000 greener stores globally by 2025*	1,000	Over 1,200 LEED®-certified stores in 20 countries
GREENER POWER	*Invest in 100% renewable energy to power operations globally by 2020*	new goal	We have purchased Renewable Energy Credits (RECs) to cover 100% of our electricity usage in global company-owned stores, and in April 2017 we announced an investment in a 260-acre solar grid in Robeson County, N.C.
GREENER APRONS	*Empower 10,000 partners worldwide to be sustainability champions by 2020*	1,120	We have officially launched our Greener Apron™ program in four markets
VETERANS AND MILITARY SPOUSES	*Hire and honor 25,000 veterans and military spouses by 2025*	7,745	In March 2017, we met our initial goal of 10,000 hires and expanded the goal to 25,000
STARBUCKS COLLEGE ACHIEVEMENT PLAN	*Graduate 25,000 partners by 2025 and increase accessibility and performance*	227	More than 400 partners have graduated to date with over 6,500 partners participating in ASU's online degree programs
OPPORTUNITY YOUTH	*Embrace and employ 100,000 Opportunity Youth by 2020*	32,096	In 2015 we set a goal to hire 10,000 Opportunity Youth; we surpassed this goal within the first year and expanded our goal to 100,000 by 2020
REFUGEES	*Welcome and employ 10,000 refugees globally by 2022*	new goal	In January 2017, we announced our commitment to hire 10,000 refugees across the 75 countries we serve; we will share our progress in the FY17 report
FOODSHARE	*Rescue 100% of food available to donate by 2020 in U.S. company-owned stores*	new goal	The FoodShare program was announced in FY16 and began its rollout; to date, we have donated over 1 million meals
COMMUNITY SERVICE	*Have 100% of our stores worldwide annually participate in community service by 2020*	new goal	We established our baseline of 25,000 stores and will track progress going forward

Figure 8.7. Sustainability goals summary table: Starbucks Company. Source: https://www.starbucks.com/responsibility/global-report

Starbucks Company has undertaken a number of sustainable initiatives. In 2016, Starbucks issued a $500 million sustainability bond, the proceeds from which are directed to improving the company's supply chain's environmental and social impact. Starbucks used the proceeds through its three programs:

- C.A.F.E. practices for coffee purchases. C.A.F.E. Practices ensures that Starbucks is sourcing sustainably grown and processed coffee by evaluating the economic, social and environmental aspects of coffee production.[69]
- The development and operation of Farmer Support Centers
- Global Farmer Fund that provides loans to farmers across the globe

The table below summarizes sustainability goals adopted by Starbucks Company in four broad areas: (1) sustainable coffee; (2) green retail; (3) creating opportunities; (4) strengthening communities.

[69] These aspects are measured against a defined set of criteria detailed in the C.A.F.E. Practices Generic and Smallholder Scorecards. According to an impact study performed by Conservation International, C.A.F.E. Practices has significantly benefited more than one million workers employed by participating farms.

Since end of the 20th century, sustainability has become an integral part of corporate strategies of many companies like those discussed in this chapter. And the number of firms adopting sustainable strategies and practices is increasing, since there is increasing awareness and understanding about the positive impact of such strategies on overall company performance.

Each industry or sector has its own peculiarities that shall be taken into account when designing sustainable supply chain strategies. The table below presents such specific characteristics in the construction industry, which is one of the major exploiters of natural resources that has significant impact on the environment.

Table 8.1. Environmental implications of construction industry

WHAT IS USED?	WHERE IT IS BUILT?	HOW IT IS BUILT?	WHAT IS BUILT?
• Where raw materials are obtained	• Location of facility; nature of terrain and ground conditions; alternative uses of the land	• Methods of construction on site	• Planning and design of facility (e.g. potential of daylight and natural ventilation)
• How raw materials are extracted; how land is restored after extraction (if necessary)	• Immediate physical environment; proximity to water sources and ecosystems	• Construction project management systems (e.g. quality management systems)	• Life-cycle economic, quality, maintainability considerations
• How raw materials are processed	• Social disruption (e.g. displacement of site's inhabitants)	• Site control measures (housekeeping)	• Extent of use of energy and other resources in operation of building
• Whether, and how renewable raw materials are regenerated	• Economic disruption (e.g. loss of livelihoods of previous inhabitants)	• Welfare of site workers, neighbors and general public.	• Ease of demolition of building (deconstruction)
• How materials are transported and stored on site	• Present infrastructure, need for expansion to serve new building, its impact	• Resource management (include waste minimization)	• Recycling and use of demolition waste
• How materials are moved on site	• Impact on local vehicular traffic		

Source: Ofori G. 1999

8.6 - INTERNATIONAL STANDARDS RELEVANT TO SUSTAINABLE/ GREEN MANAGEMENT

Together with the development, adoption and dissemination of environment protection and sustainability concepts, a large variety of industry-specific, national, and international standards and techniques have been created. This section discusses only some of the internationally well-known standards and/or certification programs which promote the implementation of sustainable/green practices among producers as well as consumers.

8.6.1 - ISO ENVIRONMENTAL MANAGEMENT AND SOCIAL RESPONSIBILITY STANDARDS

The International Organization for Standardization (ISO) developed the ***ISO 14000 family of standards*,** which provides practical tools for companies and organizations of all kinds looking to manage their environmental responsibilities. Particularly, the **ISO 14001:2015 standard** specifies the requirements for an environmental management system that an organization can use to enhance its environmental performance. ISO 14001:2015 contributes to the environmental pillar of sustainability. It is applicable to any organization, regardless of size, type and nature, and applies to the environmental aspects of its activities, products and services that the organization determines it can either control or influence considering a life cycle perspective. ISO 14001:2015 can be used in whole or in part to systematically improve environmental management. Claims of conformity to ISO 14001:2015, however, are not acceptable unless all its requirements are incorporated into an organization's environmental management system and fulfilled without exclusion.[70]

[70] There are a number of other supporting standards in this family that provide guidance on the phased development, implementation, maintenance and improvement of an environmental management system. For instance, **ISO 14005:2010** provides guidance for all organizations, but particularly small- and medium-sized enterprises. **ISO 14006:2011 - Guidelines for Incorporating Ecodesign** provides guidelines on establishing, documenting, implementing, maintaining and continually improving their management of ecodesign as part of an environmental management system (EMS). ISO 14006:2011 applies to those product-related environmental aspects that the organization can control and those it can influence.

In addition, the ***ISO 26000 - Social Responsibility*** standard provides guidance on how businesses and organizations can operate in a socially responsible way, i.e. in an ethical and transparent way that contributes to the health and welfare of society

8.6.2 - EU ECOLABEL

Since 1992, **the EU Ecolabel** identifies and promotes products and services that comply with high standards of environmental and social responsibility. As indicated, the "Ecolabel promotes Europe's transition to a circular economy, where materials stay in a loop, so new products begin when old ones end. This drives manufacturers to produce goods that:

- Promote green innovation and sustainable industries
- Generate less waste and CO 2 when they are made and used
- Use energy, water and raw materials more wisely
- Last longer and are easier to repair
- Are easier to recycle."[71]

EU Ecolabel is based on the **ISO 14024 standard - Environmental labels and declarations.** At present, there are over 50,000 products and services certified for compliance with Ecolabel requirements.

8.6.3 - LEED STANDARD

LEED (Leadership in Energy and Environmental Design) is the most widely used green building rating system in the world. Available for virtually all building project types, from new construction to interior fit-outs and operation & maintenance, LEED provides a framework that project teams can apply to create healthy, highly efficient, and cost-saving green buildings. LEED certification is a globally recognized symbol of sustainability achievement.

8.6.4 - CRADLE-TO-CRADLE CERTIFIED PRODUCT

In 2010, William McDonough and Michael Braungart established the Cradle to Cradle Products Innovation Institute, a non-profit organization, to establish and administer the ***Cradle to Cradle***

[71] Source: http://ec.europa.eu/environment/ecolabel/

***Certified*™ Product Standard**. Since then, many companies adopted C2C standards and obtained C2C certificates. This organization carries out studies with enterprises that adopted C2C to explore the economic, social, and ecological benefits of certification.

8.6.5 - FAIR TRADE CERTIFIED PRODUCT

Fair Trade is a global movement active in 70 countries of the world. Fair Trade developed standards to promote environmental and social responsibility based on ten principles of fair trade

Box 2. Ten principles of Fair Trade

1. Creating Opportunities for Economically Disadvantaged Producers	2. Transparency and Accountability
3. Fair Trading Practices	4. Fair Payment
5. Ensuring no Child Labor and Forced Labor	6. Commitment to Non-Discrimination, Gender Equity and Women's Economic Empowerment, and Freedom of Association
7. Ensuring Good Working Conditions	8. Providing Capacity Building
9. Promoting Fair Trade	10. Respect for the Environment

(see Box 2). Products and services that are Fair Trade Certified™ are produced by responsible entrepreneurs or firms which empower farmers, workers, and fishermen, and protect the environment.

8.7 - TRENDS: EFFECTS OF GLOBALIZATION AND TECHNOLOGICAL DEVELOPMENT ON GREEN SUPPLY CHAINS

Globalization leads to higher complexity of supply chain networks, more and diverse markets, more intensive competition. In this dynamically changing global environment, businesses should consider global risks and uncertainties and be flexible to tackle the uncertainties. In this regard, it is important to achieve higher flexibility of supply chains, i.e. build flexible production plants and design flexible production and distribution processes.

In the globalized environment, to effectively benefit from their competitive advantage and reduce production costs, firms often choose to have a higher level of vertical integration in the supply chain, and more fragmented ownership in international supply chains. This makes it more difficult to coordinate and manage sustainable policy design and implementation in firms that have a wide international network.

Technological development opens new horizons and opportunities for achieving sustainability. Examples of such technologies include: renewable energy sources, energy efficient machines and equipment (LED lamps), creation of new and more environmentally friendly materials, agricultural/food production technologies such as drip irrigation, hydroponics, aquaponics, and various information technologies listed above in the text.

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CHAPTER 9. SUSTAINABILITY AND SUPPLY CHAIN MANAGEMENT

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9.1 – INTRODUCTION

The origins of the concept of sustainability date back to the early seventies, but the most often cited definition of sustainable development was stated by the World Commission on Environment and Development in its so-called "Brundtland Report" (1987, p. 54). This report defines sustainable development as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* Given that this sustainability definition was fairly broad, governments across the world sought to refine it in terms more applicable to their own situations, yet closely aligned with the Brundtland definition. Most such definitions had in common the three dimensions of sustainability: economic, social, and environmental. Sustainable solutions should be economically viable, socially equitable and ethically responsible, and consistent with the long-term ecological balance of the natural environment.

9.1.1 – TRANSPORTATION & SUSTAINABILITY

Since the aim of this chapter is toward having a sustainable supply chain, there is a need to understand the core of the supply chain when it comes to sustainability. Yes, the driving force of any supply chain is transportation. We cannot discuss about sustainability of any supply chain without taking into consideration its transportation system. In other words, the transportation system of any supply chain should support the whole supply chain to achieve sustainability. First let's understand what sustainable transportation refers to. Sustainable transport refers to the broad subject of transport that is sustainable in the senses of social, environmental and climate impacts and the ability to, in the global scope, supply the source energy indefinitely. Components for evaluating sustainability include the particular vehicles used for road, water or air transport, the source of energy, and the infrastructure used to accommodate the transport. Transport operations and logistics as well as transit-oriented development are also involved in evaluation. Transportation sustainability is largely being measured by transportation system effectiveness and efficiency as well as the environmental and climate impacts of the system.[1]

Transport systems have significant impacts on the environment, accounting for between 20% and 25% of world energy consumption and carbon dioxide emissions.[2] The majority of the emissions, almost 97%, came from direct burning of fossil fuels.[3] Greenhouse gas emissions from transport are increasing at a faster rate than any other energy-using sector.[4] Road transport is also a major contributor to local air pollution and smog.[5]

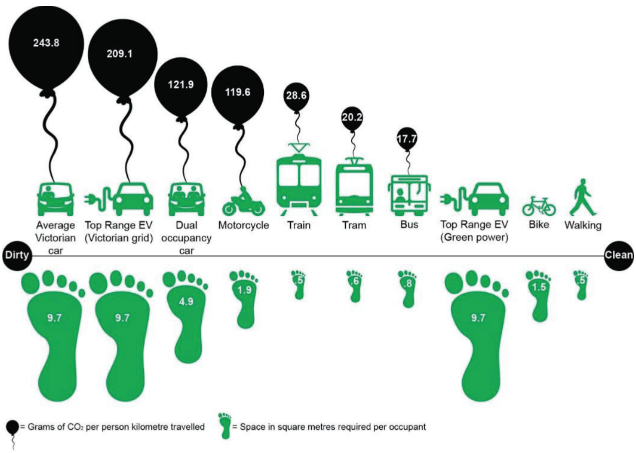

Figure 9.1 - Carbon emissions and footprints of different transport types [6]

Figure 9.1 represents the CO_2 emission and footprint, as well as space in m^2 required of different transport types while people traveling.

Below Figure (Figure 9.2) represents the amount of CO_2 emitted while transporting 1 ton of good for 1 kilometer.

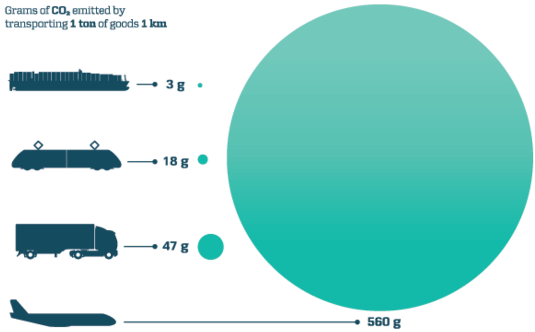

Figure 9.2 - CO2 emission for different modes of transport [7]

Looking on above chart, in terms of carbon dioxide emissions, transporting using ocean freight is 6 times more efficient than by rail, 16 times more efficient than transport by road and 187 more efficient than air cargo.

9.1.2 – LIFE-CYCLE ASSESSMENT & SUSTAINABILITY

Life-cycle assessment (LCA, also known as life-cycle analysis, Eco balance, and cradle-to-grave analysis) [8] is a technique to assess environmental impacts associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. Designers use this process to help critique their products. LCAs can help avoid a narrow outlook on environmental concerns by:

- Compiling an inventory of relevant energy and material inputs and environmental releases;

- Evaluating the potential impacts associated with identified inputs and releases;
- Interpreting the results to help make a more informed decision. [9]

LCA can be a very involved and lengthy process. However, the basic steps in LCA are:

- Goal and scope definition - this step defines the purpose of the LCA, identifies assumptions and boundaries and defines the scope (that is, what processes, elements and activities associated with the product/process/activity will be assessed).
- Analysis - the impacts of energy, materials, emissions, etc. are identified, classified and quantified. An inventory table listing all environmental impacts is one outcome of this process.
- Assessment - the environmental impacts of the product/process/activity are assessed.
- Interpretation/evaluation - the results are interpreted or evaluated. Opportunities for environmental improvement are identified, and value judgments are made. Products / services / activities are compared.

Several other sustainability concepts have arisen from LCA. Life cycle costing (LCC) examines environmental costs and is applicable to environmental accounting and budgeting. Streamlined LCA is a leaner approach to LCA, cutting costs and time involved in conducting a LCA. Life cycle inventory (LCI) looks at the inventory stage of LCA. Life cycle management (LCM) integrates life cycle principles into business and management structures, rather than just conducting a once-off LCA.

There is much debate about the validity and usefulness of LCA. However, used correctly, LCA provides meaningful results to aid decision-making.

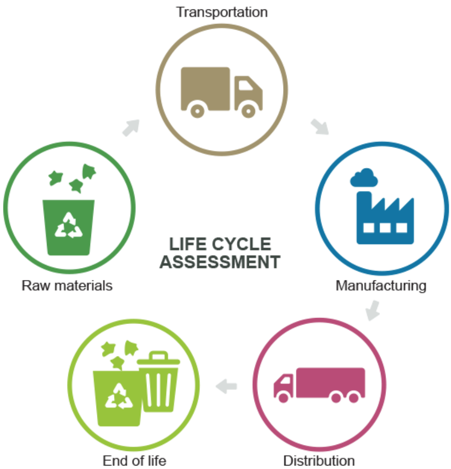

Figure 9.3 – LCA The Real Deal [10]

As it is depicted in Figure 9.3, LCA is inseparable from supply chain. On the other hand transportation is the enabler of the supply chain. Without transportation raw materials will not get delivered to the manufacturing facility. Similarly, finished goods will not get to the DCs, Retails, Stores, etc., and this is why considering LCA and Transportation is inevitable when we discuss about supply chain and sustainability.

Handling (loading & unloading of goods in DCs)

9.2 - UNDERSTAND THE NEED FOR A SUSTAINABLE SUPPLY CHAIN STRATEGY[11]

Development of the business plans through decades brings additional challenges to supply chain managers to manage today's companies. The trends causing these challenges can be globalization, increasing competition, need for stronger security, enviromental protection, and last but not least, the reliable, flexible, and cost-efficient business models capable of satisfying customers' continually changing demands. In future years supply chain management, "SCM", will therefore take additional strategic tasks that goes beyond its existing scope of activities which are more operational. In order to respond to this changes in consumer's perceptions, and at the same time to remain competitive, the supply chain managers need to identify and analyse new sustainability issues in their company and business enviroment.

Continuously adapting to sustainability demands—in order to create a sustainable, customer-focused supply chain—and the development of sustainable supply chain strategies are both essential for creating a sustainable competitive advantage.

In this chapter we will focus on how to develop a supply chain strategy for sustainability, as well as on how to integrate it in your existing supply chain. Section 19.2 introduces the fundamentals of competitive strategy, supply chain strategy, as well as the relation between those two. Section 19.3 describes the main ingredients of a sustainable supply chain strategy. Section 19.4 describes a six-step approach for developing and implementing a sustainable supply chain strategy.

9.3 – THE SUPPLY CHAIN STRATEGY: A CRITICAL SUCCESS FACTOR FOR SUSTAINABILITY

In the previous section we wrote about crucial role of strategic management in today's supply chains. Now the aim is to answer to following questions:

- What does a competitive corporate strategy involve?
- What is a supply chain strategy, and how it is linked to the competitive strategy?
- And where is the link to sustainability?

Figure 9.4 shows the three dimensions. In this section the aim is to understand the link between those three dimensions.

Figure 9.4 – Three areas to integrate [11]

The definition of competitive strategy is to gain a distinctive advantage over the competitors to guarantee profitability over a limited time period. A competitive strategy is a package of objectives to provide the firm with competitive advantages that allow the company to perform better than anyone else in its own industry. One of the measures on competitiveness is the company's profitability, compared to industry average.

There are two general types of competitive advantages that a company can follow: Low cost, or differentiation. These two basic approaches can be combined with the scope of activities of any firm and form three common strategies for achieving excellence and market success: cost leadership, differentiation, and focus—which by itself can be divided into two, as cost focus and differentiation focus.

In cost leadership, the firm aims to become the lowest-cost producer in the industry. The sources to become a cost leader are different among industries. Usually they include one or a combination of the following advantages:

- Economies of scale,
- Particular technology,
- Superior access to raw materials and/or,
- Access to well-developed distribution channels.

With a differentiation strategy, the company looks for products or services that are unique and one of a kind in that specific industry, and also create value advantage/s for its customers. This highlights the importance of considering one or more elements that customers observe as “high quality”, which generally leads to higher costs. But customers who are paying for such products/services are less price-sensitive and are more loyal to these differentiated companies, and reward the effort made by paying premium prices.

9.4 – INGREDIENTS OF A SUSTAINABLE SUPPLY CHAIN STRATEGY

After reviewing many discussions and case study interviews in the course of “bestLog” project with industry experts, we identified the ingredients of a sustainable supply chain strategy. The following gives an overview of these ingredients.

9.4.1 – INGREDIENT I: A STRATEGIC AND UNIVERSAL APPROACH

The bestLog research shows that sustainable practices, balancing environmental, economical, and social goals:

- Are extremely varied and arbitrary.
- Are often implemented in large corporations as “isolated solutions” for individual business units or functions, and often with a regional or specific customer scope.
- Often lead to solutions which seem to be sustainable at first glance, if you look only to a particular company, but not for the total supply chain.

These failings are due to an absence of:

- Specific sustainability goals in the corporate vision and strategy

- Specific sustainability goals in the supply chain strategy
- End-to-end responsibility of responsible logistics and supply chain managers
- Implementation experience and shared knowledge and
- Top management commitment

Logistics and supply chain managers are often mainly focused on measures that appear to lie within their natural scope of responsibility. They have often implemented environmental and social policies as a kind of aside, often without integrating them with the economic dimension. Sometimes to a greater and sometimes to a lesser degree, they have not really viewed or addressed economic, environmental or social responsibility issues holistically.

9.4.2 – INGREDIENT II: RECOGNIZING AND ASSESSING CURRENT AND FUTURE TRENDS

Changes in the business environment usually occur over time and affect companies in their competitive environment. "Corporate social responsibility" trends and "Green SCM" trends are examples of the extended responsibilities of companies. New supply chain objectives such as "Carbon (CO_2) management" extend the responsibilities of today's supply chain managers.

The key to ensuring long term success of any company is to adopt sustainable supply chain trends in their logistics goals and objectives. The challenge for supply chain managers in this context can be:

a) To identify the trends that are relevant to their complete supply chain and
b) To analyze and evaluate the potential positive and negative impacts in terms of supply chain performance.

9.4.3 – INGREDIENT III: IMPLEMENTATION OF ECONOMIC, ENVIRONMENTAL, AND SOCIAL OBJECTIVES

Implementation and execution of sustainable objectives into operations plays a crucial role in adaption of supply chains to "new" supply chain objectives such as environmental and social goals. Implementation is simply propagation of strategic long-term goals to specific short-term goals which are achievable by adjusting the day-to-day activities/operations. One consequence of an implementation process is a set of interrelated Key Performance Indicators (KPIs). The KPI system is a kind of quantitative tool used to implement strategic goals into company operations. Aside from the quantitative aspects of the KPIs, of course having high qualitative aspects, such as high motivation, awareness and good level of communication are also crucial for successful implementation of those strategic objectives into a company's operations.

The challenge here for supply chain managers is to break-down the strategic goals and objectives into "correct" KPIs and to define the targets for each KPI for any specific reporting time period. "Correct" KPIs should be able to measure and control the right operational processes. Another challenge is that some measures of operational goals may be complementary or have some conflict with each other; a good KPI system should consider the potential tradeoffs.

Environmental and social goals in particular are in most cases new to many operations and need to be integrated into their existing KPI system. One recent study on trends and strategies in logistics showed that 43% of large companies and only 26% of SMEs had defined concrete environmental and resource protection goals among their logistics operations' targets. [12] One reason is a lack of knowledge regarding the measurement and the assessment of environmental and social impact KPIs.

Setting SMART (Specific, Measurable, Attainable, Relevant and Time-bound) objectives is very important for accomplishing the goals of the community. The more specific the objectives are, the easier it will be to demonstrate success. For defining the KPIs we need to follow the S.M.A.R.T. requirements in order to achieve to our targets. “Specific” is at first, to ask 5 “W” questions.

- What: What do I want to accomplish?
- Why: Specific reasons for accomplishing the goal.
- Who: Who is involved?
- Where: Identify a location.
- Which: Identify requirements and constraints.

In most cases only some of these will be relevant but you should mentally check through all of them to make sure that you are not missing anything.

The second term, “Measurable,” stresses the need for concrete criteria for measuring progress toward the attainment of the goal. The thought behind this is that if a goal is not measurable, it is not possible to know whether a team is making progress towards successful completion. Measuring progress will help a team stay on track, reach its target dates, and experience the sense of achievement that spurs it on to the continued effort that is required to reach the goal. A measurable goal will usually answer questions such as:

- How many?
- How much?
- How will I know it is accomplished?

There is little point in setting a goal that is either too difficult to achieve or beyond your capabilities, as this will only serve to de-motivate you and destroy your self-confidence. The importance of being able to accomplish a goal is equally vital when you are setting goals for others, as it is for yourself. When setting a goal, you must use your knowledge and current skills as a barometer for ensuring that the goal is “Attainable”.

Setting yourself a goal that is too easily fulfilled will leave you feeling cheated once it is attained. This is because you didn't feel sufficient, if any, challenge was present in the process of accomplishing it. The more experience you have in setting your own goals, the more adept you will become at striking the necessary balance between your goal being challenging and it being attainable.

“Relevant” goals that are relevant to your boss, your team, and your organization will receive the needed support. A relevant goal can answer 'YES' to these questions:

- Is it worth the cost and resources required?
- Is this the right time to be doing it?
- Does it fit in with our overall strategy?

Relevant goals drive the team, department, and organization forward. A goal that supports or is in alignment with other goals would be considered a relevant goal.

“Time Bound” - It is essential that goals have a timeframe or target date. A commitment to a deadline helps a team focus their efforts towards completion of the goal and prevents goals from being overtaken by other, unrelated routine tasks that may arise. A time-restrained goal is intended to establish a sense of urgency.

9.4.4 – “CASH FLOW MATTERS”: LINK SOCIAL AND ECOLOGIC GOALS WITH FINANCIAL FIGURES

A green strategy or a social strategy is not a strategy for sustainability. True sustainability must give equal weight to the economic dimension. Sustainable supply chain practices must be financed and provide pay back within a reasonable time span.

The challenge is to assess the economic, in particular financial, aspect of a practice. Best practice companies are capable of this. They have extended their supply chain KPI systems to include social and environmental measures and can link this whole operational KPI system with their financial measurement systems. The Sustainable Supply Chain (SSC) Scorecard in Figure 9.5 will provide a generic template to apply this approach in your company.

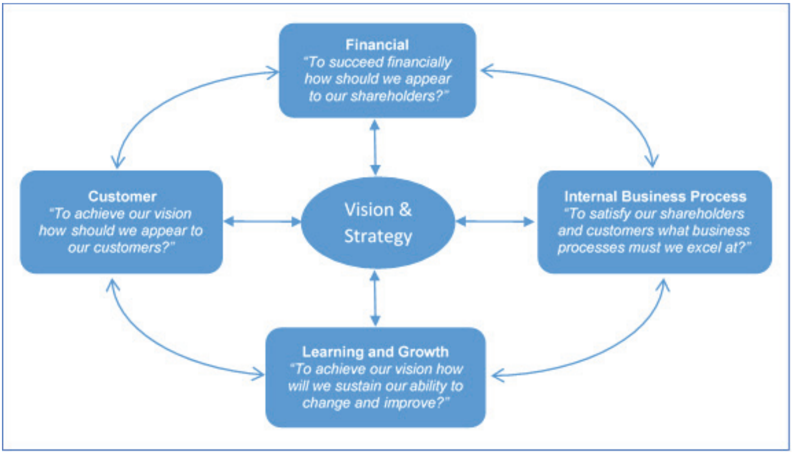

Figure 9.5 – Balanced Scorecard [11]

9.4.5 – INGREDIENT IV: BALANCING ECONOMIC, ENVIRONMENTAL, AND SOCIAL OBJECTIVES

The main issue is to understand the conflicting relationship between economic, social and environmental objective. The strategic challenge is to build realistic and balanced targets in different operations in all three dimensions. And each of these dimensions must be aligned to the overall corporate strategic goals and vision.

Best practice companies provide incentives and motivate the people involved in order to change their attitudes and to redirect their business systems towards these balanced goals. Furthermore, making people aware of the long-term benefits of change and implementing best practice into day-to-day work is an important strategic challenge.

9.5 - AN ITERATIVE APPROACH TO DEVELOPING THE SUSTAINABLE SUPPLY CHAIN STRATEGY

The ingredients of a sustainable strategy were identified in the previous section. In the following text we will describe briefly the six-step process approach to integrating these principles into the existing supply chain.

A sustainable supply chain involves more than the implementation of popular practices; most of them are "standard building blocks". Rather we need to implement individual practices to integrate long-term meaningful sustainability practices along the supply chain. For that we need a systematic approach which will help companies to develop their individual supply chain to create a value proposition. This iterative six-step technique has to be considered as a cyclical approach which should be executed regularly in your supply chain, because relevant parameters may change frequently, and sometimes quite fundamentally.

In Figure 9.3 below, you can see five questionx that define the path to a sustainable supply chain, helping to revise your existing supply chain strategy. Depending on the risks and opportunities that your supply chain faces in the present environment, and will face in the future, you can derive your action plans to adopt to sustainability requirements. The result will be a Sustainable Supply Chain (SSC-) Scorecard, which will help the supply chain manager to implement strategies for sustainability into the existing supply chain.

- Step (1) aims to take stock of the current state of company- and supply chain-specific characteristics regarding strategy, resources, and current and planned practices. It is mainly concerned with internal factors and considers elements which are usually within the control of a company.
- Step (2) aims to identify current and forecast potential future developments and trends, focusing on external factors influencing the supply chain. It considers factors which are usually not under the direct influence of a company.
- Step (3) aims to evaluate the risks and opportunities derived from these internal and external factors. It serves to define company and supply chain-specific "sensitivity".
- Step (4) takes this analysis to the existing supply chain strategy, instituting a strategy change or redesign process with regard to the sensitivity identified.
- Step (5) focuses on implementation issues in order to balance social, economic, and environmental objectives, with the aid of a novel Sustainable Supply Chain Scorecard concept.
- Step (6) focuses on the key ingredients required to successfully implement the sustainable supply chain strategy in the involved parties.

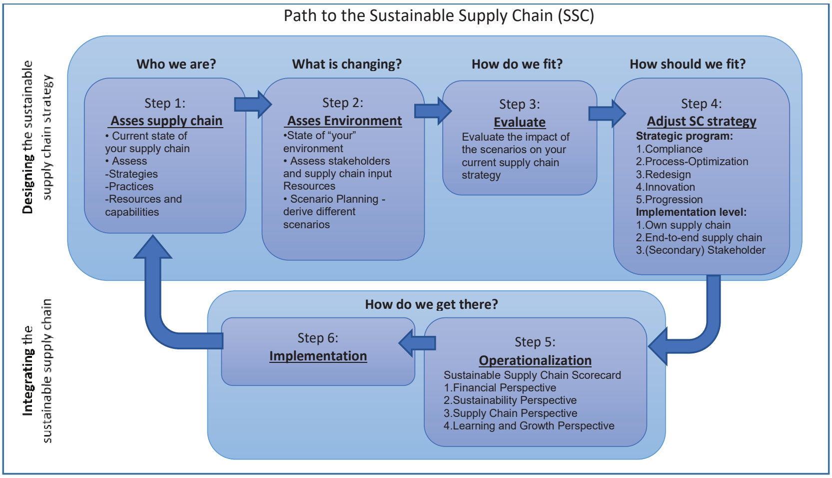

Figure 9.3 - Towards a sustainable supply chain strategy – from principles to practice [11]

9.5.1 - STEP 1. STOCKTAKING: THE CURRENT STATE OF YOUR SUPPLY CHAIN

The analysis in this step is focused on the strategies, the practices regarding sustainability, and the associated resources and capabilities in the supply chain. Studying and understanding these elements will help us to identify the risks and opportunities (step 3), and to revise and adopt our existing supply chain strategy (step 4).

The integration process of a sustainable supply chain strategy is generally not a one-step expansion. Rather, step-by-step adaption is preferable in the majority of scenarios, unless there is an external changing business environment threatening the company and its supply chain.

So for analysis and implementation/adaption of our existing supply chain we need to review:

- The existing corporate and competitive strategies
- The sustainability strategies, if it is not already part of the corporate strategy
- The company's supply chain strategies, and
- The collaboration strategy of the company within the supply chain and other functions.

The following illustration (Fig. 9.4) simply shows the result of such strategy review:

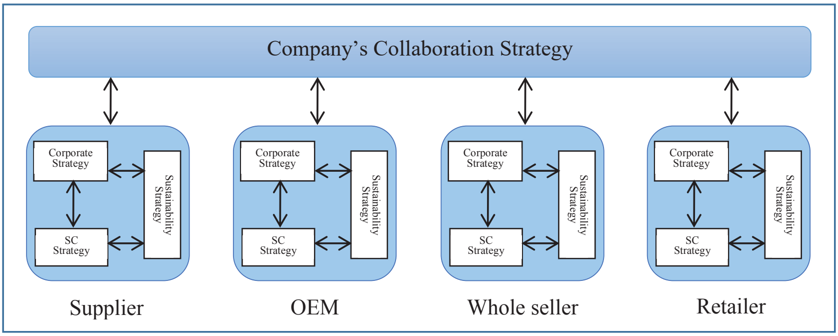

Figure 9.4 – Strategies of simple supply chain [11]

Potential short- and long-term goal conflicts can rapidly become serious barriers to implementing a sustainable supply chain along its members, especially if the supply chain is required to adapt quickly to change.

A holistic understanding of the existing business models and their goal relations in such a system will also allow a better balancing of economic, environmental and social objectives, which may also result in a change of existing business models between supply chain partners.

Practices, Resources, and Capabilities: With regard to best practice companies your stocktaking analysis should also serve to increase transparency, revealing existing, planned, and failed sustainability practices, particularly along the end-to-end supply chain. This allows you to understand on the one hand the trends in your supply chain regarding your customers' requirements and the market's needs, and on the other, to see where skills and resources may be lacking.

Step one ends with an "as-is" analysis of the current state of company- and supply chain-specific characteristics. The next step aims to identify current and forecast potential future developments and trends emerging from external factors influencing the supply chain. It is an external view and considers aspects which are usually not under the direct influence of a company.

9.5.2 - STEP 2. YOUR ENVIRONMENT: CURRENT, POTENTIAL, AND FUTURE IMPACT FACTORS

The second step in our approach is linked to Ingredient II and deals primarily with what is changing in the business environment, what kind of scenarios your company will face in the medium and long term, and finally, what the main driver of change may be.

Supply chain input resources such as fuel, energy, and natural resources nowadays deserve close attention in supply chain management logistics. The trend of rising prices and increasing scarcity make input resources major risk management factors in an economic perspective, especially if you run cost- and energy-sensitive supply chains, such as the commodity microchip industry with its international production and transport flows for example. Understanding and forecasting input resource-related information helps in developing your sustainable supply chain strategy.

One well known and useful tool to use in step 2 is "Scenario Planning". This is a method of medium- and long-term planning, simulation, and of forecasting probable future developments based on the continuous observation of indicators. Scenarios allow supply chain managers to gain a better understanding of the possible business environments they will need to tackle in the future.

The first step in determining the scenarios is to explore the drivers that are most likely to shape the future of your supply chain. These are primarily, as mentioned earlier, the stakeholders and the supply chain input resources. For practical reasons, the number of possible basic scenarios is usually limited to the following three types: optimistic, pessimistic, and most likely. The analysis of existing practices during step 1 may help to determine some of the drivers and trends. In a highly uncertain business environment as described earlier, it makes sense to analyze the drivers according to two criteria: first, their predictability, and second, their impact on your supply chain (see Figure 9.5).

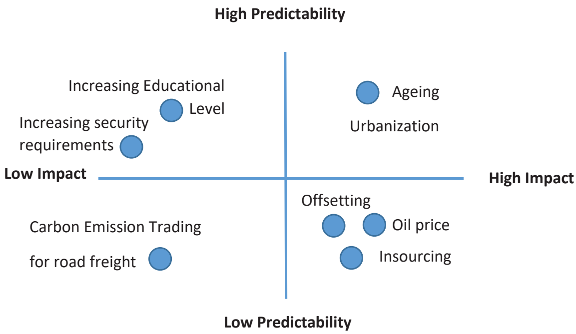

Figure 9.5 - Clustering scenario drivers – examples [11]

9.5.3 – STEP 3: EVALUATION: IDENTIFYING POTENTIAL RISKS & OPPORTUNITIES

Based on the assessment of your supply chain and of your business environment, you can now identify potential risks and opportunities. These will serve in step 4 to change or re-design your existing supply chain strategy. We have given a separate chapter to the topic of risk management, as increasing complexity, accelerating change and uncertainty are posing growing challenges for supply chain managers on the way to a sustainable supply chain. [13]

You need to understand the cause-and-effect relationships between potential success factors to undertake this evaluation. For example, you should be able to estimate that the regionalization of procurement structures in response to an oil price increase would be likely to reduce your transport costs by x%. Only an effective understanding of the relevant levers in your supply chain and of their potential impact on the planning scenarios permit precise analysis of strengths and weaknesses and finally the “right” definition of risks and opportunities.

9.5.4 - STEP 4. ACTION PLAN: EXTEND OR RE-DESIGN THE SUPPLY CHAIN STRATEGY

As mentioned earlier, the integration of sustainability principles into the supply chain is usually not a greenfield development; it has to be a step-by-step approach. The scope of this supply chain review can vary. The larger the gaps, the broader the implications for implementing change, and the more aggressive the strategic program and the associated action plan must be. The extension or the re-design of your existing supply chain strategy should be precisely defined. Of course, this is a strongly context-driven process, based primarily on the results you have now obtained from this six-step approach.

Let's have a detailed look at the following Figure 9.6. The implementation level determines who you involve in the implementation of initiatives. These actors could be the members of your own supply chain, which you influence directly; they could extend further to scope 1 externals from the end-to-end supply chain (primary supply chain stakeholders), or yet further to scope 1 and 2 (secondary) stakeholders. The implementation level involves more than the parties involved; it is also defined by the time horizon you consider in your program.

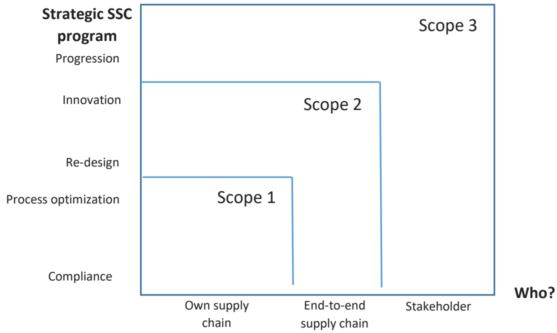

Figure 9.6 - Scope of sustainable supply chain strategy implementation [11]

The implementation level should not be mixed up with the driving forces you take into account when developing your plans. For example, the "compliance" program naturally requires a good understanding of governmental and regulatory requirements, but you will not aim to develop and implement compliance solutions proactively together with policy makers.

The strategic sustainable supply chain program (SSC-program) determines the set of actions/initiatives needed to close the gap and to create your customized sustainable supply chain on the long-term, customized because it fits your gap precisely. The following strategic programs can be distinguished:

1. Compliance
2. Process-Re-engineering
3. Restructuring
4. Innovation
5. Progression

Again, the strategic program does not represent a new supply chain strategy, but rather a program to extend or re-design the existing strategy. And again, the bigger the gap, the stronger and more aggressive will be the action that needs to be taken. The first two programs are essentially defensive and focus mainly on the company's own supply chain. The last three programs are more aggressive and require an extended implementation level beyond the company's own supply chain. Below we will take a brief look at each of these strategic programs.

Supply chain managers should follow the "Compliance" program to obtain the benefit and competitive value of "Reducing and managing risk", which represents a precautionary response to stakeholders, shareholders, owners, and employees in particular. This program is mainly driven by the compliance requirements of stakeholders such as governments, customers, and special interest groups. Supply chain managers satisfy their stakeholders' concrete requirements and monitor developments in the regulatory arena.

Supply chain managers should follow the "Process Optimization" program to obtain the benefit and competitive value of "improving productivity and efficiency" and in consequence, of reduced supply chain costs, increased resource productivity, and reduced environmental impacts. This program is mainly driven by additional supply chain and logistics costs, due to e.g. increasing resource prices or increasing regulation compliance costs. Actions taken to improve efficiency do not aim to change existing structures; rather they try to improve the existing system itself, based on optimization and improved planning. The overall goal is to invest in improvements showing a positive net present value in the short term; this is difficult in many cases of current, existing "green" technologies, for example. The scope of such activities starts within the company and should be extended to the whole supply chain. The first activities should focus on the “low-hanging fruit” and on the areas in which supply chain managers already operate and respond to change, e.g. transport planning. Some examples of program actions can be:

- Training of truck drivers
- Simple re-design of packaging or optimized packaging processes
- Implementation of environmental management systems, to standardize processes and to reduce unnecessary complexity costs.
- Consolidation of material flows by re-scheduling
- Route optimization and transport planning
- Business process optimization to reduce lead times, which enable longer planning cycles, which in turn create more consolidation possibilities
- Applying intermodal transport
- Applying fleet management systems
- Energy management in warehouses, etc.

These first two strategic SSC-programs (Compliance and Process Optimization) fit very well for companies and supply chains with cost leadership strategies and efficient supply chain processes.

But one common finding in the literature is that cost advantages based on efficiency and productivity concepts do not lead to a long-term, sustainable competitive advantage; this is because (a) competitors will most probably have the same opportunities to emulate such cost advantages and (b) efficiency and productivity improvements fail, if the concepts do not achieve the required critical mass of throughput: for example, during the 2008 global economic crisis. And in addition to that: The high investment demands of logistics-related technologies (e.g. regenerative energy, alternative-fuel engines, telematics, etc.), often have long payback periods and lead to higher logistics costs, which such companies will most likely pass to the customers or partners, if they stick to the mentioned cost leader strategy. This means that cost leader companies with cost-efficient supply chain strategies face big challenges in aligning efficiency strategies with sustainability principles in the long run. In conclusion, the stand-alone integration of the "Process-Optimization" and "Compliance" SSC-programs will not necessarily lead to competitive advantages, if the strategic gap in the context under consideration is large and very diverse, and along the main supply chain; in more concrete terms, you should shift to more aggressive strategies and extend programs to further implementation levels when stakeholders create strong direct and indirect pressure on the supply chain, or when sustainability drivers such as, for example, rising resource prices impact forcefully on current and future supply chain performance.

Supply chain managers should follow the "Re-design" program to obtain the benefit and competitive value of "the long term and cardinal improvement of effectiveness and early prevention of risk". This program is mainly driven by additional supply chain and logistics costs resulting from rapidly increasing resource prices and regulatory costs which affect a company's competitive position. The actions around "Re-design" aim to change existing structures and processes. The scope of activities covers the whole supply chain. Hence, a collaborative approach is one key success factor. The decision-making processes need to be quantified as much as possible, in order to draw up and assess several scenarios, since re-design actions are mostly linked to high costs and investments, and are often irreversible.

Supply chain managers should follow the "Innovation" program to obtain the benefit and competitive value of "differentiation". This program is mainly driven by external stakeholders: customers, consumers, NGOs and suppliers who demand new solutions, products, and services. The actions around "Innovation" aim to change existing business models, to break existing mindsets in the supply chain, and to achieve a sustainable image, which, in the end, will increase the credibility of a company. The scope of activities is mainly intra-organizational, e.g. between R&D, SCM, manufacturing, and sales as well as inter-organizational in the end-to-end supply chain. Hence, communication and awareness are key success factors; top management commitment throughout the key supply chain players is a must.

Supply chain managers should follow the "Progression" strategy to obtain the benefit and competitive value of "differentiation, first mover advantage, and establishing market entry barriers". The main drivers in the relevant industry, and even society as a whole are: a lack of standards, of knowledge, and of regulations, highly developed corporate social responsibility, and a lack of common market direction. The actions around "Progression" do not have a direct, measurable payback for a given time period. The benefits are more long-term and qualitative, and go along with reputation and image. The reach of activities is widespread, mainly found in the relevant sector, at governmental institutions, at associations, and in different countries. Hence, a focused approach with concrete milestones is a key success factor, and top-management commitment along the key supply chain players is a must.

9.5.5 - STEP 5. IMPLEMENTATION WITH THE SUSTAINABLE SUPPLY CHAIN (SSC-) SCORECARD

The capability to translate the new strategy elements into a structured KPI system, explaining cause-and-effect relationships and justifying implemented practices, remains a challenge ahead of us. Step 5 will address these issues.

One well known tool/concept for translating strategic goals into operations is the "Balanced Scorecard" developed by Kaplan and Norton from 1990. The Balanced Scorecard is a (performance) management system providing a framework to translate a strategy into balanced operational terms via objectives and measures, organized into four different perspectives: financial, customer, internal business process, and learning and growth (see Figure 9.5).

"The Balanced Scorecard expands the set of business unit objectives beyond summary financial measures. Corporate executives can measure how their business units create value for current and future customers and how they must enhance internal capabilities and the investment in people, systems, and procedures necessary to improve future performance."13

The measures represent a balance (Kaplan and Norton (1996), p. 9)

- Between external measures for shareholders and customers, and internal measures of critical business processes, innovation, learning and growth;
- Between the outcome measures—the result from past efforts—and the measures that drive future performance; and
- Between objective, easily quantified outcome measures and subjective, somewhat judgmental, performance drivers of the outcome measures.

These characteristics fit ideally with our ingredients of a sustainable strategy and justify the use of this general concept, but not as a pure performance measurement system. "Many people think of measurement as a tool to control behavior and to evaluate past performance. The measures on a Balanced Scorecard are used in a different way – to articulate the strategy of the business, to communicate the strategy of the business, and to help align individual, organizational, and cross-departmental initiatives to achieve a common goal. Used in this way, the scorecard does not strive to keep individuals and organizational units in compliance with a pre-established plan, the traditional control system objective. The Balanced Scorecard is used as a communication, informing, and learning system, not a controlling system."[14]

The comparison of the SSC-Scorecard with the "traditional" Balanced Scorecard of Kaplan and Norton shows the structural similarities. The four perspectives, Finance, Customers, Processes, and Learning and Growth, are retained, and are extended by several other aspects regarding supply chains and sustainability. The main reason to stick with the traditional four perspectives is to allow an “easier” integration and “plug-in” to a company’s existing use of a “traditional” Balanced Scorecard.

9.6 – REVERSE LOGISTICS & SUSTAINIBILITY

Reverse logistics is for all operations related to the reuse of products and materials. It is "the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal. Remanufacturing and refurbishing activities also may be included in the definition of reverse logistics."[15] Growing green concerns and advancement of green supply chain management concepts and practices make it all the more relevant.[16] The reverse logistics process includes the management and the sale of surplus as well as returned equipment and machines from the hardware leasing business. Normally, logistics deals with events that bring the product towards the customer. In the case of reverse logistics, the resource goes at least one step back in the supply chain. For instance, goods move from the customer to the distributor or to the manufacturer.[17]

When a manufacturer's product normally moves through the supply chain network, it is to reach the distributor or customer. Any process or management after the delivery of the product involves reverse logistics. If the product is defective, the customer would return the product. The manufacturing firm would then have to organize shipping of the defective product, testing the product, dismantling, repairing, recycling or disposing the product. The product would travel in reverse through the supply chain network in order to retain any use from the defective product. The logistics for such matters are reverse logistics.

Reverse logistics involves more than just returns management; it is "activities related to returns avoidance, gatekeeping, disposal and all other after-market supply chain issues".[18] Returns management—increasingly being recognized as affecting competitive positioning—provides an important link between marketing and logistics. The broad nature of its cross-functional impact suggests that firms would benefit by improving internal integration efforts. In particular, a firm's ability to react to and plan for the influence of external factors on the returns management process is improved by such internal integration.[19] In a firm's planning for returns, a primary factor is the remaining value of the material returning and how to recover that value.[20] "Returned goods, or elements of the product, could even be returned to suppliers and supply chain partners for them to re-manufacture".[21]

In certain industries, goods are distributed to downstream members in the supply chain with the understanding that the goods may be returned for credit if they are not sold e.g., newspapers and magazines. This acts as an incentive for downstream members to carry more stock, because the risk of obsolescence is borne by the upstream supply chain members. However, there is also a distinct risk attached to this logistics concept. The downstream member in the supply chain might exploit the situation by ordering more stock than is required and returning large volumes. In this way, the downstream partner is able to offer high level of service without carrying the risks associated with large inventories. The supplier effectively finances the inventory for the downstream member. It is therefore important to analyze customers' accounts for hidden costs.

9.6.1 – SUSTAINABLE DISTRIBUTION

Sustainable distribution refers to any means of transportation/hauling of goods between vendor and purchaser with lowest possible impact on the ecological and social environment, and it includes the whole distribution process from storage, order processing and picking, packaging, improved vehicle loadings, delivery to the customer or purchaser and taking back packaging. [22] [23] Commonly, distribution means all the processes that occur between producers, retailers and customers. The functions of distribution are physical transportation, storage and warehousing, packaging, labeling, and reverse logistics.

In order for distribution processes to be considered sustainable, characteristics of sustainable products and services have to be derived and applied:

1. Recipient's satisfaction: sustainable distribution has to ensure satisfaction of demand by means of time and place.
2. Dual focus: it should tackle social and ecological problems
3. Life-cycle orientation: sustainable distribution processes have to suit the life-cycle approach of sustainability products in order for them to be completely sustainable. There is also a close link to the post-use phase as reverse logistics complete the distribution process
4. Significant improvements: sustainable distribution has to deliver a substantial reduction of environmental and social impacts on a global level
5. Continuous improvement: permanently monitoring and improving socio-ecological impacts of distribution processes is needed in order to implement newest (efficient) technology developments and latest perceptions of the sustainability term.
6. Competitiveness: sustainable distribution has to be at least as competitive as conventional distribution processes in order to be successful in the long run. Environmental and social issues should be tackled without compromising the efficiency of the conventional distribution functions.[24]

9.6.2 – SUSTAINABLE WAREHOUSING

Warehousing is one of the main spheres of logistics. The very broad meaning of it is storage of finished goods or materials (raw, packing, components) for manufacturing, agricultural or commercial purposes. In fact, warehousing contains numerous functions, like acceptance of products (loading, unloading), inspection, and proper storage. It is the whole system (warehouse management system) that includes warehouse infrastructure, tracking systems and communication between product stations.

Sustainable applications in warehousing

One of the most sustainable trends in storage solutions is the Just In Time technique. It means product delivery directly from supplier to producer without warehousing. But this system has quite limited application, as the distances between intermediaries are growing with the globalization process of the world economy. Modern logistics cannot survive without warehousing services, but various sustainable modifications of warehousing infrastructure can be introduced.

There are some basic sustainable attributes available for the warehouse applications that are able to reduce energy consumption and the amount of carbon emission:

- 'Solar photovoltaic roof panels: generation of energy from a renewable source, minimizing the need for fossil fuels and reducing the dependency on the electrical grid distribution system. Additionally, the energy produced is free of carbon emissions.
- Optimizing architecture of warehouses; increased natural daylight can reduce the need for electric lights
- Ground source heat pumps: use the ground's constant temperature to supply heating and cooling systems for office buildings
- Solar thermal collectors: create free hot water in the summer and deliver hot water in the winter
- Energy efficient light systems equipped with motion sensors: environmentally-friendly reduction of storage costs
- Rainwater harvesting
- Low water use appliances
- Sustainable building materials

9.6.3 – SUSTAINABLE PACKAGING

Rising climate change awareness started contributing to the need of considering sustainability in packaging decisions. Sustainability objectives relate to packaging life cycle in terms of material sourcing, packaging design, manufacturing, transportation and disposal. According to the Sustainable Packaging Coalition, packaging can be considered sustainable if it meets the following criteria:

- Is beneficial, safe & healthy for individuals and communities throughout its life cycle
- Meets market criteria for both performance and cost
- Is sourced, manufactured, transported, and recycled using renewable energy
- Optimizes the use of renewable or recycled source materials
- Is manufactured using clean production technologies and best practices
- Is physically designed to optimize materials and energy
- Is effectively recovered and utilized in biological and/or industrial closed loop cycles

Besides the traditional "3 R's" of "reduce", "reuse", and "recycle", [25] the "7 R's" of Eco Friendly Packaging principles should be applied to the packaging and product development in order to move it towards sustainability objectives:

- Renew - use materials made from renewable resources
- Reuse - use materials over and over when economically feasible
- Recycle - use materials made of highest recycled content without compromising quality
- Remove - eliminate unnecessary packaging, extra boxes or layers
- Reduce - minimize and optimize packaging materials
- Revenue - achieve all above principles at equal or lower cost
- Read - get educated on sustainability, educate producers and customers [26] [27]

Optimizing packaging materials and design can significantly help to optimize logistics by improving vehicle load. For example, changing firm packaging to flexible can help to deliver maximum lorry load per kilometer travelled, increasing the volume of goods being transported by lorry, thus reducing CO2 emissions along with time and costs optimization. [28]

Reverse logistics has become an important extension within the supply chain as it carries high potential to achieve a sustainable distribution process that fulfills both environmental and social needs. It deals with reclaiming used packaging as well as unsold and end-of-life products that have to be disposed in order to make materials available for recycling or reuse. [29] By taking back waste and packaging, appropriate and environmental-friendly recycling of the product's components and materials can be ensured while at the same time reducing the amount of waste brought to landfills. Additionally, vehicle loadings can be optimized as empty return trips of trucks employed for distribution processes are avoided in case they take back materials. By combining and implementing these measures, producers can substantially improve their environmental performance and comply with the requirements given by the so-called life-cycle approach.

As a higher goal, reverse logistics may also contribute to lower producers' dependency on scarce or non-renewable resources by remanufacturing and reusing recycled materials for the production of new goods. The inherent perspective of replacing polluted and energy-intensive processes of exploitation and manufacturing by remanufacturing complies with a cradle-to-cradle approach. However, for this to be worth the effort, new products already have to be designed and developed in accordance with easy and inexpensive disassembling steps. [30]

The implementation of reverse logistics faces a number of challenges with respect to sustaining competitiveness of products and conforming to convenience-related expectations of customers. As end-of-life products are usually returned in varying conditions and have to be picked up in private households, the dimension of take-back systems has to be determined particularly per product and with respect to its value, disassembling costs, and potential inconveniences inherent for customers. [31] Therefore, a critical success factor is the easiness and accessibility of take-back options to promote a post-use phase that is highly convenient for the customer. Additionally, companies have to continuously reduce costs of refurbishment and recycling. [32]

By applying political regulations and obligations banning highly toxic products from being disposed on landfills, by increasing disposal costs, and by promoting incentives for companies or customers who return their products, the return rate and therefore the environmental impact of end-of-use products can be improved. As example, the European Union implemented directions to particularly regulate extended producer responsibilities for end-of-life cars and electrical devices. [33]

9.7 - STUDENT ACTIVITIES:

1) Can you write down, without checking company documents, the mission, strategy and supply chain strategy of your chosen organization? Can you list any organizational strategic goals?

2) Is sustainability included into your chosen company strategy and/or supply chain strategy? Discuss how company actions at the strategic level influence sustainability (for example by: choice of supply chain design, selection of transportation mode, sourcing).

3) How does your chosen organization communicate strategic goals to its employees and stakeholders?

4) What is the “balanced score card”? How does it help to translate the strategic objectives into operations?

5) Explain both cost leadership and differentiation leadership.

6) What is KPI? How does it help to translate the long-term sustainable objectives into day-to-day operational activities?

7) Bring an example of KPIs in a company of your choice which have operational contradictions, and explain how you would resolve those contradictions.

8) What is reverse logistics, and how you can define sustainability in a reverse logistic system?

9) What are the main 7 rules that will help the supply chain managers to move the packaging through sustainability objectives?

10) Name four criteria that packaging should meet in order to be considered sustainable.

11) Explain four principles of your choice that will help to achieve sustainable warehousing practices.

12) What is “return management”? How does it help companies to gain competitive advantage on sustainability?

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Teaching Aid Material for the Master of Engineering in Industrial Engineering and Systems Management's "SUSTAINABLE OPERATIONS AND RESOURCE MANAGEMENT" concentration

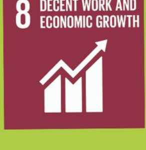
Developed within the framework of the Erasmus+ MARUEEB project, this book covers concepts that promote sustainable operations and resource management. The book is divided into five different parts, “Frameworks and holistic policies”, “Sustainable generation and use of energy”, “Water for sustainability and resilience”, “Solid waste and sustainable material flows”, and “Supply chain and logistics”. The book addresses several of the United Nations Sustainable Development Goals, including SDG 6, 7, 8, 9 and 12, and could be a useful resource for university students and professionals.

Դասավանդմանն օժանդակող նյութ Արդյունաբերական ճարտարագիտություն և համակարգերի կառավարում մագիստրոսական ծրագրի «ԿԱՅՈՒՆ ԳՈՐԾԸՆԹԱՑՆԵՐ ԵՎ ՌԵՍՈՒՐՍՆԵՐԻ ԿԱՌԱՎԱՐՈՒՄ» մասնագիտացման համար

Սույն գիրքը, որը գրվել է Էրասմուս պլյուս «ՄԱՐՈՒԷԷԲ» ծրագրի շրջանակներում, ծավալվում է կայուն գործընթացները և ռեսուրսների կառավարումը խթանող գաղափարների շուրջ: Գիրքը բաղկացած է 5 բաժնից՝ «Գործողությունների շրջանակ և ամբողջական քաղաքականություն», «Էներգիայի կայուն արտադրություն և օգտագործում», «Ջուրը կայունության և դիմակայունության համար», «Կոշտ թափոններ և նյութերի կայուն հոսք», «Մատակարարման շղթա և լոգիստիկա»: Գիրքն անդրադառնում է ՄԱԿ-ի Կայուն զարգացման նպատակներից մի քանիսին, ներառյալ 6-րդ, 7-րդ, 8-րդ, 9-րդ և 12-րդ նպատակները, և կարող է օգտակար լինել ուսանողների և մասնագետների համար:

Учебное пособие для программы магистратуры по специализации «Промышленная инженерия и управления системами» - «УСТОЙЧИВОЕ ДЕЯТЕЛЬНОСТЬ И УПРАВЛЕНИЕ РЕСУРСАМИ»

Данная книга, написанная в рамках проекта MARUEEB программы Erasmus+, посвящена устойчивым процессам и идеям, способствующим управлению ресурсами. Книга состоит из пяти разделов: «Сфера действий и всеобъемлющая политика», «Устойчивое производство и использование энергии», «Вода как средство устойчивости и неизменяемости», «Твердые отходы и стабильность материалов», «Цепочка поставок и логистика». В книге рассматриваются некоторые из целей ООН в области устойчивого развития, в том числе цели № 6, 7, 8, 9 и 12, и она может быть полезным ресурсом для студентов и специалистов соответствующего направления.



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